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THE MAPLIN MAGAZINE

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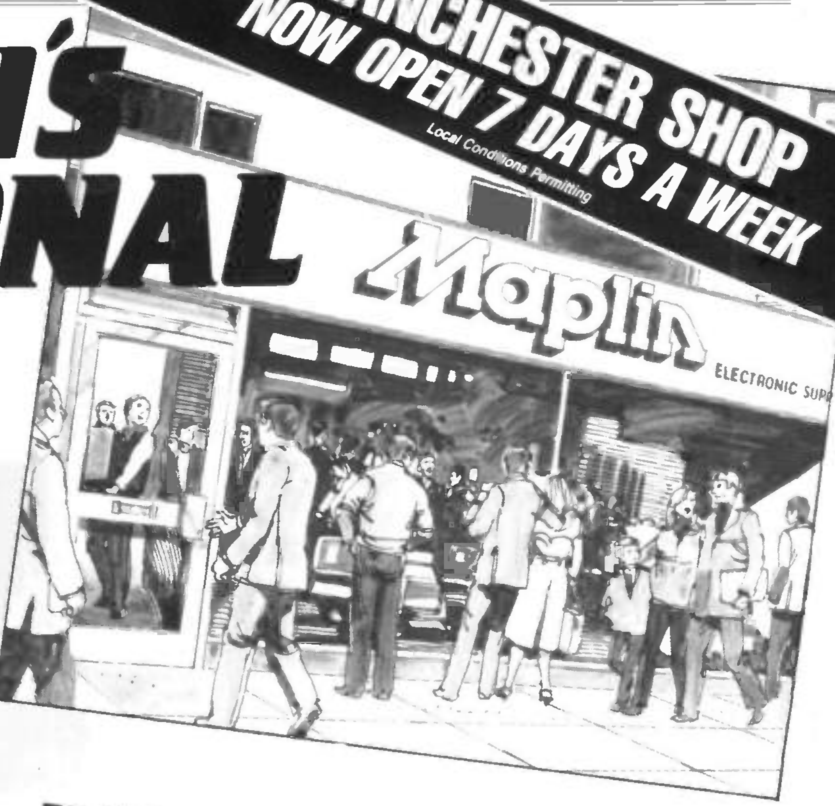

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March 1987 to May 1987
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CONTENTS

Electronics
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PROJECTS

FEATURES

REGULARS

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M·I·D·I INTERFACING TECHNIQUES

by R.D. Ball

The System

MIDI is the acronym for Musical Instrument Digital Interface, MIDI is now the universal standard for connecting and controlling electronic musical instruments.

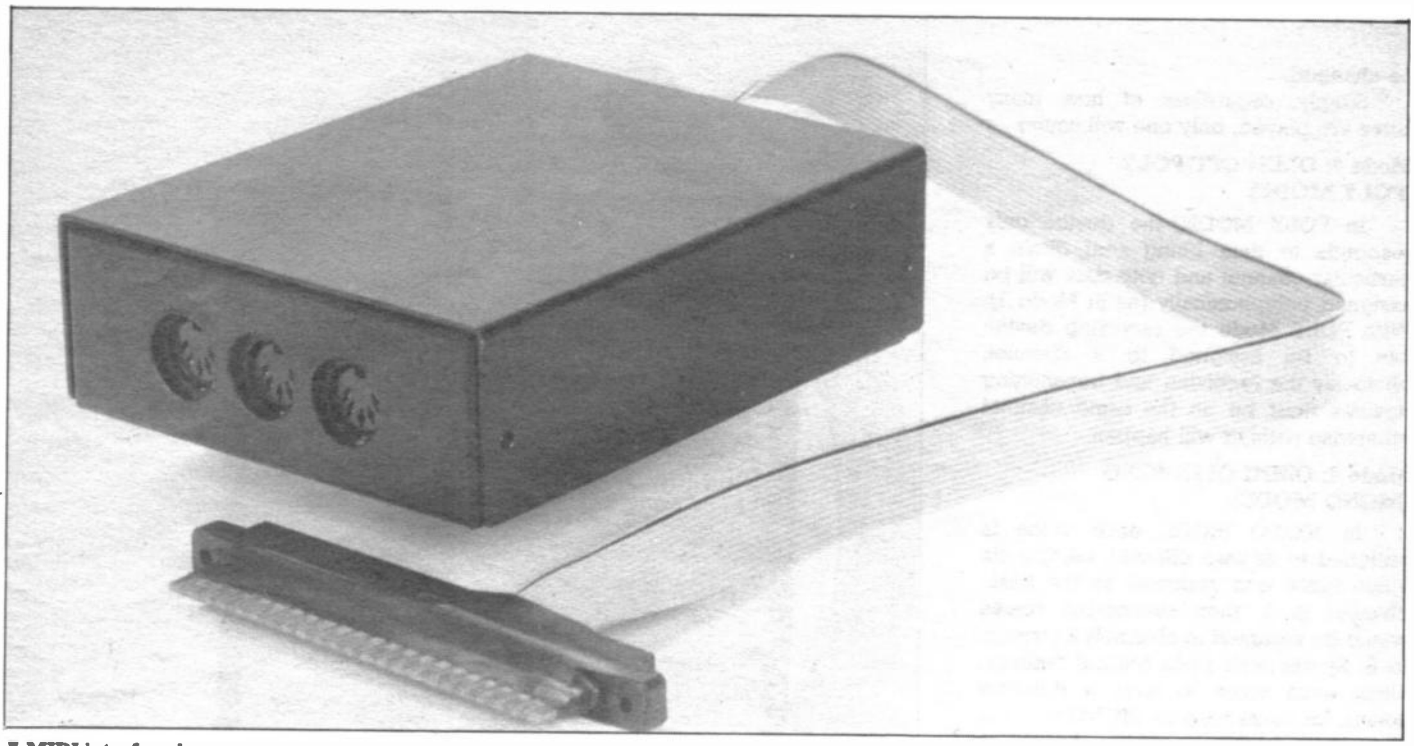
Originally, synthesisers were controlled using two signals; 'gate' and 'CV', the 'CV' signal is simply a DC voltage corresponding to the pitch of the note, a change of 1V would give a change in pitch of one octave. The 'gate' signal is used to control the sample and hold circuitry, i.e. it gates the control voltage. It is also used to trigger the envelope generator. This system suited monophonic analogue synthesisers but is not really practical for modern polyphonic digital synthesisers.

Fortunately, synthesiser manufacturers adopted a single standard, this system was developed by Roland in conjunction with other manufacturers. MIDI was the result.

The outline of MIDI is that all synthesisers and drum machines (or any other MIDI compatible device) use the same set of codes to initiate and stop notes. If certain information does not apply to a particular machine (i.e. velocity information on a non-velocity sensitive synthesiser) it is ignored.

The system outline may seem limited at first, but special functions exclusive to a particular manufacturer or machine are incorporated using special 'system exclusive' codes to indicate a non-standard function.

To allow easy connection between devices, a serial system is used. Operation is similar to RS423, except that MIDI uses a current rather than voltage loop, however the main difference is speed; most serial systems have a maximum speed of 9600 BAUD. MIDI uses an incredible 31.25 Kilo BAUD!! The


A MIDI interface box

system runs at this speed to avoid apparent gaps between simultaneous events. The data word format is 8 bits, 1 stop bit and no parity.

A full implementation of MIDI utilises three sockets on the equipment. These are MIDI IN, MIDI OUT and MIDI THRU'. MIDI IN is the serial data into the equipment. MIDI OUT is the serial data from the equipment. MIDI THRU is a buffered version of the data that appears at MIDI IN. The connection between equipment is similar to the way that Commodore printers and disk drives may be chained together.

To prevent possible hum and earth loop problems all MIDI inputs are Opto Isolated. Connection between equipment is usually via 5 pin 180° DIN leads with some equipment intended for use 'on the road' XLR connectors may be found), only two cores and screen are used on 5 pin leads though. Ready made MIDI leads can be purchased or leads may be made up using good quality screened cable and connectors. MIDI leads should not be longer than 50 metres.

What can MIDI be used for?

(a) Producing a 'thicker' sound

This means connecting two or more synthesisers together so that notes played on the MASTER synth will also be played on the SLAVE synth(s). This can be very effective, especially if the attack rate of the envelope generator on the SLAVE is considerably slower than that of the MASTER. This effect is generally termed layering or doubling.

(b) Allowing computer control

By using MIDI, electronic musical instruments can be controlled by a home computer. This means that synths can 'talk' to computers and vice-versa. This opens up possibilities of using the computer as a sequencer or to produce effects such as appregiation of chords or even to act as an extra modulation generator. This does however require the computer to be MIDI compatible, this article also includes a circuit for a MIDI interface and it is hoped that this will provide a stepping stone into computer controlled electronic music.

(c) Reducing equipment space and cost

By using a master keyboard a number of slave synths can be driven, since the slave synths do not need keyboards, the keyboards can be omitted!! Keyboardless synths are much cheaper and occupy a lot less space than full synths. The master keyboard may be a special MIDI MASTER KEYBOARD which has no sound generation circuitry; just MIDI sockets. Master keyboards generally feel and respond more like a real piano keyboard and normally include good facilities for program and parameter changes on slaves. Some also allow the keyboard to be 'split' so that different octaves transmit on different MIDI channels. A good master keyboard will transmit velocity and aftertouch information as well as note information.

(d) Reducing obsolescence

All MIDI equipment is compatible, so that old equipment will quite happily work along side the very latest equipment and that applies to all equipment yet to be designed!! Even old analogue synths can join the MIDI revolution as MIDI to CV converter boxes are now available.

(e) The MIDI studio

By using a sequencer, different instruments can be recorded into memory, just like multi-track recording on tape. Each 'track' is assigned to a different MIDI channel allowing simultaneous playback, and because the information is in memory it can easily be modified or edited. It is also possible to change instruments once tracks have been recorded. One great advantage is the total absence of recording medium noise. Once multiple tracks have been laid down, the slave devices can now be mixed onto conventional tape.

MIDI Modes

Mode 1: OMNI ON/POLY (OMNI MODE)

In OMNI MODE, the MIDI device receives data transmitted on all 16 MIDI channels, note data is assigned to the device's voices polyphonically.

This means that whether the transmitting device sends data down channel 1 or 16 (or any channel for that matter), the device in omni mode will receive it. Data corresponding to notes will turn on and off the devices voices polyphonically, i.e. a number of different notes simultaneously sounding; as in a chord. The degree of polophony will depend on the device and is usually around six or eight notes.

Mode 2: OMNI ON/MONO

In this mode, data is received from any channel as above, but note data is assigned to only one voice (monophonically).

If multi note information is sent, the device will either respond to the highest, lowest or last note to be received, this depends on the device and some manufacturers allow the assignment to be changed.

Simply, regardless of how many notes are played, only one will sound.

Mode 3: OMNI OFF/POLY (POLY MODE)

In POLY MODE, the device only responds to data being sent down a particular channel and note data will be assigned polyphonically (as in Mode 1). With POLY Mode the receiving device has to be assigned to a channel, obviously the receiving and transmitting devices must be on the same channel otherwise nothing will happen.

Mode 4: OMNI OFF/MONO (MONO MODE)

In MONO MODE each voice is assigned to its own channel, i.e. if a six voice synth was assigned so the basic channel is 1, then successive voices would be assigned to channels 2 through to 6. Synths with multi timbral facilities allow each voice to have a different sound, for these reasons MONO mode is very powerful but needs careful use to get good results. Facilities in this mode can vary and the owners manual should outline how to use this mode fully.

MIDI Data Messages

NOTE ON

The following sequence of data will initiate a note. Exchange consists of a three byte transfer.

BYTE 1 Channel No. (0 to 15) and NOTE ON command.

BYTE 2 Key No. (0 to 127) 0=lowest, 127=highest. MID 'C' = 60.

BYTE 3 Key Velocity; how hard key is pressed, (0 to 127) 0=no velocity, 127=max velocity. Non-velocity keyboards use 64.

NOTE OFF

The following sequence of data will stop a note. Exchange consists of a three byte transfer.

BYTE 1 Channel No. and NOTE OFF command.

BYTE 2 Key No.

BYTE 3 Key Release Velocity; how quickly key is released, (0 to 127).

POLYPHONIC KEY PRESSURE (AFTERTOUCH)

Some keyboards also respond to the pressure applied to the key after the key has been pressed. Exchange consists of a three byte transfer.

BYTE 1 Channel No. and KEY PRESSURE command.

BYTE 2 Key No.

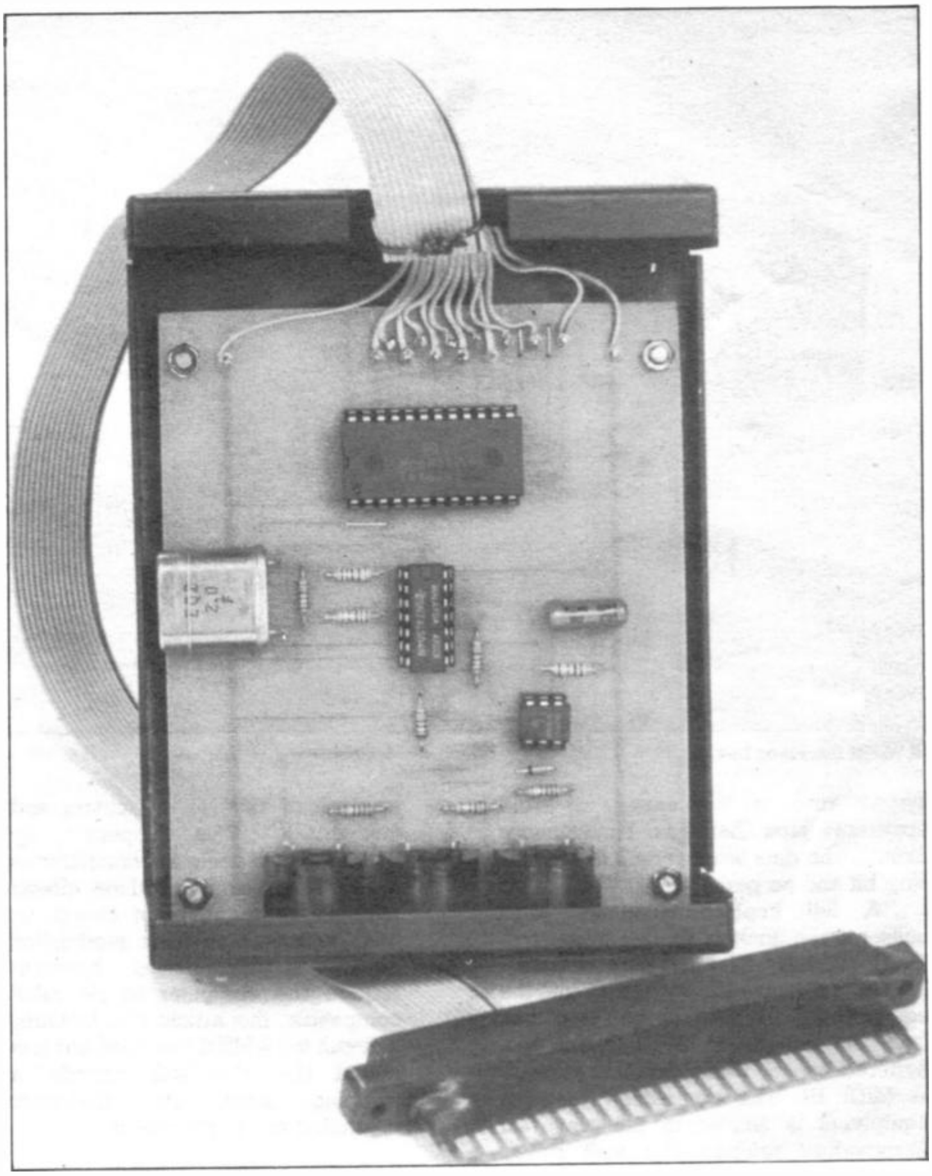
BYTE 3 Key Pressure (0 to 127) 0=no pressure, 127= max pressure.

OVERALL PRESSURE (AFTERTOUCH)

Similar to above, but is the overall pressure of all the notes down. Exchange consists of a two byte transfer.

BYTE 1 Channel No. and OVERALL PRESSURE command.

BYTE 2 Overall Pressure (0 to 127) 0=no pressure, 127 = max pressure.



Inside the box

CONTROLLERS

These are used to transmit information corresponding to operation of such things as portamento, damper and operation of modulation wheels or joysticks. This means, for example, that when the damper is operated on the master, it is also operated on the slave.

There are two main types of controller command:

CONTINUOUS - these correspond to turning a pot on the control panel or operating a modulation wheel, i.e. anything that needs to have a continuous value corresponding to position, to be transmitted.

ON/OFF - these correspond to switch operations such as the damper pedal being pressed.

For the different types of controllers a set of sub-channels or controller numbers are used:

0 to 31 for continuous controllers (low and high resolution).

32 to 63 for continuous controllers (high resolution).

64 to 95 for on/off controllers.

96 to 121 undefined.

122 to 127 for channel mode messages.

Controller messages consist of a three byte transfer.

BYTE 1 Channel No. and CONTROLLER message.

BYTE 2 Controller No. (0 to 127).

BYTE 3 Controller Value (0 to 127) 0=full off, 127=full on.

PITCH BEND

Pitch bend is considered such an important controller it is assigned as a separate message. Pitch bend is a three byte transfer.

BYTE 1 Channel No. and PITCH BEND command.

BYTE 2 Pitch Bend value (0 to 127) LSB.

BYTE 3 Pitch Bend value (0 to 127) MSB.

PROGRAM CHANGE

This enables program, or patches corresponding to different sounds to be selected, this is a two byte transfer.

BYTE 1 Channel No. and PROGRAM CHANGE command.

BYTE 2 Program No. (0 to 127).

MODE MESSAGES

This group of messages affect the modes of operation and are under the class of controllers.

LOCAL/REMOTE

This is used for selecting whether note data for voices within the synth is obtained from the keyboard and MIDI or just MIDI. In the second option, operation of the keyboard just sends out MIDI data. This option is useful for adding such features as appregiation, auto chording or other MIDI effects and is achieved by using a MIDI effects box or micro computer.

ALL NOTES OFF

Causes all notes on that channel to cease sounding. This command should be used with some care as not all devices respond to it!

OMNI/POLY/MONO SELECT

This allows selection of the channel and note assignment mode as previously discussed.

SYSTEM EXCLUSIVE (★)

This allows totally non-standard information to be exchanged between compatible equipment. Such as data for a particular patch or even data for a sampled sound.

The exclusive message was provided for manufacturers different needs and is one facility that means MIDI cannot become obsolete.

The exclusive message is a multi byte transfer and the length depends on the application.

BYTE 1 SYSTEM EXCLUSIVE Command.

BYTE 2 MANUFACTURERS ID No.

BYTE 3 }

'DATA'

BYTE n }

BYTE n+1 END OF EXCHANGE Command.

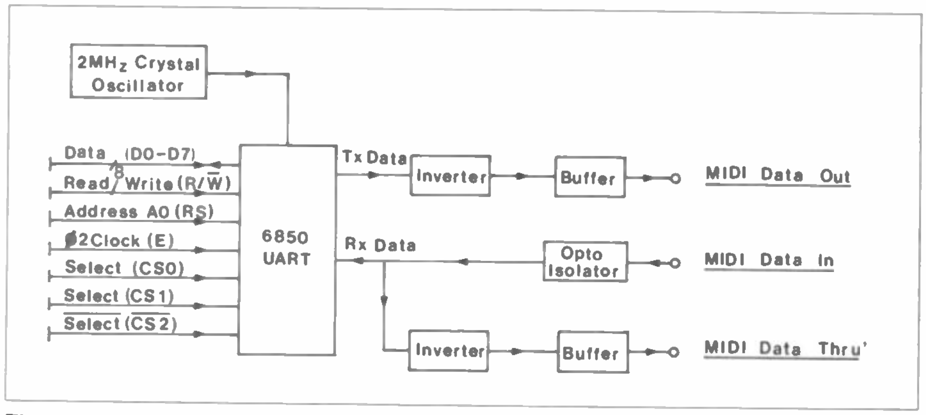


Figure 1. Block diagram.

SYSTEM RESET (★)

Puts all the equipment into the reset state, as if it had just been powered up. There are many other messages but only the main ones have been covered here.

N.B. (★) = Any 'SYSTEM' message that is transmitted, is received on all channels.

MIDI Requirements

INTERFACE HARDWARE

Data rate 31.25 K BAUD ± 1%, Asynchronous.

1 start bit, 8 data bits, 1 stop bit.

Total 10 bits, one complete word takes 320μs to transmit.

Circuit operates using 5mA current loop. The receiver must be opto-isolated. Opto isolator must require less than 5mA to turn on.

MESSAGES

i) Channel messages

The status byte contains a four bit number corresponding to the MIDI channel required (1 to 16); the number transmitted is 0 to 15 (0000_2 to 1111_2).

ii) System messages

These are not given a channel number and are received on all channels.

COMMON - for all devices connected.

REAL TIME - for timing and synchronisation purposes.

EXCLUSIVE - manufacturers exclusive data exchange.

Block Diagram

Figure 1 centres around the 6850 Universal Asynchronous Receiver Transmitter; this device is used to convert parallel data from the computer to serial MIDI data and also to convert serial MIDI data to parallel data for the computer.

The data from the 6850 UART is not suitable to directly drive a MIDI device. The data has to be buffered to drive the MIDI bus. The buffer has quite a low

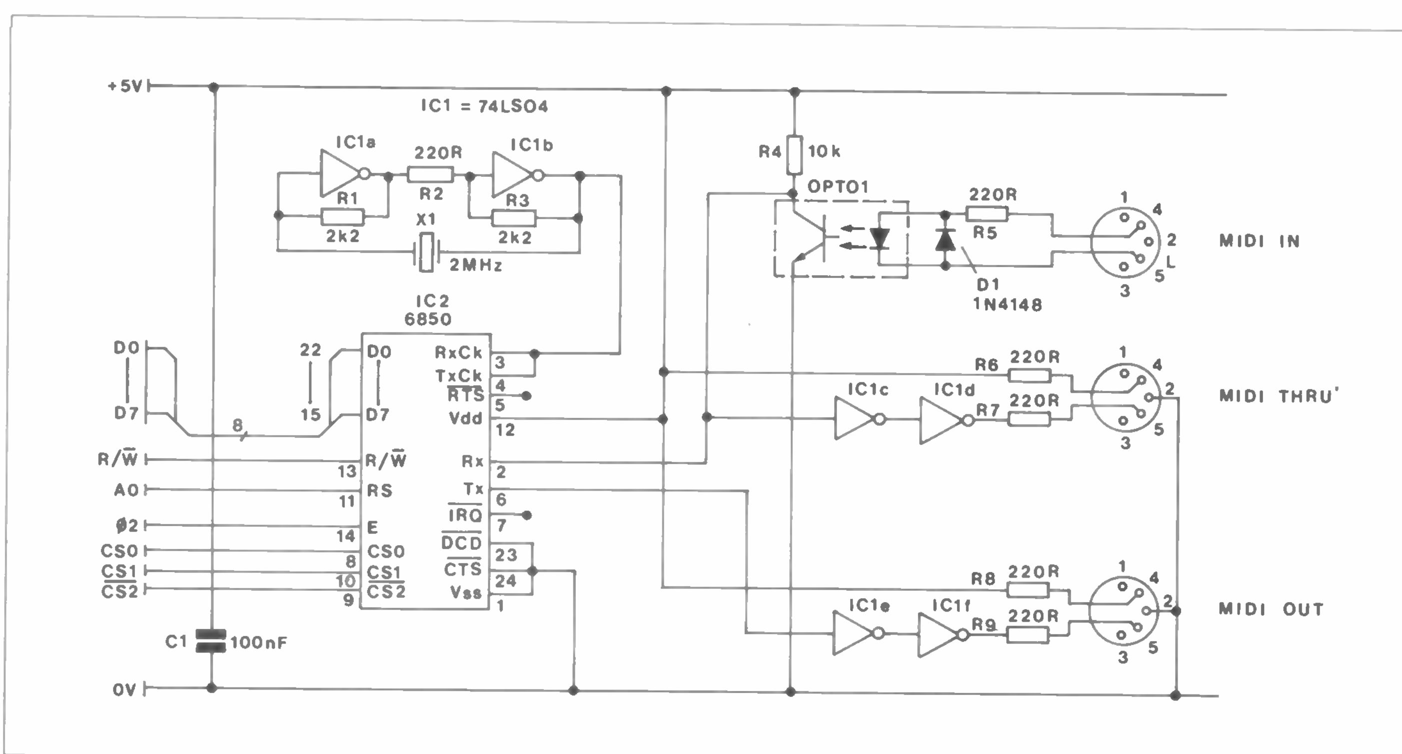


Figure 2. Circuit.

output impedance so as to prevent problems caused by induced noise or a low cable capacitance. The output is current limited to protect the equipment.

As previously mentioned, MIDI inputs need to be Opto Isolated, this gives added safety and prevents troublesome (and annoying!) hum loops from being formed through cables and equipment. After data is passed through the Opto Isolator it follows two routes; into the 6850 UART and via an inverter into another buffer (duplicate of MIDI OUT buffer) to provide MIDI THRU' data.

The data rate is derived from a 2MHz crystal oscillator, this is subsequently divided by 64 in the 6850 to give the 31.25 K BAUD data rate used in the MIDI system.

Connection to the computer data bus is via the tri-state buffers in the 6850, data transfer is controlled by read/write, enable and select signals.

Register selection is achieved by using read/write and register select lines.

Circuit Description

In Figure 2, IC1a, IC1b, R1, R2, R3 and X1 form a conventional two inverter crystal oscillator which runs at 2MHz. The output of which is fed to IC2's transmit and receive clock inputs, the 31.25KHz data clock is obtained by an internal divide by 64 circuit in IC2. In the interface, IC2 does most of the work; parallel/serial and serial/parallel conversion, as well as interfacing to the computer expansion bus. Bus control is achieved using 'E' (enable) and 'R/W' (read/write). The E line is normally connected to the processors '∅2' (phase 2) system clock. Data transfer takes place when the ∅2 line is high. The R/W line controls the data direction. With R/W high data is read from the 6850's registers and with R/W low data is written to the 6850's registers. Since the 6850 has two pairs of registers, a selection signal is required, this is the 'RS' (register select) line, and is connected to the least significant bit of the address bus. Data is exchanged via 8 bi-directional lines (D0-D7), when IC2 is de-selected D0-D7 are in the tri-state mode. To insert the 6850 into the computer's memory map, 3 select lines are provided; two active high (CS0 and CS1) and one active low (CS2), these lines may have to be fed from a separate address decoder if suitable memory map decode lines are not available on the computer.

Serial data transmitted from the 6850 is not suitable to directly drive the MIDI bus, so it has to be buffered. This is achieved using IC1f, since this is an inverting buffer, the data has to be first inverted using IC1e. By taking the MIDI output from between the +5V line and IC1f, IC1f is sinking rather than sourcing current. R8 and R9 limit the maximum current that can be drawn under possible fault conditions, protecting the computer, interface and MIDI device. IC1f forms the MIDI OUT buffer. Data received drives the LED half of OPTO1. R5 serves to limit current and D1 affords reverse bias protection for the LED. When the LED turns on, the transistor half of OPTO1 is biased on, and pulls the input to IC1c and the receive data input of IC2, low. When the LED is off, the transistor is also off, the input to IC1c and the receive data input of IC2 are pulled high via R4. IC1c, IC1d, R6 and R7 form the MIDI THRU' buffer, operation is identical to the MIDI OUT buffer except that data is obtained from the opto isolator instead of the transmit data output of IC2.

6850 UART Registers

Table 1 shows the registers contents on all 8 data lines. Table 2 shows the reset and divide settings in the Control register and Table 3 gives the various settings required for various word formats. Bit D7 of the Control register is the Receive Interrupt Enable bit and if bit D7 is set, an interrupt will be generated when RX Register Full bit goes high. If bit D7 is not set, receive interrupts are disabled. To RESET 6850 UART; set bits D0 and D1 to 1 (i.e. decimal 3). To ENABLE 6850 UART; set bit D0 to 0, bit D1 to 1, bit D2 to 1, bit D3 to 0, bit D4 to 1 (i.e. decimal 22). (This corresponds to Divide by 64 and 8 bits, No Parity, 1 Stop Bit). To TRANSMIT data; check that the TX Register Empty bit, (D1; Control Register) is high, if not wait until bit D1 is high, then place transmit data into bits D0-D7 of TX Register. To RECEIVE data; check that

Data Bus	Addr+1 (TX) Transmit	Addr+2 (RX) Receive	Addr+0 (WR) Control	Addr+0(RD) Status
D0	Data bit 0	Data bit 0	CK divide	RX reg full
D1	Data bit 1	Data bit 1	CK divide	TX reg empt
D2	Data bit 2	Data bit 2	Word form	*not* *used*
D3	Data bit 3	Data bit 3	Word form	*not* *used*
D4	Data bit 4	Data bit 4	Word form	Framing err
D5	Data bit 5	Data bit 5	(TX ctrl)	RX overrun
D6	Data bit 6	Data bit 6	(TX ctrl)	Parity err
D7	Data bit 7	Data bit 7	(INT en)	(INT requ)

Table 1. Register contents.

Function	D0	D1	D2	D3	D4	D5	D6	D7	Decimal Value
Reset	1	1	*	*	*	*	*	*	3
Divide by 64	0	1	*	*	*	*	*	*	2
Divide by 16	1	0	*	*	*	*	*	*	1
Divide by 1	0	0	*	*	*	*	*	*	0

Table 2. Control register (Reset and Divide).

Word format	D0	D1	D2	D3	D4	D5	D6	D7	(Decimal value)
7 bits, even parity 2 stop bits	*	*	0	0	0	*	*	*	0
7 bits, odd parity 2 stop bits	*	*	1	0	0	*	*	*	4
7 bits, even parity 1 stop bit	*	*	0	1	0	*	*	*	8
7 bits, odd parity 1 stop bit	*	*	1	1	0	*	*	*	12
8 bits, no parity 2 stop bits	*	*	0	0	1	*	*	*	16
8 bits, no parity 1 stop bit	*	*	1	0	1	*	*	*	20
8 bits, even parity 1 stop bit	*	*	0	1	1	*	*	*	24
8 bits, odd parity 1 stop bit	*	*	1	1	1	*	*	*	28

Table 3. Control register (word format)

the RX Register Full bit, (D0; Control Register) is high, if not wait until D0 is high, then retrieve data from bits D0-D7 of RX Register.

MIDI Interface Software Writing

Sequencing can be accomplished from BASIC quite easily. All that is required is that the appropriate data be output to the 6850 in the correct order. This data may be stored in an array or in data statements.

For recording or processing of MIDI data received, it is really necessary to use machine language, either entirely or using subroutines which can be called from BASIC; this should not be too much of a problem to anyone who has an understanding of assembly language, however guidelines will be given.

Before the 6850 is used it has to be RESET and the CLOCK DIVISION rate set. This is achieved by writing decimal 3 then decimal 22 to the control register of the 6850.

Data being exchanged between devices is passed through the TX and RX data registers. To achieve correct data transfer, the STATUS register must be checked; i.e. that the TRANSMIT DATA REGISTER is empty before sending more data; TDRE bit of STATUS REGISTER will be high when it is OK to send more data, and similarly for receiving data; data must be present in the RECEIVE DATA REGISTER before it can be read; RDRF bit of STATUS REGISTER will be high when it is OK to read the data.

The Registers will be configured in the computers memory map as shown in Table 4; the actual locations will depend on the machine and the address decoding used, but addresses for the VIC 20 and the Commodore 64 are shown. Figures 3 and 4 show the pin functions of VIC 20 and Commodore 64 edge connectors respectively, and Table 5 shows connections from the two edge connectors to the circuit.

To illustrate how simple the software can be, a few examples are shown in Listings 1 to 5, these show how to RESET the 6850 and READ and WRITE data, examples are given in both BASIC and 6502 assembly code. In the examples:

'base' means base address,

'base+1' means base address+1 location,

'data' means either variable or memory location containing data.

Please note that BASIC should not be used to directly get data from the 6850 since BASIC is slow. However BASIC may be used to send data without problem. If data needs to be fetched in BASIC, a machine language subroutine must be used.

Table 6 is intended as a guide to what data should be sent and in what order. Table 7 gives Controller assignments and Table 8 describes Mode Messages.

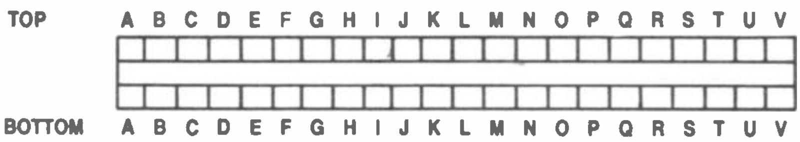
Base address	(read)	Status Register
Base address	(write)	Control Register
Base address +1	(read)	Receive Data Register
Base address +1	(write)	Transmit Data register

		VIC-20 (dec)	(hex)	CBM-64 (dec)	(hex)
Base address	=	39936	$9C00	57088	$DF00
Base address +1	=	39937	$9C01	57089	$DF01

The base address is the position in memory where the 6850 has been placed.

Table 4. Register Memory Map.

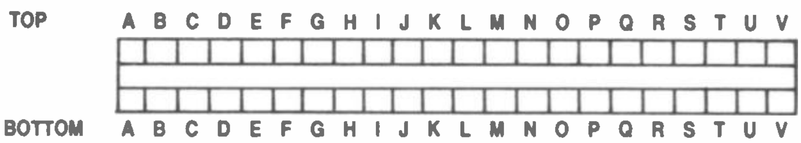
(Viewed looking into expansion slot)



Top		Bottom	
A GND	L BLK 3	A GND	L CA10
B CD0	M BLK 5	B CA0	M CA11
C CD1	N RAM 1	C CA1	N CA12
D CD2	O RAM 2	D CA2	O CA13
E CD3	P RAM 3	E CA3	P I/O 2
F CD4	Q V R/W	F CA4	Q I/O 3
G CD5	R C R/W	G CA5	R SO2
H CD6	S IRQ	H CA6	S NMI
I CD7	T nc	I CA7	T RESET
J BLK 1	U +5V	J CA8	U nc
K BLK 2	V GND	K CA9	V GND

Figure 3. VIC 20 Edge Connector.

(viewed looking into expansion slot)



Top		Bottom	
A GND	L ROML	A GND	L A10
B D0	M I/O 2	B A0	M A11
C D1	N EXROM	C A1	N A12
D D2	O GAME	D A2	O A13
E D3	P I/O 1	E A3	P A14
F D4	Q Dot clock	F A4	Q A15
G D5	R R/W	G A5	R SO2
H D6	S IRQ	H A6	S NMI
I D7	T +5V	I A7	T RESET
J DMA	U +5V	J A8	U ROMH
K BA	V GND	K A9	V GND

Figure 4. Commodore 64 Edge Connector.

MIDI Circuit	VIC 20	CBM 64
0V	GND	GND
D0	CD0	D0
D1	CD1	D1
D2	CD2	D2
D3	CD3	D3
D4	CD4	D4
D5	CD5	D5
D6	CD6	D6
D7	CD7	D7
R/W	C R/W	R/W
RS	CA0	A0
E	SO2	SO2
CS2	I/O 3	I/O 2
+5V	+5V	+5V

Note the CS0 and CS1 lines should be tied to +5V, as only CS2 is used.

Table 5.

Example 1

```
10 REM **RESET 6850**
20 POKE 'base',3
30 REM **SET DIVIDE RATE & WORD FORMAT**
40 POKE 'base',22
```

Listing 1

Example 2

```
@reset   LDA#$03        load acc with hex 03
         STA$'base'     store acc at 'base'
         LDA#$16        load acc with hex 16
         STA$'base'     store acc at 'base'
         RTS            return from subroutine
```

Listing 2

Example 3

```
@get data LDA $'base'      load acc with STATUS
          AND#$01          AND with bit 0
          CMP#$01          test
          BNE$@ get data   branch if no data
          LDA$'base+1'     get data
          STA$'data'       store acc at 'data'
          RTS              return from subroutine
```

Listing 3

Example 4

```
10 REM **IS TX REG EMPTY?**
20  IF (PEEK('base') AND 2)=0 THEN 20
30 REM **SEND DATA to 6850**
40 POKE 'base+1','data'
```

Listing 4

Example 5

```
@send data LDA$'base'     load acc with STATUS
           AND#$02        AND with bit 1
           CMP#$02        test
           BNE$@ send     branch if not ready
           data
           LDA$'data'     get data to send
           STA$'base+1'   send data
           RTS            return from subroutine
```

Listing 5

MIDI INTERFACE PARTS LIST

RESISTORS: All 0.6W 1% Metal Film

R1,3	2k2	2	(M2K2)
R2,5,6,7,8,9	220Ω	6	(M220R)
R4	10k	1	(M10K)

CAPACITORS

C1	100nF Polyester	1	(BX76H)

SEMICONDUCTORS

IC1	74LS04	1	(YF04E)
IC2	MC6850P	1	(WQ48C)
D1	1N4148	1	(QL80B)
OPTO1	Hi-Sensitivity Opto-Isolator	1	(RA57M)

MISCELLANEOUS

X1	2MHz crystal	1	(FY80B)
SK1-3	PC DIN skt 5-pin A	3	(YX91Y)
	24-pin DIL skt	1	(BL20W)
	14-pin DIL skt	1	(BL18U)
	Box AB10	1	(LF11M)

First byte	Second byte	Third byte	Description
1001 mmmm	0nnn nnnn	0vvv vvvv	NOTE ON (Velocity 0 = note off) [1]
1000 mmmm	0nnn nnnn	0vvv vvvv	NOTE OFF [1]
1010 mmmm	0nnn nnnn	0ppp pppp	POLYPHONIC KEY PRESSURE (Aftertouch) [2]
1101 mmmm	0ppp pppp	———	OVERALL KEY PRESSURE (Aftertouch) [2]
1011 mmmm	0ccc cccc	0ddd dddd	CONTROLLER CHANGE [3]
1110 mmmm	0ddd dddd	0ddd dddd	PITCH BEND [4]
1100 mmmm	0PPP PPPP	———	PROGRAM CHANGE [5]
1111 0000	0 i i i i i i i	0*** ****	SYSTEM EXCLUSIVE [6]
1111 0111	———	———	EOX (End of exchange) [7]
1111 1111	———	———	SYSTEM RESET

Key

mmmm	=	MIDI channel No. (0 to 15)
0nnn nnnn	=	NOTE on keyboard (0 to 127)
0vvv vvvv	=	VELOCITY (0 to 127)
0ppp pppp	=	PRESSURE (0 to 127)
0ccc cccc	=	CONTROLLER No. (0 to 127)
0PPP PPPP	=	PROGRAM No.
0ddd dddd	=	DATA (0 to 127)
0 i i i i i i i	=	I D Code (0 to 127)
0*** ****	=	Undefined number of data bytes (as 0ddd dddd)

Notes

[1]	0nnn nnnn	= 60 is middle 'C'
	0vvv vvvv	0 = off, 1 = ppp, 64 = between mp and mf, 127 = fff
	0vvv vvvv	= 64 in non velocity sensitive devices
[2]	0ppp pppp	0 = no pressure, 127 = max pressure
[3]	0ccc cccc	= controller number; see list
	0ddd dddd	= data for controller
[4]	0ddd dddd	2nd byte = LSB, 3rd byte = MSB
		2nd byte = 0, 3rd byte = 64, gives no bend
[5]	0PPP PPPP	= program or patch number
[6]	0 i i i i i i i	= manufacturers ID code
	0*** ****	= undefined number of data bytes, terminate by sending [7]
[7]		Use to return to normal use after EXCLUSIVE data exchange

Table 6.

Controller assignment

Controller No.	Description
0	Continuous controller 0 MSB
1	Modulation wheel MSB
2 to 31	Continuous controllers 2 to 31 MSB
32	Continuous controller 0 LSB
33	Modulation wheel LSB
34 to 63	Continuous controllers 2 to 31 LSB
64 to 95	Switch controllers
96 to 121	**undefined**
122 to 127	MODE MESSAGES (see Table 8)

Controller data

For continuous controllers 0 to 127 (min to max).
Fore switch controllers 0 = off, 127 = on.
For continuous controllers; if only 7 bits of resolution required, send only MSB. If full resolution is required send MSB first, then LSB. If only LSB has changed in value, LSB can be sent without MSB.

Table 7.

Mode Messages

Controller No.	Description	Data
122	Local control	0 = off, 127 = on
123	All notes off	0
124	Omni off (all notes off)	0
125	Omni on (all notes off)	0
126	Mono on [poly off] (all notes off)	number of channels
127	Poly on [mono off] (all notes off)	0

Note

All messages which can be sent successively (e.g. NOTE ON) under the same STATUS byte, can be sent without STATUS byte until a different STATUS is required.

Table 8.

TEST GEAR AND MEASUREMENTS

by Danny Stewart
Part 4

Part 3 discussed potentiometers, and DC meters, and we now move on to AC meters and their uses.

Alternating Current Meters

The most common methods of measuring AC currents and voltages is to rectify them before applying them to a d'Arsonval movement. The alternative is to meaure the heating effect in a wire and relate this to the current or voltage. In addition to these two methods are the electrodynamometer and the electrostatic voltmeter.

Electrodynamometers

An electrodynamometer is similar to a d'Arsonval movement except that the former uses the current being measured to produce a magnetic field through the field coils, see Figure 1, whereas a d'Arsonval movement uses permanent magnets. The meter reading using an electrodynamometer is proportional to the average of the square of the current and its use is limited to the lower audio frequency range. The sensitivity is also low, between 10Ω and 30Ω per volt compared to 20,000Ω per volt for a d'Arsonval.

Electrostatic Voltmeter

This instrument is interesting for several reasons. It does not consume any power except for a charge up period when first connected. Therefore it presents an infinite impedance to the circuit being measured. It measures voltage directly instead of measuring the effect of the current. It is also independent of the waveform under measurement, and an instrument calibrated with DC can be used for AC measurements just as well.

Figure 2 shows the construction of an electrostatic voltmeter whose operation depends on Coulomb's Law: the force between two parallel plates is proportional to the applied voltage. To start with, the plates do not overlap, but applying opposite voltages to the plates causes attraction between them and the moveable plate starts to overlap the stationary plate. The moveable plate will stop travelling when the torque of the spring equals the torque produced by the attraction between the plates. Using this method, voltages up to 300,000 volts can be meaured, and a series resistor is usually included in circuit just in case the plates are in danger of shorting!

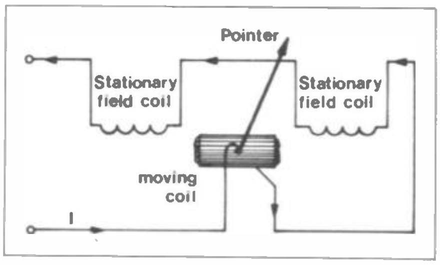


Figure 1. Electrodynamometer.

Rectification

Since a DC movement has a higher sensitivity than an electrodynamometer, it makes sense to rectify AC and then apply it to a DC movement. One arrangement is shown in Figure 3, which uses a full wave rectifier, i.e. both positive and negative going half cycles are rectified. This results in a train of pulses which the meter is capable of reading and, because of the inertia of the moving coil, the reading is an average value. The DC

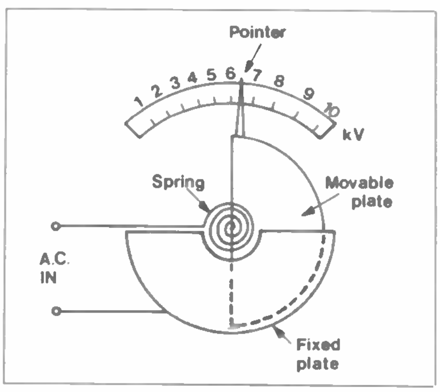


Figure 2. Electrostatic Voltmeter.

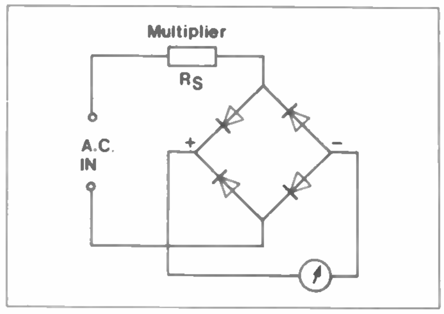


Figure 3. Rectifier for AC signals.

equivalent of these peaks is given by:

$I_{DC} = 0.636I_p$ or $\frac{2}{\pi} I_p$

where I_p is the peak value.

An AC current is usually gauged by its heating effect or root mean square (rms) value. It is related to the peak value by:

$I_{rms} = 0.707I_p$ or $\frac{\sqrt{2}}{2} I_p$

The form factor is the ratio of rms to DC reading, i.e:

Form factor = $\frac{I_{rms}}{I_{dc}} = 1.11$

This is an important parameter since the 1.11 form factor applies only to a sinusoidal waveform, see Figure 4. For other wave shapes, the form factor will be different.

Selenium rectifiers and copper oxide rectifiers are no longer used since they have low reverse voltages and can handle low currents only. Present day rectifiers are silicon or germanium with reverse voltages of 1000V and 300V respectively. Germanium diodes can handle 100mA and low current silicon

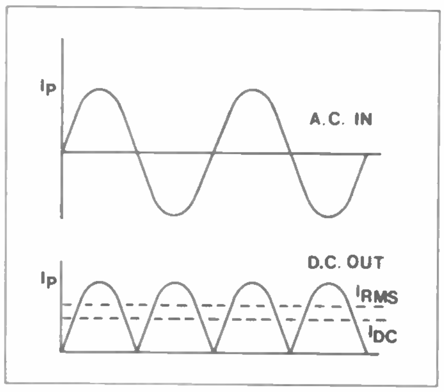


Figure 4. I_{DC} and I_{rms} related to I_p.

diodes can handle in the region of 500mA.

An ideal rectifier should have infinite reverse resistance and zero forward resistance, but the rectifier is not a linear device. The practical rectifier is also temperature and frequency sensitive. At higher frequencies the capacitive effect of the rectifier acts as a bypass and could affect readings by about 0.5% per 1kHz rise in frequency.

From the temperature point of view, a rectifier operates satisfactorily at room temperatures but if the device is meant to operate in much lower or higher temperatures then it should be enclosed in an 'oven'.

AC Multirange Meter

An AC multirange volt meter is made by providing values of series resistors, see Figure 5. Most multirange meters use this arrangement where the meter indicator is fed by only one half of the waveform. In a full wave rectifier, $I_{DC} = 0.9I_{rms}$. Therefore if only half the waveform is read:

$$I_{DC} = 0.4I_{rms}$$

Also the multiplier resistors need to be of lower values so that both DC and AC may use the same meter scale. The circuit of Figure 5 operates as follows; D1 conducts during

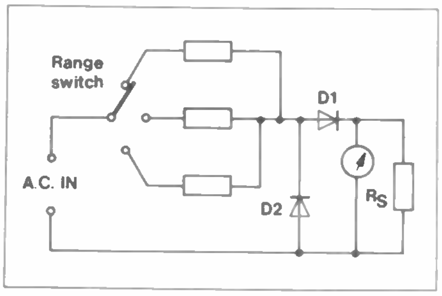


Figure 5. AC Multirange Voltmeter.

positive half cycles and D2 during negative half cycles. The negative cycles bypass the meter. If D2 were not present, there would be a reverse leakage current through D1 which, although small, would reduce the reading. The shunt resistor Rs helps draw more current through D1 and hence enables it to operate on the linear portion of its characteristic. As with DC meters, the series resistors can be arranged such that there is no need for a make before break contact, as shown in Figure 6.

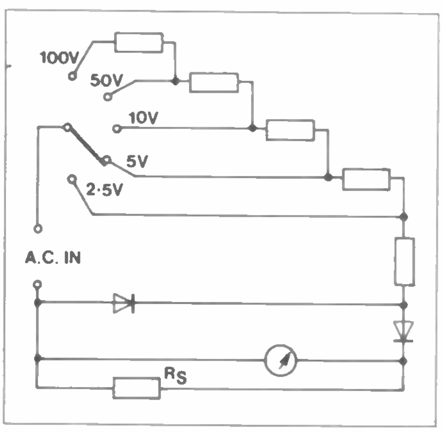


Figure 6. Different Multirange.

Moving Iron Meters

Since moving iron instruments do not recognise polarity they can be used on AC signals. These instruments can work on the attraction or repulsion principle using concentric vanes, see Figure 7, or radial vanes, see Figure 8. Both vanes receive the current under measurement, regardless of polarity. This magnetises the vanes equally, causing repulsion and the needle travels against a spring, coming to rest when the repulsion equals the tension of the spring. The

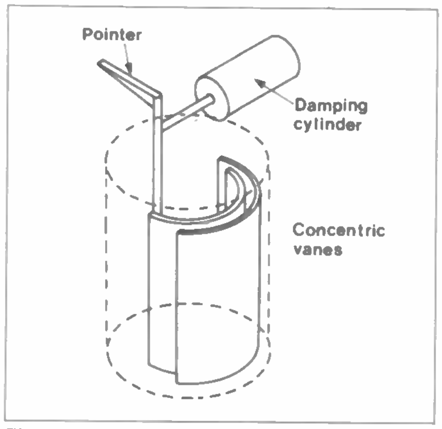


Figure 7. Moving-iron Meter (Concentric vanes).

vanes are made of aluminium and a separate aluminium vane moving in a close fitting chamber provides the damping. Since the moving parts do not carry any windings, the moving iron instrument is rugged. However, the accuracy is limited by the non-linear magnetisation curve shown in Figure 9.

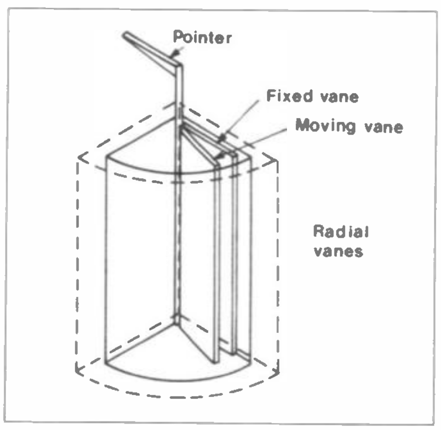


Figure 8. Moving-iron Meter (Radial vanes).

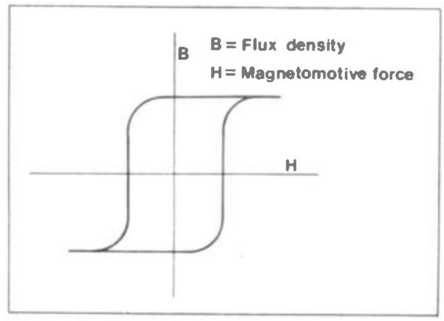


Figure 9. Magnetisation curve.

The frequency of operation is also limited to an approximate range of 25Hz to 125Hz, and at higher frequencies the impedance increase gives lower readings. Special compensation circuits can be used but they are unlikely to improve the performance much beyond 2,500Hz.

Thermal Instruments

The original hot wire instrument is shown in Figure 10. Wire AB carries the alternating current and expands in length due to the heating effect. Wire CD, attached to a spring, takes the slack out of AB ,driving a pointer up the scale. This instrument is too bulky and fragile for general usage and has largely been replaced by thermojunction instruments.

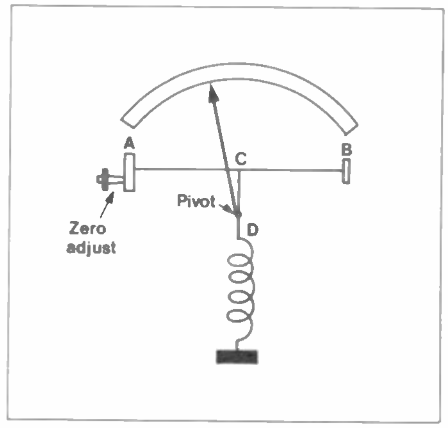


Figure 10. Hot Wire Instrument.

Figure 11 shows the arrangement of a thermojunction instrument. Point B is called the cold junction and XBY the hot junction. If two dissimilar metals are joined, the voltage generated is proportional to the temperature at the junction, and rises in proportion to the temperature. The dissimilar metals are AB and BC joined at point B but this arrangement does not take into account compensation for ambient temperature. This can be achieved as

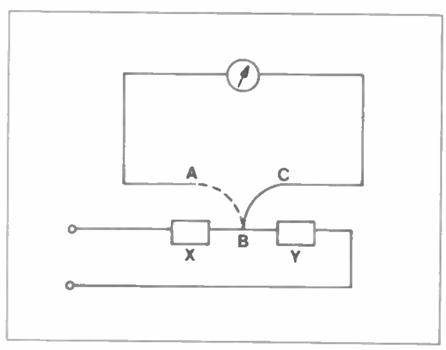


Figure 11. Thermojunction.

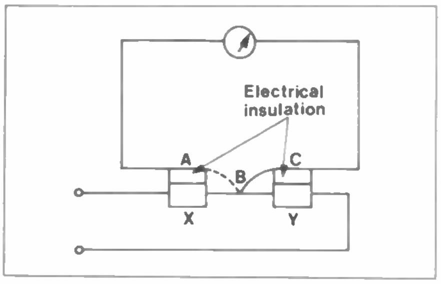


Figure 12. Temperature compensation.

Figure 12 by bending back points A and C in order to be in thermal contact (but not electrical contact) with points X and Y. Since the heat generated is proportional to the square of the current, the voltage at the bi-metal junction will also be proportional to the square of the current. This square law relationship is reflected in the meter scale which is crowded at the lower end and more diffuse at the top end, see Figure 13.

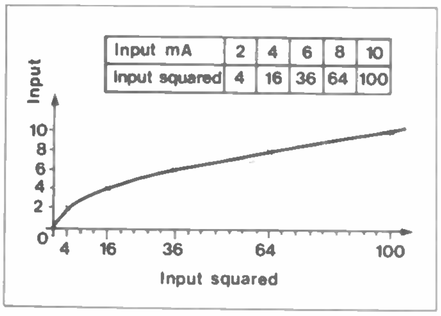


Figure 13. Square Law curve.

This instrument is good for current in the range 0.5A to 20A. Below this, from 0.1A to 0.75A, thermojunctions in a bridge formation can be used with a bi-metal in each arm of the bridge. For currents above 20A, the junction is air cooled by placing it outside the case so that the heat may dissipate.

Thermojunction instruments are excellent for RF measurements, being accurate to 1% up to 50MHz and handling currents of around 1A. At the higher frequencies, current exhibits a skin effect, i.e. it travels only in the outer layers of the conductor. Therefore, the wires can be replaced by tubes.

Current and Voltage Transformers

For DC, a simple divider will tap off a proportion of current or voltage which can then be measured. With AC, the dividers can exhibit reactance and therefore reduce the accuracy of the reading. A transformer is

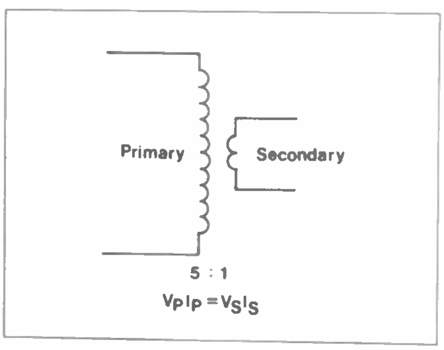


Figure 14. Transformer.

useful both for isolating the high voltage from the voltage being measured as well as to drop the voltage to a lower value and hence extend the range of the indicating instrument.

Figure 14 shows the primary isolated from the secondary since the transfer of power is via inductive coupling. A transformer is around 98% efficient and it is essentially power that is transferred. So, if the voltage is stepped down, the current goes up. Therefore there are voltage transformers and current transformers. In the case of the latter, if the current needs to be stepped up, there will be thicker wire in the secondary to cope with the higher current. If, in Figure 14, the primary current is 1A and the voltage 250V, a 5:1 voltage step down will give a secondary voltage of 50V.

$$V_pI_p = V_sI_s$$

$$I_s = \frac{V_pI_p}{V_s}$$

$$\text{Secondary current} = \frac{250 \times 1}{50} = 5\text{A}$$

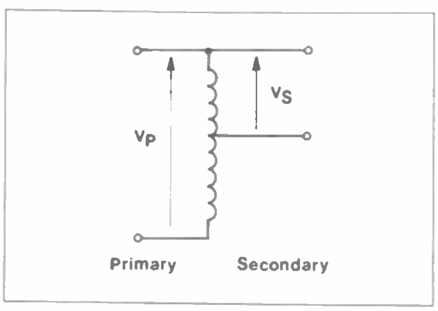


Figure 15. Autotransformer.

Figure 15 shows an autotransformer and there is no isolation between primary and secondary since the secondary uses the same windings as the primary. It is smaller, cheaper and lighter than the previous transformer construction and the required turns ratio is obtained by tapping off an appropriate number of turns on the primary in order to obtain the secondary.

Power Measurements

Up to now, we have been concerned with measurement of current and voltages, both AC and DC. But some means must be found of measuring power, else the Electricity Board will not have any means of knowing what to charge us for the power we consume. In a DC circuit the voltage is in phase with the current but as soon as a frequency is introduced into power to make it alternating current, any load becomes reactive, i.e. voltage is not in phase with the current.

This frequency is 50Hz in the UK, but 60Hz (110V) in the USA. A current with a frequency will 'see' capacitance and inductance where these are not intentional. For instance, a pair of parallel wires wrapped in insulation will present a capacitance bypass path, see Figure 16.

The phase angle between current and voltage is shown in the phase diagram of

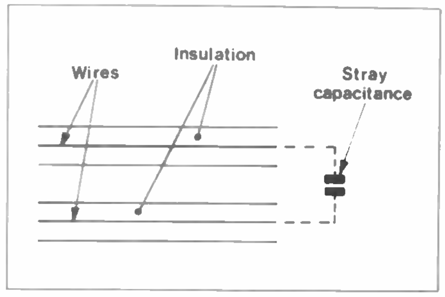


Figure 16. Reactance in AC measurement.

Figure 17. It was shown earlier how the field and moveable coils of a dynamometer were connected in series to read AC. Figure 18 shows how these coils can be connected across the supply terminals to read power. The field coils in Figure 18 effectively read the current and the moveable coil reads the voltage (R is a limiting resistor). In this way, the average power delivered to the load is registered. The voltage V in the phase diagram of Figure 17 will have components

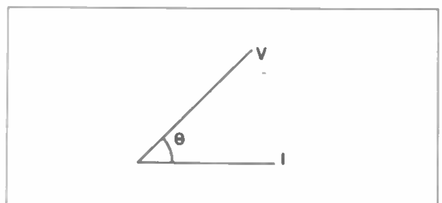


Figure 17. Phasor diagram.

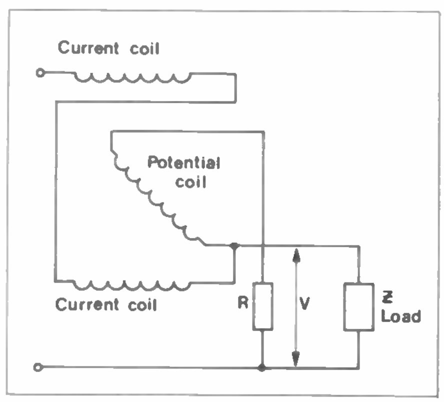


Figure 18. Single phase Wattmeter.

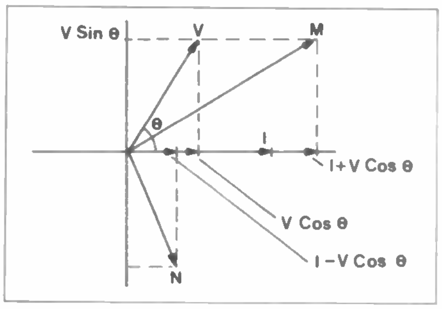


Figure 19. Sum and Difference vectors.

along the x and y axis as in Figure 19. If these are summed with the current phasor, the resultant is:

$$M^2 = V^2 + I^2 + 2VI\cos\Theta$$

If the difference is taken, the resultant is:

$$N^2 = V^2 + I^2 + 2VI\cos\Theta$$

From the two above equations:

$$M^2 - N^2 = 4VI\cos\Theta$$

Using thermocouples, this sum and difference can be measured, hence measuring the power proportional to VI cos Θ.

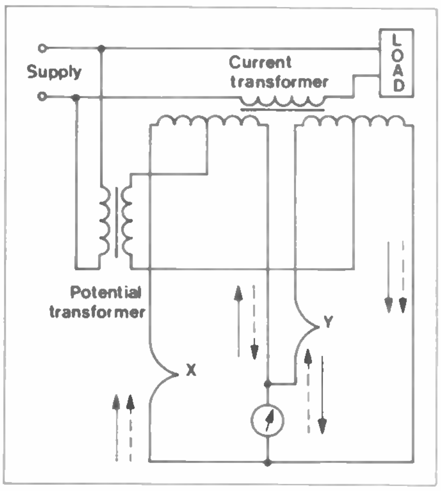


Figure 20. Thermal Watt Converter.

Figure 20 shows a thermal watt converter. Thermocouple X receives the sum of the currents and thermocouple Y receives the difference. Since the heating effect is proportional to the square of the currents, M^2 and N^2 are obtained. If these thermocouples are connected in opposition, the effect is $M^2 - N^2$ which was shown to equal four times the power and the reading can be scaled down by a factor of four.

In Figure 20, the dotted arrow shows the direction of current through the current transformer and the straight arrow shows the direction of current through the potential transformer. Although only one thermocouple has been shown for each of X and Y, several series connected thermocouples are used in place of X and Y to give higher voltages.

A commercial arrangement of a watt/hour meter is shown in Figure 21. This is typical of that found on domestic properties for the recording of single phase power consumption. The voltage coil is connected across the supply and the current coil in series with the

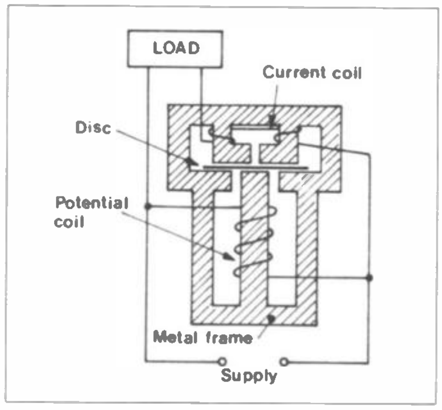
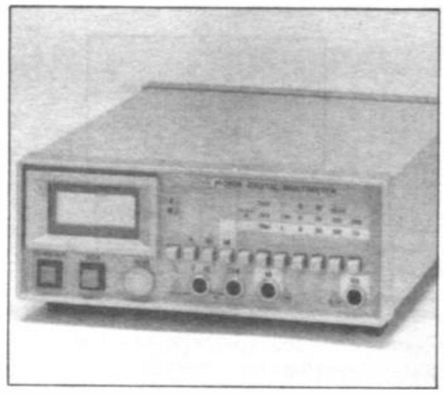


Figure 21. Watthour Meter.



supply. A light aluminium disc is suspended as shown and rotates because of the voltage field as well as the eddy currents induced by the current coil. The number of revolutions of the disc is therefore proportional to the voltage as well as current and through a suitable gearing mechanism, the power consumed in kilowatts is displayed on the meter face. The rotation of the disk is damped by two small permanent magets opposite each other on the edge of the disc, see Figure 22. The absence of these magnets could cause the disc to spin too fast or continue spinning when the load is removed. The meter is calibrated over a range covering 10% of full load to full load; all other loads then produce satisfactory readings. Adjustment at full load consists of altering the position of the permanent magnets. But adjustment at 10% of full load is more difficult, and requires an extra winding on the voltage coil, or a metal shield to reduce the field of the voltage coil.

The power delivered is maximum when the voltage is in phase with the current or Θ = 0 in the power formula VI cos Θ, since the cosine of zero is one. For all other values of Θ, the cosine is less than one.

In some instances it may be necessary to measure this phase angle, and a suitble circuit must be devised. Figure 23 shows one such circuit based on the dynamometer. The field coils carry the line current and the moveable coils gauge the line voltage. The displacement of the moveable coils relative to the field coils is a measure of the phase angle or power factor, and the scale can be calibrated directly in phase angle (Θ) or power factor (cos Θ). The moveable coil is a pair of crossed coils, one with a resistor in series, the other with an inductor.

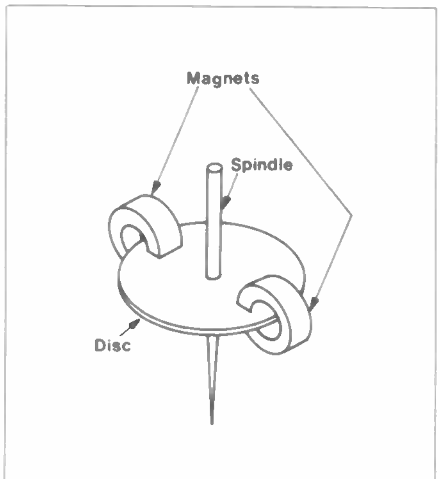


Figure 22. Disk damping.

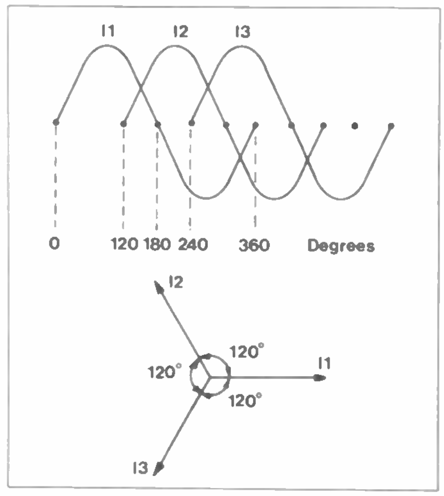


Figure 24. Three phase representation.

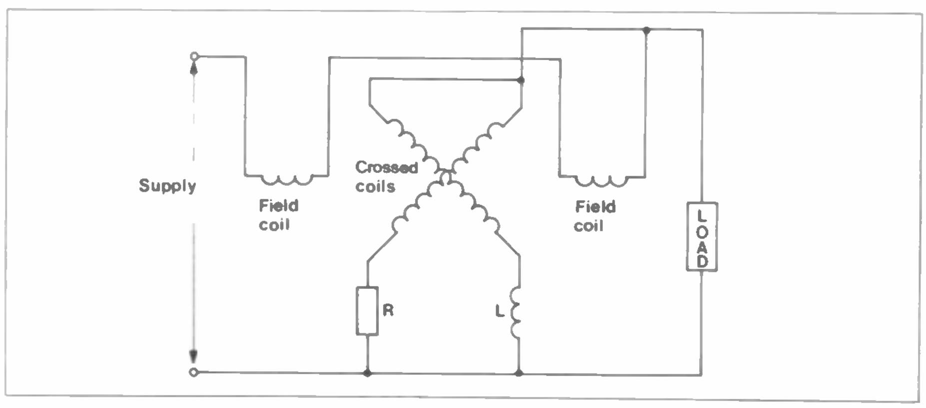


Figure 23. Phase angle measurement.

Up to now, we have considered only single phase supplies, but the Electricity Board supplies three phase power to industrial premises. In a three phase supply the currents and voltages are separated by 120° and Figure 24 shows two methods of displaying these currents.

Blondel's theorem states that if one wire of a polyphase system can be made common to all the potential circuits then the number of wattmeters required to measure the total power is one less than the number of phases. Figure 25 shows a three phase delta supply and the connection arrangements for two wattmeters to measure the power consumption.

Before we leave power measurements we must look at the decibel (one tenth of a Bel). The Bel is too big a unit for most applications, and therefore the decibel (dB) is used.

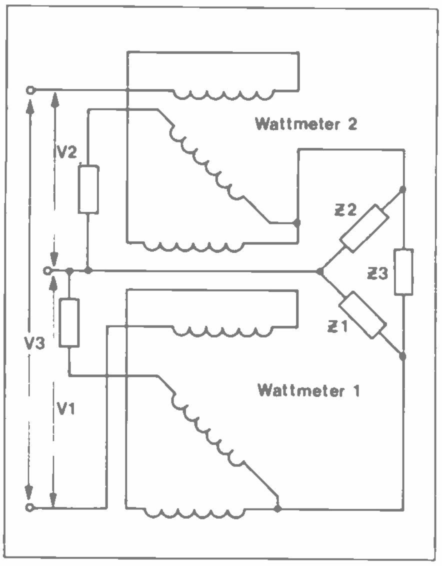


Figure 25. Measuring Three phase power.

The decibel is a logarithmic power ratio with reference to a particular power level, usually 1mW in a 600Ω load or 0.775V across the same load. A sinusoidal waveform is also assumed:

$$dB = 10 \log \frac{P_o}{P_r}$$

Where P_o = output power and P_r = reference power (mW).

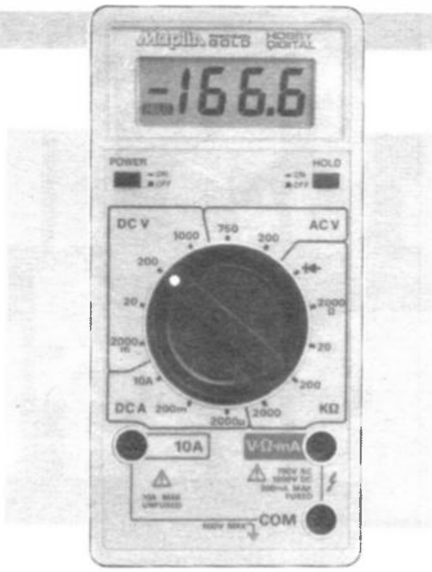
Currents and voltages can also be used provided both the output as well as reference is across identical resistors. The equations are:

$$dB = 20 \log \frac{V_o}{V_r}$$

$$dB = 20 \log \frac{I_o}{I_r}$$

The logarithms used are all to the base 10 and the human eyes and ears perceive on a logarithmic scale. That is, a tenfold sound output will be recognised by the ear as a doubling in sound power. For instance:

log 10 = 1, log 100 = 2



Similarly with vision; a tenfold increase in light intensity will be seen by the eye as a doubling of brightness.

Decibels are often used in defining the amplification of a signal through an amplifier, assuming the input and output impedances are similar. Another advantage of defining circuit gain in dB's is that the gain of successive stages can be added directly. It was said above that 0.775V is a reference voltage, therefore any multimeter with a dB scale will have 0dB aligned with 0.775V on the voltage scale.

Summary

In Part 3, we saw how potentiometers can be likened to bridge circuits and a high accuracy can be obtained by this method of measurement by comparison. The basic slide wire can be made more compact by lumping the resistance into loops. Volt boxes are used to extend the voltage range and shunt boxes to extend the current range.

Compact meters are required by technicians measuring current, voltage and resistance, both DC and AC. The original suspension galvanometer has evolved into the permanent magnet moving coil. Both rely on one magnetic field reacting against another. This usually consists of a fixed permanent magnet and a moving coil which stretches a spring. Therefore the spring must be of good quality and linear over its useful range. Phosphor bronze springs of good quality and several counter weights to balance the needle, all make the movement more refined. Soft iron pole pieces ensure a uniform magnetic field and incabloc mountings reduce shock to the movement.

Damping is provided by mechanical or electromagnetic means. Mechanical damping is achieved by vanes moving in a chamber, stiction being provided by air, and electromagnetic damping by counteractive eddy currents. Temperature compensation is done by means of swamping resistors, but the disadvantage is that a higher applied voltage is required to give the same deflection.

The basic PMMC range is extended by series resistors for measuring voltage, or shunt resistors for measuring current. These resistors can either be individual or in series. If they are individual, a make before break contact is required to protect the meter. The series arrangement with taps between the resistors ensures there is always some resistance in the circuit.

A meter's sensitivity is quoted in terms of so many ohms per volt. The larger this figure, then the *less* does the meter load the circuit under test and alter its behaviour, thereby producing erroneous results. Of course, sensitivity is synonymous with quality of manufacture, so it is only to be expected that the more 'transparent' the instrument appears to the circuit being tested then the more expensive it is.

Resistance can be determined by measuring both the current and voltage, i.e. the ammeter/voltmeter method. However, resistance measuring instruments can be devised, namely the series and shunt ohmmeters. In the shunt ohmmeter the supply battery is in circuit all the time, and a switch is required to disconnect it when not in use. The series ohmmeter is the type most commonly used, with zero reading on the right hand side of the scale and infinity on the left.

So far we have seen that AC meters require a rectifier to convert the AC into DC, or some method to measure the heating effect of the AC. In both instances it is the rms value that is being measured.

Electrodynamometers pass the same current through both field and moving coil and measure the repulsion between the two coils. An electrostatic voltmeter measures the deflection between two plates and is independent of the applied waveform.

Moving iron instruments also work on the attraction/repulsion principle and employ radial or concentric vanes. Although these instruments are rugged, the accuracy is limited by the non-linear magnetisation curve.

Rectification can be either full-wave or half-wave and the following relationships apply: $I_{DC} = 0.636I_p$, $I_{rms} = 0.707I_p$, $I_{DC} = 0.9I_{rms}$ and the form factor of a sine wave is 1.11.

The original hot wire instrument has been replaced by thermojunctions, which are particularly good at radio frequencies up to 50MHz, and currents up to 3A. Current and voltage transformers help to extend the range of AC instruments, as well as isolating the power line from the measuring instrument.

Power can be measured by using thermocouples to measure the sum and difference of the currents squared. In AC measurements, because of the frequency involved, loads become reactive and the voltage is not in phase with the current. One method of measuring this phase angle or power factor is with the crossed coils power factor meter.

Single phase power can be measured with a wattmeter and three phase power requires only two wattmeters according to Blondel's theorem. The currents in a three phase supply are separated by 120 degrees.

The decibel is a useful unit of power measurement, since eyes and ears perceive on a logarithmic scale. The advantage of measuring circuit gains or losses in dB's is that these can be added or subtracted conveniently.

Decibel measurements are always with reference to a particular power level, usually 1mW across 600Ω, or 0.775V across the same resistor. A sinusoidal waveform is also assumed.

Watts in an Amplifier?

by Dave Goodman Part 2

Decibels

A decibel (dB) is one tenth of a bel and is a commonly used logarithmic unit for power, voltage and current gain (or loss!). Table 1 shows decibel levels of sound.

Frequency response graphs, such as those used for microphones and loud speakers are compressed using a logarithmic scale expressed in dB, as large quantities of information can be represented in a small area in this way. As an example, a range of sound intensities in live music can be 70dB or more, which represents a ratio of approximately 20 million to 1 (2×10^7:1). When decibels are used for voltage or power ratios, 3dB represents a doubling of audio power. Mathematically, the 'power' of a sound wave or pressure and energy is expressed as:

Electrical Power Ratio:

$$dB = 10\ LOG_{10}\ (W/W_0)$$

Where W and W_0 is the ratio of two powers.

As sound power is proportional to sound pressure squared, then:

$$\text{Voltage Ratio: } dB = 10\ LOG_{10}\ (P/P_0)^2 \text{ or } 20\ LOG_{10}\ (P/P_0)$$

In the previous issue, several terms used in amplifier specifications were discussed, along with a small amplifier project. This part will look at further parameters and terms often used in specs, and investigate an amplifier which uses MOSFET technology.

Again, P/P_0 is the ratio of two pressures.

Internationally, the accepted reference level 0dB corresponds to 0.0002 microbars, or the approximate sound pressure threshold of hearing. The ear can accommodate a pressure range from 0.0002μb to 200μb and possibly the pain threshold (130dB) of 600μb.

Decibel	Energy	Relative Level	Pressure
120	10^{12}	Pain threshold	200μb
110	10^{11}	Discos, low level jet aircraft	
100	10^{10}	Noisy factory environment	20μb
90	10^9	Tube trains, city street	
80	10^8	Large orchestra	2μb
70	10^7	Inside small car, noisy office	
60	10^6	Domestic Hi–Fi, radios	0.2μb
50	10^5	Conversation in restaurant	
40	10^4	Library, quiet office	0.02μb
30	10^3	Low conversation	
20	10^2	Whisper, quiet church	0.002μb
10	10^1	Soundproof room	
0	10^0	Hearing threshold	0.0002μb

Table 1.

Voltage ratios can be expressed in a similar fashion to power ratios:

$$dB = 20\ LOG_{10}\ (V/V_0)$$

And resistance ratios:

$$dB = 10\ LOG_{10}\ (R/R_0)$$

From these two expressions of V and R, I (current) ratios can be found from:

$$dB = 20\ LOG_{10}\ (V/V_0) + 10\ LOG_{10}\ (R/R_0)$$

Power ratios commonly found in specifications.

Where W = measured power level, and W_0 = reference power level.

	$10\ LOG_{10}\ (W \div W_0)$
3dB	where $W \div W_0 = 2$
6dB	where $W \div W_0 = 4$
12dB	where $W \div W_0 = 16$
18dB	where $W \div W_0 = 64$
24dB	where $W \div W_0 = 256$

Voltage ratios where 0dB is referenced at 0.775mV V_0). dB = 20 $LOG_{10}\ (V \div V_0)$ where V is the measured voltage level.

3dB	When V = 1.4V
6dB	When V = 2V
12dB	When V = 4V
18dB	When V = 8V
24dB	When V = 16V

Loudness

This term describes the very subjective effect that sound waves have on a listener, and is the listener's perception to the strength of sound. The unit of loudness is the 'phon' and it refers to the audible comparison between a reference sinewave signal of 1kHz and the signal source under consideration. The loudness level in phons is then equal to the reference level when both sound levels are judged by the listener to be equally loud. As perception of sound is essentially personal in apparent level and frequency, then the term loudness is subjective in its effect. Loudness or contour controls are often found in music reproduction equipment where very low speaker output levels suffer in low frequency content. The use of this control lifts or enhances bass output or occasionally treble output and may even be used to enhance poor speaker systems.

Noise

Amplifiers and pre-amplifiers should be able to electrically increase the amplitude of applied signals with the minimum of colouration or added sound. All electrical devices produce noise to a greater or lesser degree and this effect can become accumulative. For an amplifier with a given amplification factor or gain, measurements are taken at the output with signal applied and removed; the two readings are then expressed as a ratio in dB. Modern CD amplifiers have an extremely high noise or signal to noise ratio, whereas tape reproduction systems and phono players of not too long ago, had at best 65 to 70dB figures. Tone control circuits allowing high degrees of boost (especially treble filters) can often be heard to produce an audible hiss when set at maximum. This noise may well be annoying on its own, but becomes masked when a music source is applied.

Expansion and compression techniques are used to improve system response to high dynamic range signals, noise levels are also greatly improved this way and the method is known as companding. Digital recording methods also allow added noise signals to be analysed and modified or even removed. As CD systems do not suffer from low frequency noise introduced from motors, drive wheels and arm resonances, the CD amplifier can concentrate on reproducing signals down to very low frequencies, and technology has introduced complex systems for doing this with extremely low noise levels.

Earth Loops

Looking at the example in Figure 1, the block diagram represents a microphone connected to a mic' pre-amp. The pre-amp is connected to a stage mixer which feeds a power amplifier and loudspeaker. The chassis symbols arrowed represent ground or Earthing connections on each of the three stages. If each of these chassis points are connected to mains Earth then a separate return loop is set up, shown by the dotted area below the circuit. All signal return circuits have tiny currents flowing and generally are not a problem, but long connecting cables between each stage will accumulate induced noise and hum as well as adding to the Earth loop. At best, system signal to noise levels will be acceptable and at worst, hum will be amplified by the P.A. One method of reducing loop problems is to wire the Earth to a central point and re-connect other stage Earth points to this as shown in Figure 2. Return path eddy currents

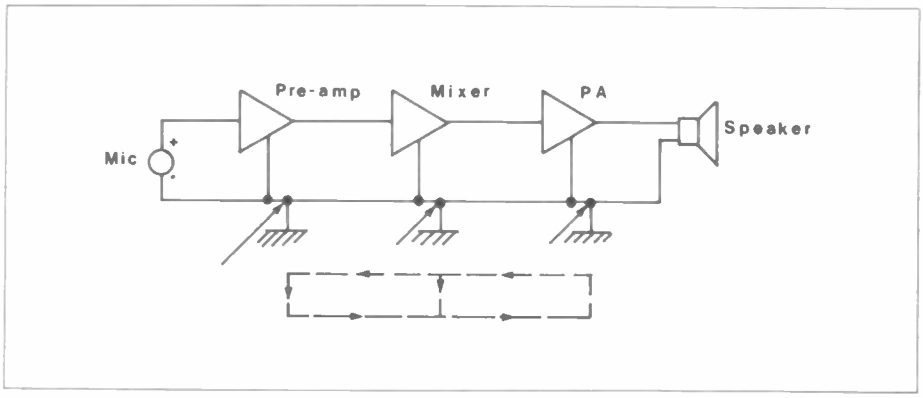


Figure 1. Earth loops.

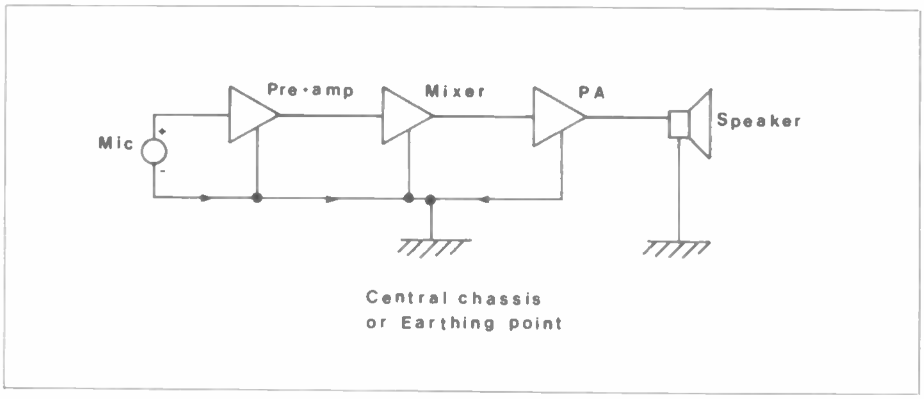


Figure 2. Central Earthing.

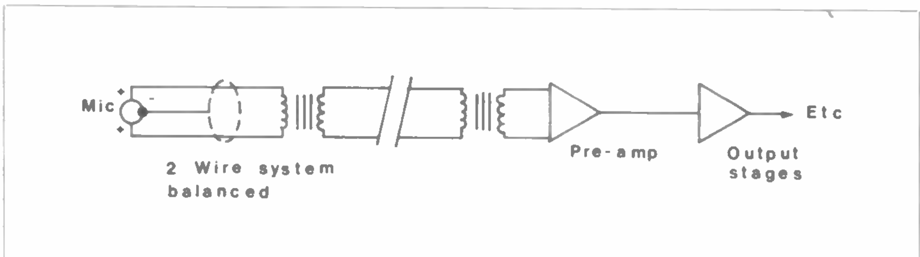


Figure 3. Balanced system.

will then flow into the central chassis point without forming a loop.

Loudspeaker return paths should not be part of any other signal path at all, and must be taken to appropriate grounding points on the PSU. On commercial equipment this may be a problem if their internal chassis ground cannot be lifted from Earth by switching, especially as legal regulations prohibit the removal of mains Earth from mains operated equipment. Further loop problems can be reduced by using low Z balanced lines for low level signals and short interconnecting cables, see Figure 3.

Damping Factor

The output source resistance of an amplifier effects the amount of electromagnetic damping, at low frequencies, of a connected loudspeaker. The lower source resistance becomes, then the higher damping effect becomes. For instance, the damping factor Fd can be roughly assessed by dividing the normal speaker load (e.g. 8Ω) R_L by the amplifiers' source resistance (e.g. 0.1Ω)R_S giving:

$$Fd = \frac{R_L}{R_S} = \frac{8}{0.1} \text{ or } 80.$$

Modern amplifiers usually have very low, even negative, values of R_S and the damping factor tends to be affected by speaker connecting leads. Long connections of thin wire between amp' and speaker can have quite high resistance values, thus increasing R_S and reducing the damping factor Fd. The effect of low damping factor values is to allow increased overshoot at the loudspeakers' resonant frequency, producing a booming sound from the speaker enclosure. Speaker damping is also affected by enclosure design, accousting damping material and the loudspeaker Q factor as well as amplifier R_S!

A more accurate method to determine amplifier Fd is by measuring the change in amplitude of a low frequency sine wave, at the amp' speaker terminals, when a known load is alternately applied and removed. Damping factor can then be calculated from:

$$Fd = \frac{V}{V_1 - V}$$

Where V = voltage with load applied.
V_1 = voltage with load removed.

As amplitude variations are likely to be small, accurate voltage measuring equipment is required.

Output Stage Classes

Class A is most commonly found in low-power stages where quiescent current is small. Power output stages occasionally use class A configurations, although biasing power transistors for continuous collector current throughout a complete signal cycle requires large heatsinks to prevent thermal run-a-way. A simple example of class A use is shown in Figure 4.

Power output stages often employ two transistors (or FET's) in 'push-pull'. Here, current decreases in one device and increases in the other throughout the signal cycle (see Figure 5) and voltage, current do not drop to zero. Both power transistors receive input signals in phase at each base. Non-complementary devices, shown in Figure 6, require 180° out of phase base signals (anti-phase) and to drive both inputs, a phase splitter stage is used.

Biasing output stages for Class A allows a peak output voltage of half the supply across the output load. Peak load current will be twice that of quiescent current and the efficiency:

$$\text{Class A} = \frac{\text{supply volts x quiescent current}}{\text{2x supply volts x quiescent current}} \times 100\%$$

or 50%

Class B

This type of output stage has very little collector current flowing until drive signals are applied. Collector current will then flow through one of the output pair, for half of the signal cycle, while the other is non-conducting. The procedure is reversed for the remainder of the signal cycle. Base biasing is usually set so that a small amount of collector (quiescent) current flows in the absence of any drive signal. Increasing the quiescent current further, places the output stage towards Class A and the term Class AB is used to define this situation. In practice, Class B causes current to increase in one of the pair and decrease through the other until no current flows in one device, at a particular time during the drive signal cycle. This situation being reversed during the remainder of the cycle. Due to non-linearity between base/emitter junctions in transistors, both halves of the output signal do not reconstitute exactly and a small step at the cross-over point develops. This distortion can be severe at high frequencies, but increasing the quiescent current through each device can reduce this effect. Complementary Class B MOSFET output stages exhibit this effect as they are not biased like transistors, due to their high input (gate) impedance and this is dealt with later on (see 150W MOSFET Amp). In theory,

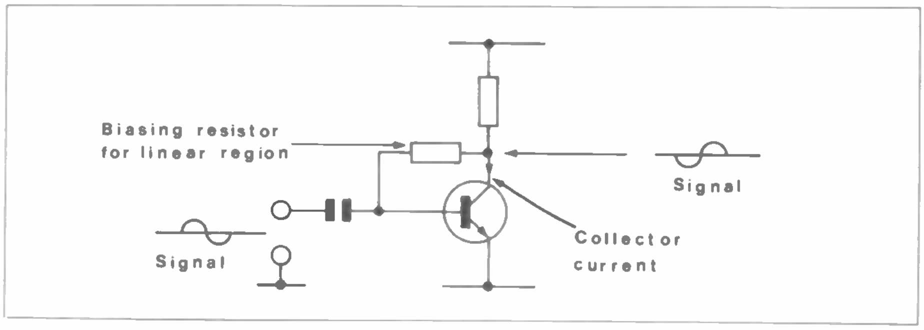


Figure 4. Simple Class A.

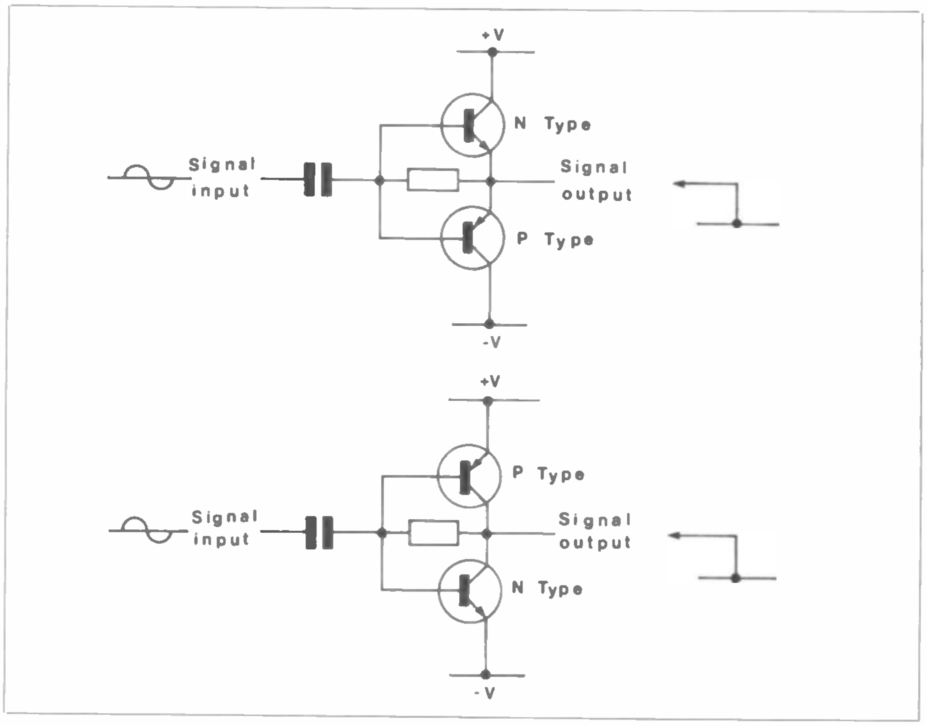


Figure 5. Complementary Push-Pull.

with no quiescent current flowing, the maximum power is $V^2 \div 8 \times \text{LOAD}$ and efficiency is:

$$E_f = \frac{V^2}{8R} \times \frac{2 \times \pi \times R}{V^2} \times 100\% \text{ or } 78.5\%$$

Class D

'Digital' amplifiers are becoming available in Hi-Fi systems, again due to the increasing popularity of CD. Several manufacturers produce high power Class D P/A's for stage use as they offer extremely high efficiency (90% and more). The operating principle is entirely different to the previous types of amplifier described as audio signals are converted to variable mark-space ratio square waves. The output stage transistors are configured as switches and are turned on and off by a separate switching signal, or carrier. The pulse-width-modulated signal is then sampled

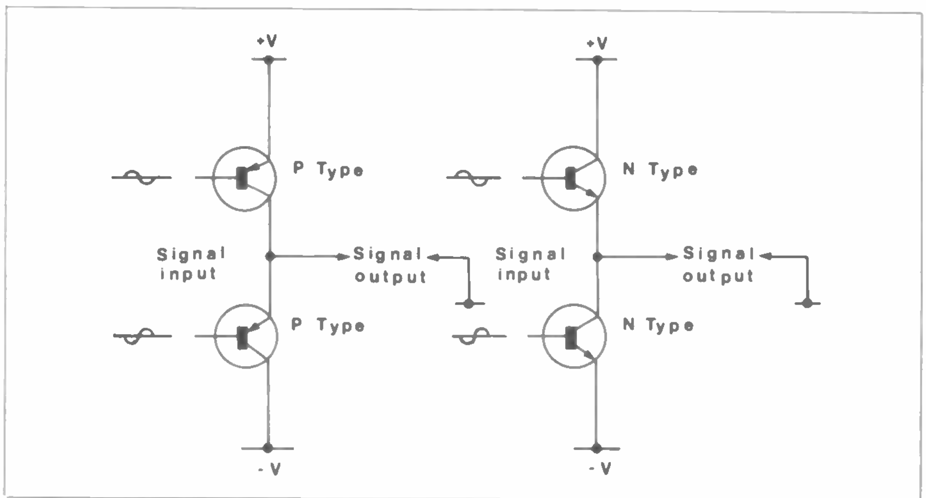


Figure 6. Push-Pull non-complementary.

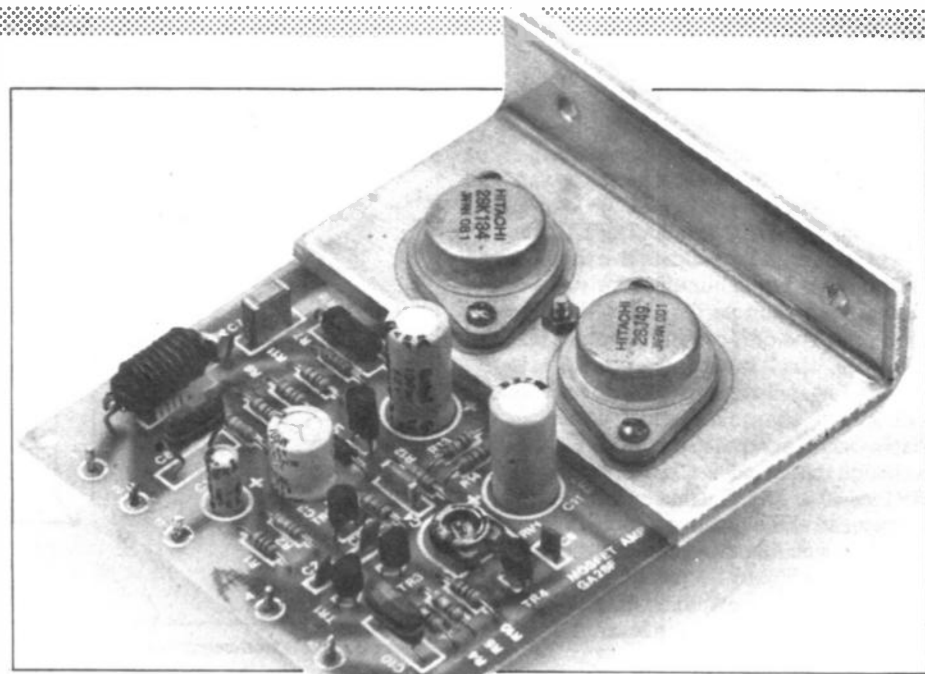
at the appropriate time and a carrier stepped representation of the original audio signal is generated.

Switching signals are usually three to four times the frequency of maximum audio frequency signals likely to be amplified, to reduce aliasing effects on harmonically related sub-tones which will become audible. The carrier signal is then removed by suitable low-pass filtering, leaving a good quality audio signal without cross-over problems common to Class B. As switching principles are used in Class D, wasted power in the form of heat is reduced and more power is available to the load. Therefore, efficiency of these amplifiers is very high and in theory only, a maximum of 100% power is available.

100/150W MOSFET Audio Amplifier

The specification is taken from the standard MOSFET Amp kit (LW51F), also available in ready-built form (YM27E) for non-constructors. Figure 7 shows the circuit diagram of the amplifier module and Figure 8 details a simple, unregulated power supply (not available in kit form at the time of publishing!).

This particular amplifier has been an extremely good seller for several years now and its popularity is mainly due to simplicity and reliability. MOSFETs are able to take an enormous amount of



Specification

Power supply voltage	–	+50/0/−50 V DC Max.
Supply current quiescent	–	50 to 100mA variable
Supply full load	–	3 Amp continuous
Short circuit	–	Fused supply, no O/P protection
Power output ratings	–	100W rms into 8Ω continuous
	–	150W rms into 4Ω continuous
T.H.D.	–	0.01% at 1kHz
Power response	–	15Hz to 40kHz
Slewing rate	–	20V/µs
Damping factor	–	Fd = 200 (8Ω load)
Input sensitivity	–	850mV (2.4V pk/pk) into 47kΩ for rated output

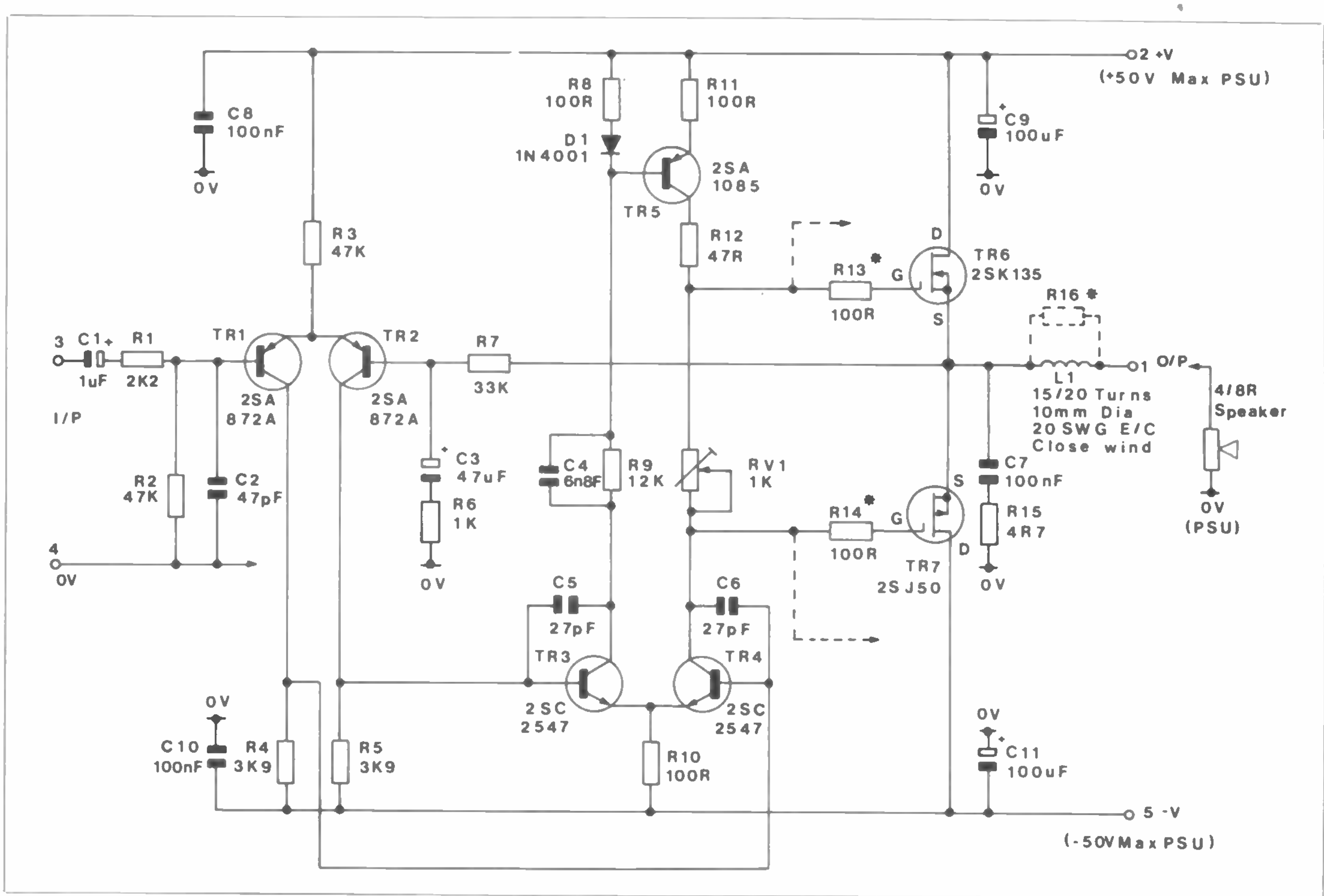


Figure 7. 100/150W MOSFET amplifier circuit.

'punishment' and as secondary breakdown problems are non-existent they can prove to be superior to bipolar circuits in an open-ended design such as this. Both N and P channel MOSFET gates are of such high impedance that they can be connected together effectively and driven from a simple, Class A voltage amplifier. The only biasing required for the FETs, which is not really critical, is to allow a few milliamps of collector current (via RV1) to charge the gate/source capacitance internal in the MOSFET. although this circuit is Class B, setting RV1 for 50 to 100mA drain current (measured at the positive supply rail) gives a Class AB output and cross-over distortion at higher frequencies can be reduced by close matching of the FETs, and possibly increasing quiescent current.

These particular MOSFET devices (see Figure 9) can be paralleled with each other, but several considerations and precautions must be taken. Their fairly high input capacitance limits the HF bandwidth, but, having a high input impedance, they are prone to internal oscillation. The gates can easily feed several megacycles of RF back into the driver stages, but as feedback is fairly low, this does not present a problem in these stages. The problem becomes noticeable by R15 overheating and quiescent current increasing. Instability often cannot be seen on low bandwidth oscilloscopes or on multimeters, but can be limited by fitting gate drive resistors to each device with values between 330Ω to 1kΩ.

Small, low wattage types are just inductive enough to prevent instability, but at high peak signal levels small bursts of RF may appear at the FET cross-over points, due to a lack of biasing current. Small polystyrene capacitors of 47pF to 330pF can be fitted between each gate and source (Figure 9) which discharge at high frequency and also balance varying internal capacitances between N and P type FETs. Connecting devices in parallel will not allow a higher power supply voltage to be used, but will allow higher currents to be delivered into lower impedance loads (1 to 2Ω). Combinations of 1 to 4 FETs can be fitted in each supply with suitable gate loading and feedback resistors (0.18 to 0.22Ω) inserted in each Source as shown. Supply decoupling *must* be fitted very close to the Drain pins on each rail, and wiring between all gates to driver stage (shown dotted in Figure 7) must be kept short. Generally a maximum of 5cm (2 inch) is acceptable.

The resistor R16 can be fitted to damp the coil L1 if ringing on the waveform becomes noticeable when driving into very low-Z loads. L1 itself can have values around 1 to 10μH and its impedance increases with frequency, thus preventing excessive HF current flowing when driving into a short circuit. Fuses fitted in both supply rails will blow at low frequency drive into short circuits.

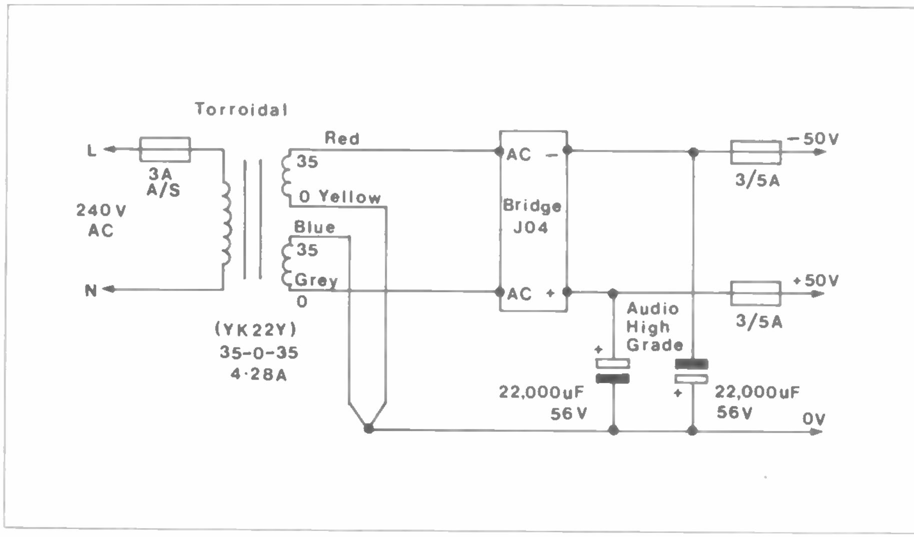


Figure 8. Simple non-regulated supply.

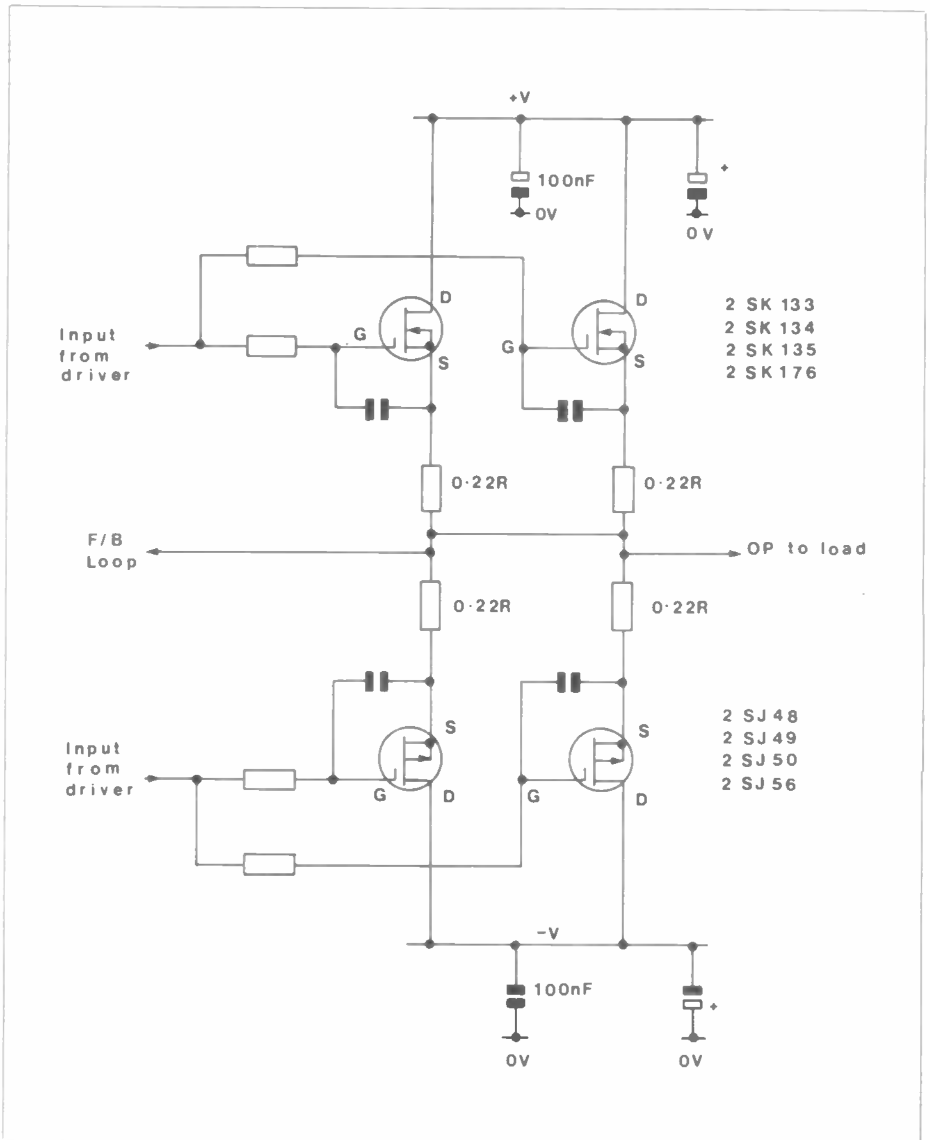


Figure 9. MOSFETs in parallel.

Due to their negative temperature co-efficient, MOSFETs rarely overheat, under normal conditions, as the drain-source channel resistance increases with increasing temperature. At 25 to 30°C their resistance is just over 1Ω, and at 60°C approximately 2.5Ω, so copious heatsinking allows higher current flow by keeping the FET case temperature down.

Finally, PSU's should be capable of delivering high currents for good transient response and all wiring, within the PSU, and from PSU rails to module, *must* be kept as short as possible, using heavy gauge wire. One very good reason for using torroidal transformers, which have low magnetic radiation and good regulation.

HI-FI LOUDSPEAKERS AND ENCLOSURES

by Dave Goodman

Loudspeakers generally appear to be simple devices, where electrical signals are applied to one end with sound eminating from the other! In fact their design and application is very complex - not just a question of 'bashing up a quick box' hoping it will sound O.K.

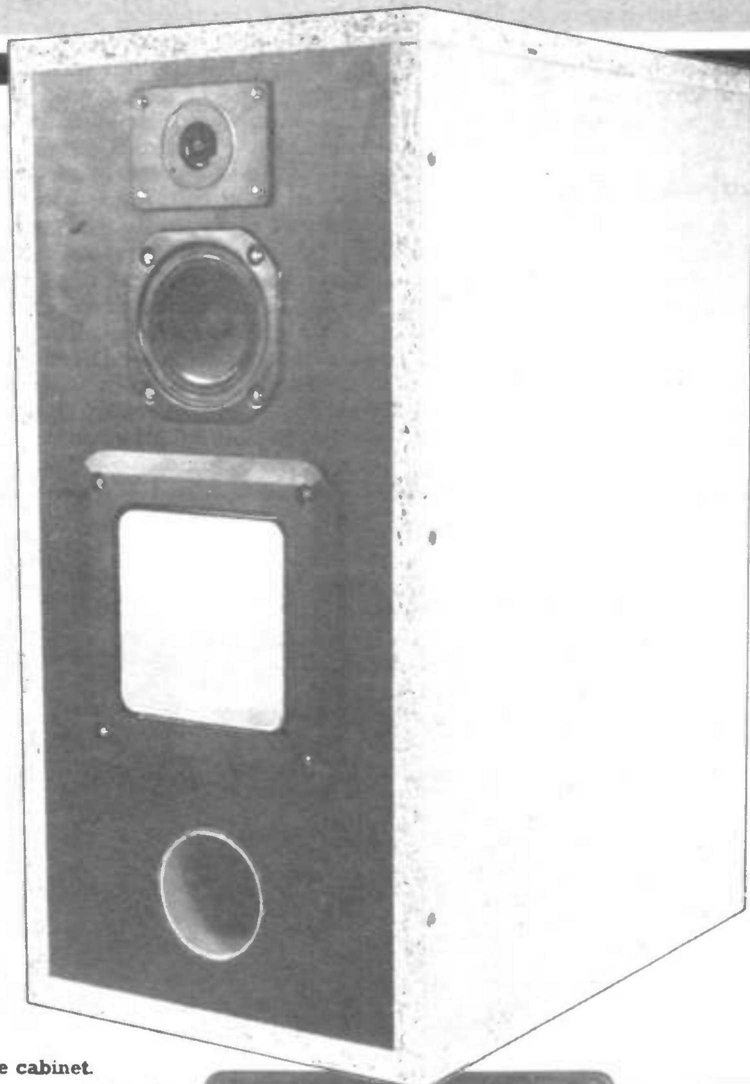
This series will be featuring the very latest range of High Fidelity Loudspeakers in the Maplin catalogue, explaining manufacturers' specifications, and how to use them in your own designs. In addition, kits in the form of pre-shaped baffles with speakers, X-over, etc., will be available to accompany the series.

The three main drive units available at this time are:

Bass Driver YN24B
50W Extended Bass YN47B
Fibreglass Driver YN25C

Each unit has a high temperature aluminium voice coil former allowing good heat dissipation with very low distortion characteristics.

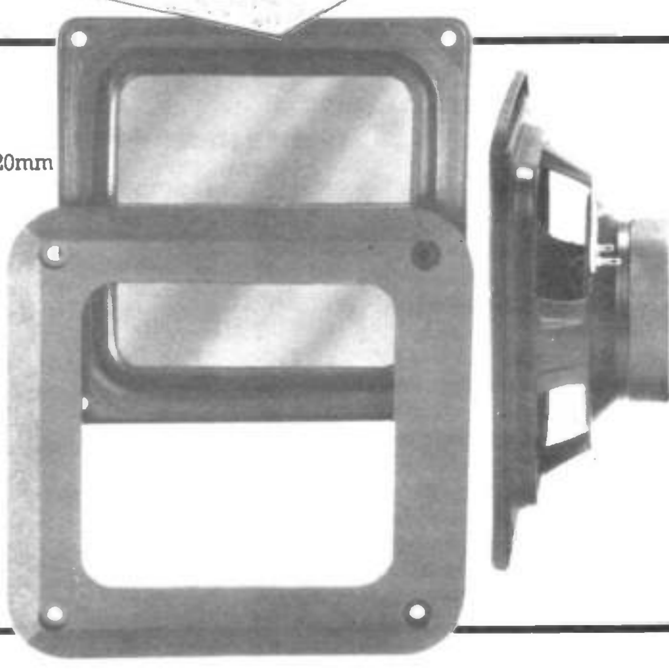
The six inch, square bass driver (YN24B) has a flat diaphram constructed from microfoam damped polymer foam that has been sandwiched between aluminium sheets. This design offers good vibration control with excellent spatial dispersion making it ideal for use with digital recordings (CD). Cabinet



40 litre cabinet.

BASE DRIVER - YN24B

Chassis		150 x 150mm
Baffle		133 x 133mm. Corner radius 20mm
Fixing		134 x 134mm. 5mm clear
Flux Density	(B)	7800 Gauss
Frequency Response		65Hz - 4kHz
Power Handling		60W peak, 30W RMS
NOM Impedance		8 ohm
Sensitivity		87dB (1W - 1M)
Coil Diameter		25mm
Free Air Resonance	(Fs)	50Hz $\pm$8Hz
Moving Mass	(Mmd)	0.0107Kg
Suspension Compliance	(Cms)	0.0009
Mechanical Q	(Qms)	2.26
Electrical Q	(Qes)	0.61
Total Q	(Qts)	0.48
Equivalent Air Load	(Vas)	22 Litres
Effective Surface	(Sd)	0.0131m^2



mounting is from the outside using the 170mm square plastic trim supplied.

The eight inch extended bass driver (YN47B) is a more traditional looking unit constructed with a paper cone and dust cover, and a foam rolled surround. The chassis finish is cosmetic, for outside cabinet mounting and the quality of reproduction is excellent.

The six and a half inch bass/mid range driver (YN25C) has a yellow, varnished fibre glass cone with velbex dust cover and rolled surround. This unit has excellent bass response and superbly defined mid range reproduction, producing a clear, airy overall sound with a high degree of realism.

Designing a System

Loud speaker performance characteristics are of great importance when looking for optimum performance in a system. Cabinet dimensions can be calculated quite accurately for a particular drive unit, although the final performance may not always be what the constructor expects. For instance, a relatively small (8in.) woofer may require a 250 litre cabinet for optimum performance. 250 litres of volume is approximately 8.83 cubic feet, which if imagined as a cube would measure over 2 feet high by 2 feet wide by 2 feet deep. Today's 'midi system' popularity in hi-fi systems favours the small book case size cabinet, and it would take some book case to hold a cabinet of these proportions! Therefore, one must decide on a cabinet size suitable for the room available and also the cost and complexity of construction.

For this series, we will be considering the *closed box* and *ported box* (reflex) type of design only, using the mathematical models introduced by an Australian Engineer, A.N. Thiele. Speaker manufacturers supply data for use in these calculations, which makes life a lot easier for the constructor.

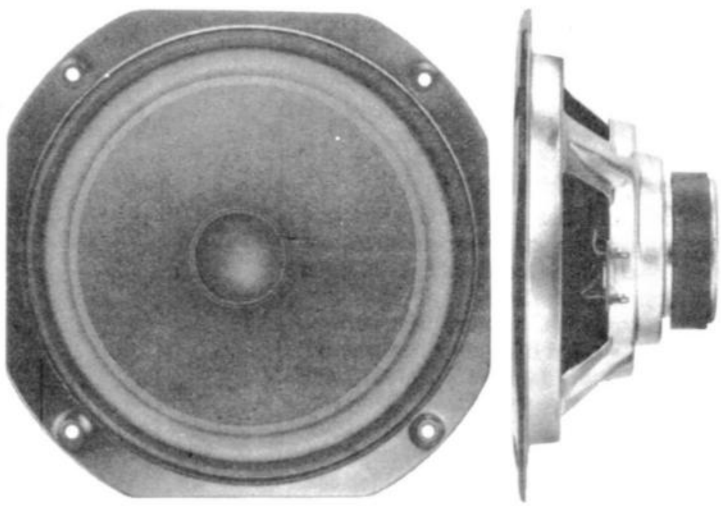
A closed box means just that! A completely sealed and air tight box, whereas the ported box has a tuned port which may be a simple hole or slot cut in the front panel. Closed boxes are usually smaller in size than reflex types and much favoured by the system manufacturer. They exhibit a gradual roll off or slope at low frequencies, and particularly small cabinets can sound lacking in bass. The ported box is larger in size with much greater bass response and a more pronounced cut-off below the tuning point or resonance. However, such a cabinet still requires to be designed and made carefully or it too will have only a poor performance!

Speaker Parameters

The first step in optimising a cabinet design requires information based on the driver specification. Figures 1 and 2 show graphical responses of the square bass driver calculated from the given data. On the vertical X axis, Vb is the box volume shown as both cubic feet and litres, the horizonal Y axis shows the box resonance (Fb or Fc), and the −3dB cut-off frequency (F3). Two plots on each graph are shown for the free air resonance frequency (Fs) of 51.5Hz ±8Hz; one curve for 44Hz and the other for 59Hz. These are however extreme variations, and random tests on various samples have produced Fs figures of 44Hz quite consistantly. If an average

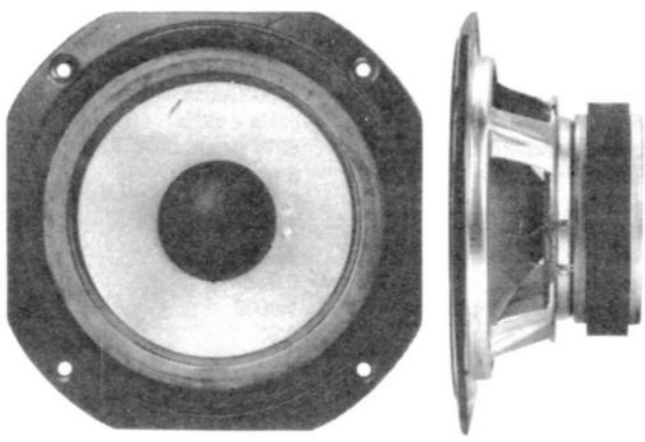
50W EXTENDED BASS - YN47B

Chassis		212 x 212mm
Baffle		186mm
Fixing		154 x 154mm. 5mm clear
Flux Density	(B)	10000 Gauss
Frequency Response		40Hz - 5kHz
Power Handling		50W peak, 25W RMS
NOM Impedance		8 ohm
Sensitivity		91dB (1W - 1M)
Coil Diameter		25mm
Free Air Resonance	(Fs)	42Hz ±7Hz
Moving Mass	(Mmd)	0.0122Kg
Suspension Compliance	(Cms)	0.0007
Mechanical Q	(Qms)	2.57
Electrical Q	(Qes)	0.7
Total Q	(Qts)	0.55
Equivalent Air Load	(Vas)	42 Litres
Effective Surface	(Sd)	$0.0196m^2$



FIBRE GLASS DRIVER - YN25C

Chassis		173 x 173mm
Baffle		145mm
Fixing		124 x 124mm. 5mm clear
Flux Density	(B)	13000 Gauss
Frequency Response		35Hz - 5kHz
Power Handling		45W peak, 22W RMS
NOM Impedance		8 ohm
Sensitivity		91dB (1W - 1M)
Coil Diameter		25mm
Free Air Resonance	(Fs)	44Hz ±7Hz
Moving Mass	(Mmd)	0.0114Kg
Suspension Compliance	(Cms)	0.00017
Mechanical Q	(Qms)	1.01
Electrical Q	(Qes)	0.22
Total Q	(Qts)	0.18
Equivalent Air Load	(Vas)	30 Litres
Effective Surface	(Sd)	$0.0113m^2$



point between both curves is taken, then from Figure 1:

(1) Box volume Vb = 57 litres
Resonance Fc = 60Hz
Cut off F3 = 80Hz

(2) Box volume Vb = 28 litres
Resonance Fc = 69Hz
Cut off F3 = 76Hz

(3) Box volume Vb = 18 litres
Resonance Fc = 75Hz
Cut off F3 = 75Hz

The smallest practical size of a closed box for this speaker is just over 0.5 cubic feet internal volume, but as can be seen, the low frequency response is not very good. From Figure 2:

(1) Box volume Vb = 57 litres
Resonance Fb = 38Hz
Cut off F3 = 32Hz

(2) Box volume Vb = 28 litres
Resonance Fb = 48Hz
Cut off F3 = 45Hz

(3) Box volume Vb = 14 litres
Resonance Fb = 58Hz
Cut off F3 = 63Hz

Using a tuned port in a 0.5 cubic feet box extends the low frequency response below 63Hz, which is a significant improvement over the closed box. To realise the full potential of this speaker, but keeping the cabinet size down, a ported box of 24 to 40 litres internal volume is required.

Predetermined equations are used to calculate box volumes. For a ported box: $Vb = Vas \times Qts^2 \times S$

Where:

Vas is the equivalent air load.
Qts is the total speaker Q.
S is the peak or dip in response at resonance (sensitivity).
Vb is the box internal volume.

The S factor is related to active port surface area in a reflex cabinet, which determines the amount of increase or decrease in output at resonance. Values of S range from 4 to 16 where, S = 4 is −3dB down and S = 16 is +3dB up at the cabinet/driver resonant point (Fb). As an example of determining the effect of S in designs, a value of 8 offers a relatively flat response at Fb with smooth roll off to F3. As a matter of interest classical music tends to favour a slight drop in output at Fb, S = 5.7 (approx. 1dB down), and pop music = 11 (approx. 1dB up).

Using data from the Bass Driver specification and S = 5.7 in the equation as follows:

Vas = 22 litres
Qts = 0.48
S = 5.7

$Vb = 22 \times 0.48^2 \times 5.7$ i.e. Vb = 28 litres.

With S = 8:

$Vb = 22 \times 0.48^2 \times 8$ i.e. Vb = 40 litres.

With S = 11:

$Vb = 22 \times 0.48^2 \times 11$ i.e. Vb = 55 litres.

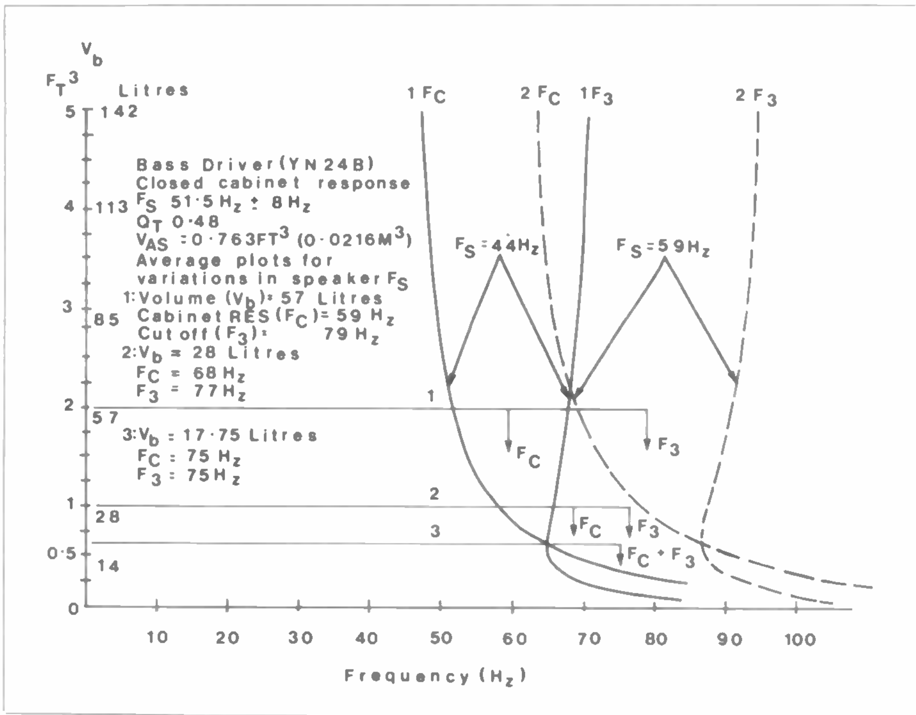


Figure 1. Bass Driver closed cabinet response graph.

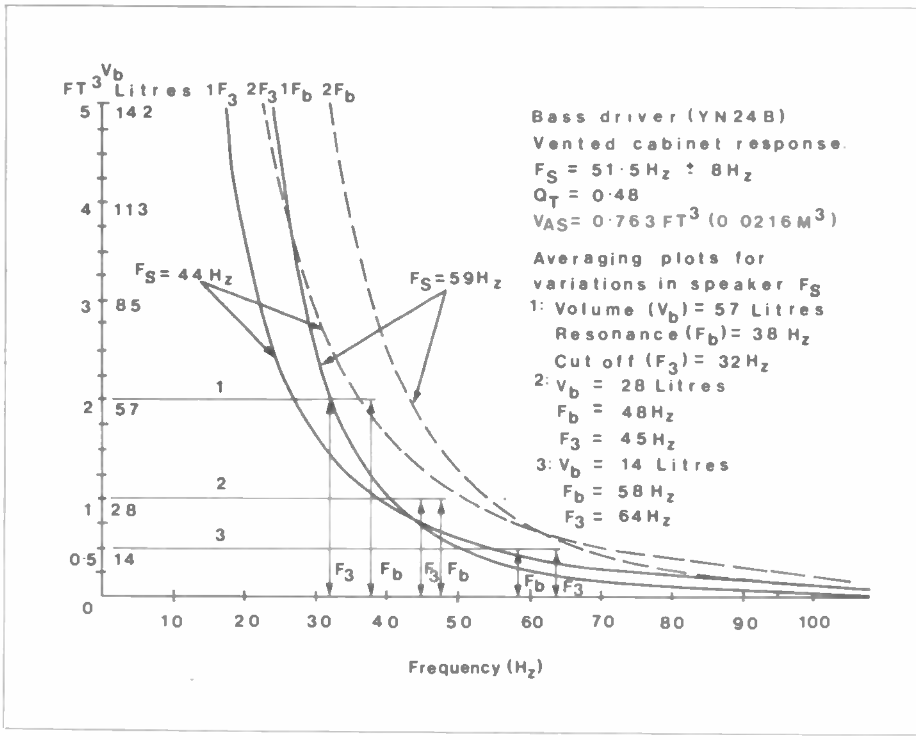


Figure 2. Bass Driver vented cabinet response graph.

A larger box could be designed in this way, but then the driver will be under-damped, thus reducing its power handling capabilities. Similarly, smaller boxes will over-damp the driver, thus lifting the Fb with subsequent loss of bass output.

With values of S equal to eight, Vb is the optimum value. Cabinet resonance can be calculated from $Fb = (0.39 \times Fs)/Qt$ and the −3dB cut-off point by squaring Fs, multiplying this by Fs squared, dividing the result by Vb and finding the square root of the total, i.e.

$$F3 = \sqrt{\frac{Vas \times Fs^2}{Vb}}$$

Therefore, for Qts = 0.48, Fs = 44Hz and Vb = 40 litres:

$Fb = (0.39 \times 44)/0.48$ i.e. Fb = 36Hz

$$F3 = \sqrt{\frac{22 \times 44^2}{40}} \quad \text{i.e. } F3 = 32\text{Hz}$$

The next step is to find port dimensions to suit Vb and Fb by referring to Figure 3 and 4 for tube length and diameters.

Each of the curves represents a different cabinet volume, Vb, and cabinet resonance, Fb, is on the vertical X axis. If a line is drawn horizontally from Fb = 40Hz to a point between both 28 litre and 43 litre curves, corresponding to Vb = 40 litres, then tube lengths can be read along the horizontal scale. Either 50mm internal diameter or 75mm internal diameter tubes are suitable for use as a port on low volume systems and for this design a 50mm(d) x 63mm(l) or 75mm(d) x 167mm(l) tube is called for. Larger diameter tubes are always longer in length and may be too long to fit inside the cabinet. When this happens with a 75mm tube, the 50mm tube used instead will be shorter for the required resonance. At extremely low frequencies, or when speaker/cabinet design offers a high SPL (output sensitivity), air movement through the tube can produce a chuffing noise which can be very disturbing. Always try to use the largest port possible ensuring a clearance between inside back panel to tube of at least 75 to 100mm.

Cabinet Dimensions

Producing an enclosure that adds to the sound from a loud-speaker is to be avoided, or kept to an absolute minimum. Any added resonances will 'colour' and distort the original sound. A cabinet made from thin materials will audibly vibrate and absorb low frequency energy, to the detriment of bass response. The enclosure shape can also affect performance by lumping air resonances at different frequencies and from sound energy reflecting off internal wall panels through the speaker cone. Designing an enclosure with non-parallel walls minimises internal reflection problems, but is extremely difficult to build. The finished triangular cabinet shape may also look like anything but a speaker system!

To keep construction simple with the minimum of panel resonances and reflections, heavy duty or industrial grade chipboard of 19mm (3/4 inch) thickness is best employed. Flakey chipboard that looks like a slab of compacted straw should be avoided. Each of the three cabinet dimensions have a relationship in the ratio of 1 : 1.6 : 2.3, thus ensuring that no side is an exact multiple of any other and thereby spreading resonances instead of lumping them. Figure 5 shows Vb (the internal volume) three dimensionally as (w)idth 1, (d)epth 1.6, and (h)eight 2.3. With volume Vb = 40 litres (40,000cc) the equation used for calculating each dimension is the third root (cube) of Vb divided by the ratio product, and multiplied by each side ratio in turn.

Thus from $3\sqrt{Vb/(\text{ratio product})}$ we get:

$$w = 3\sqrt{40000/(1 \times 1.6 \times 2.3)} \times 1$$
$$d = 3\sqrt{40000/(1 \times 1.6 \times 2.3)} \times 1.6$$
$$h = 3\sqrt{40000/(1 \times 1.6 \times 2.3)} \times 2.3$$

Therefore: w = 22.15cm, d = 35.44cm, h = 50.95cm.

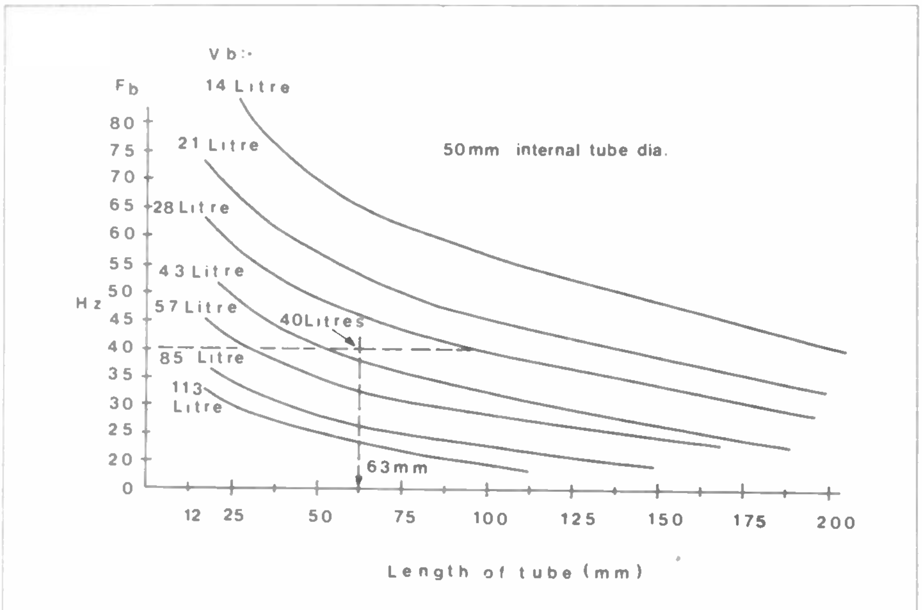
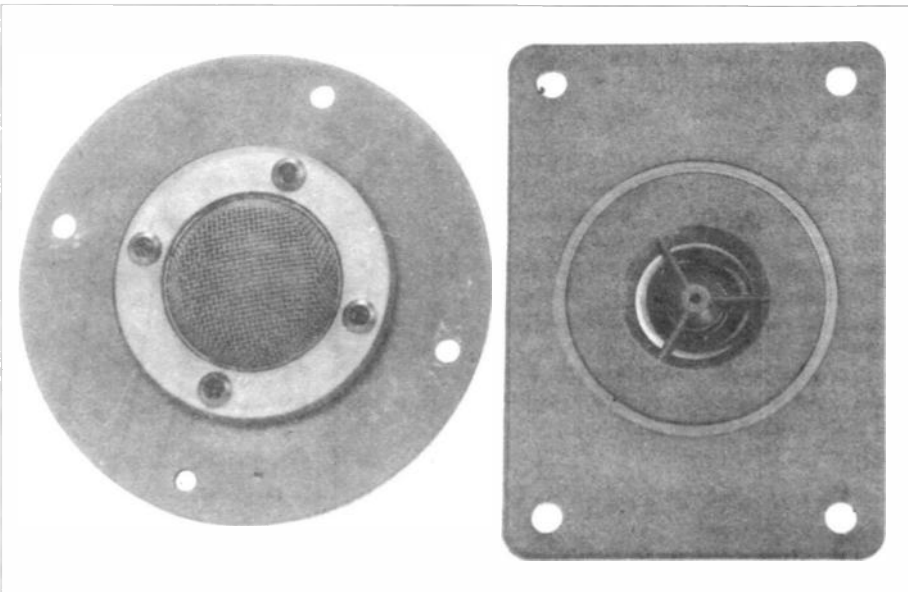


Figure 3. 50mm I/D tube length graph.



Tweeters.

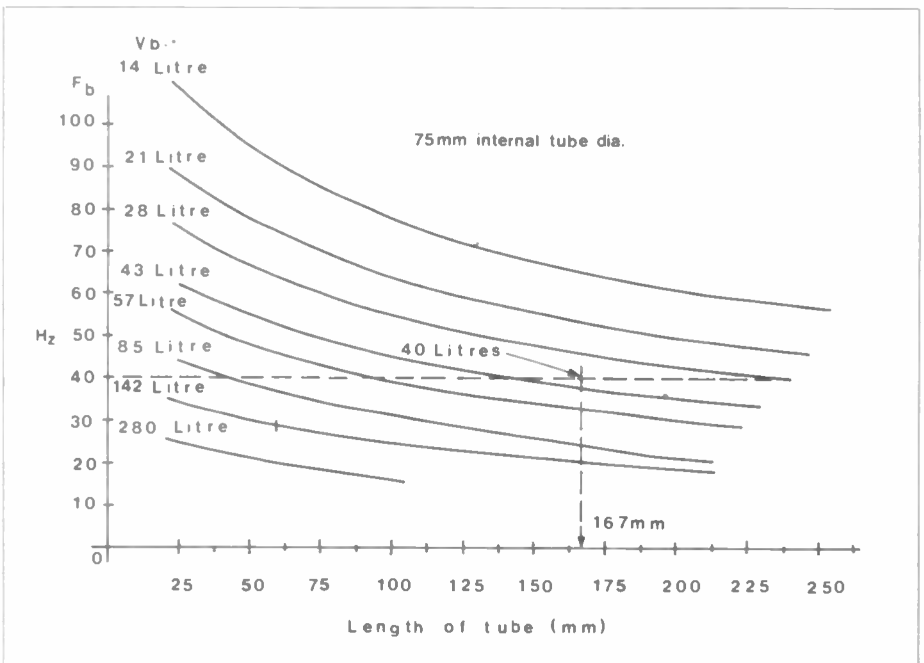


Figure 4. 75mm I/D tube length graph.

If these dimensions are simplified to integers, then cabinet *internal* sizes are w = 23cm, d = 35cm, h = 50cm. The volume Vb is now 40,250cc or 40.25 litres, a small increase of 0.6%.

For Vb = 23 litres (23,000cc),

w = 19cm, d = 29cm, h = 42cm.

Construction

It must be stressed that calculations used in this article are based on theoretical principles and do not necessarily reflect the perfect design. In practice, parameters like volume are reduced by speaker metalwork, cross-over modules, bracing, port tube volumes and stuffing material. Jointing methods affect volume and all of these factors should be considered before cutting any panels. In this particular design, the 40 litre Vb figure allows for approximately 5% over volume to accomodate the extras. Butt joints should be used for assembling panels, fixing with white wood glue and 1.5 inch chipboard screws.

Only a front baffle is supplied in these kits so the constructor must arrange to have five side/back panels made to the cutting lists shown. Most timber suppliers have facilities for cutting chipboard quite accurately to customer requirements and the material costs should not be very high.

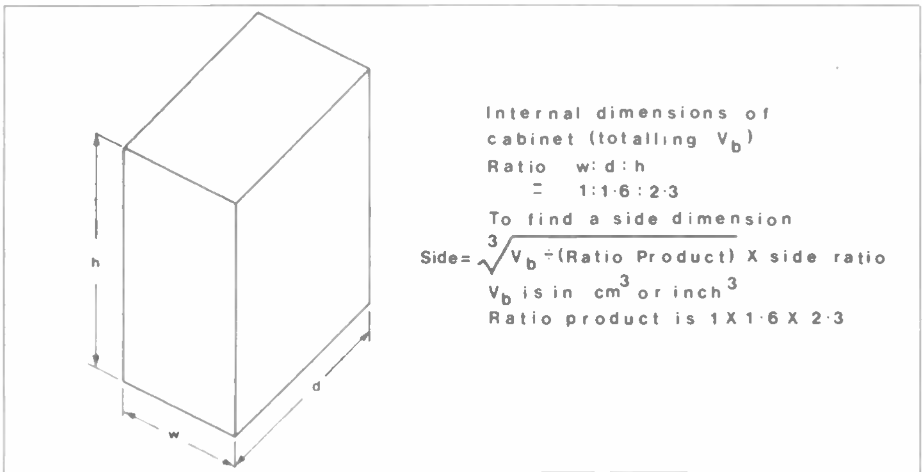


Figure 5. Relationship between width, depth and height.

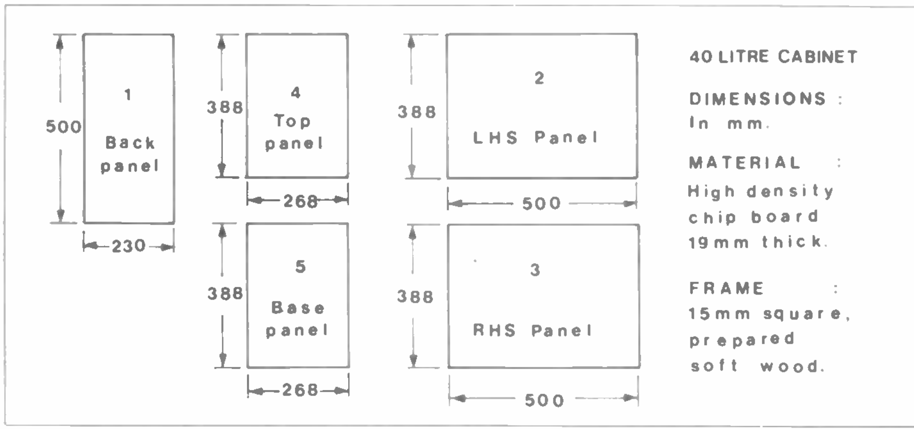
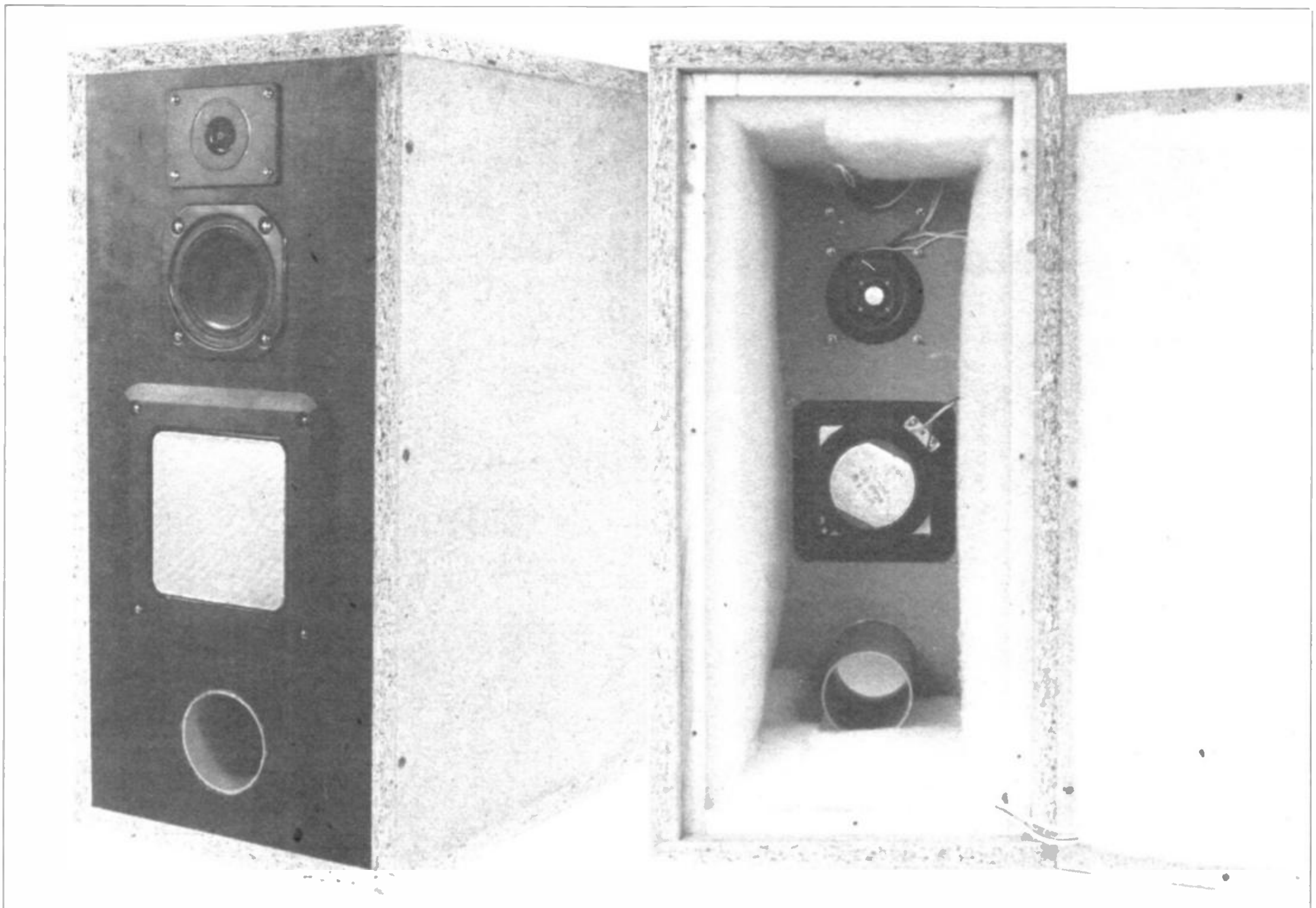


Figure 6. 40 Litre cabinet panels.



Inside the 40 litre cabinet and front baffle layout.

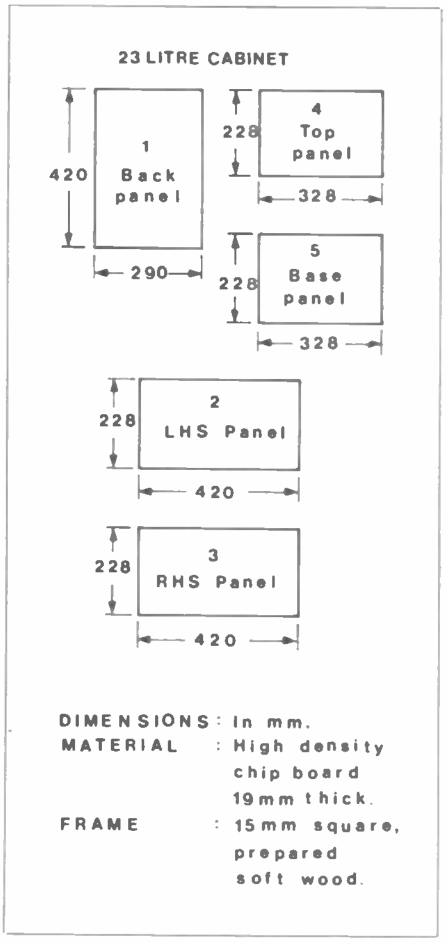
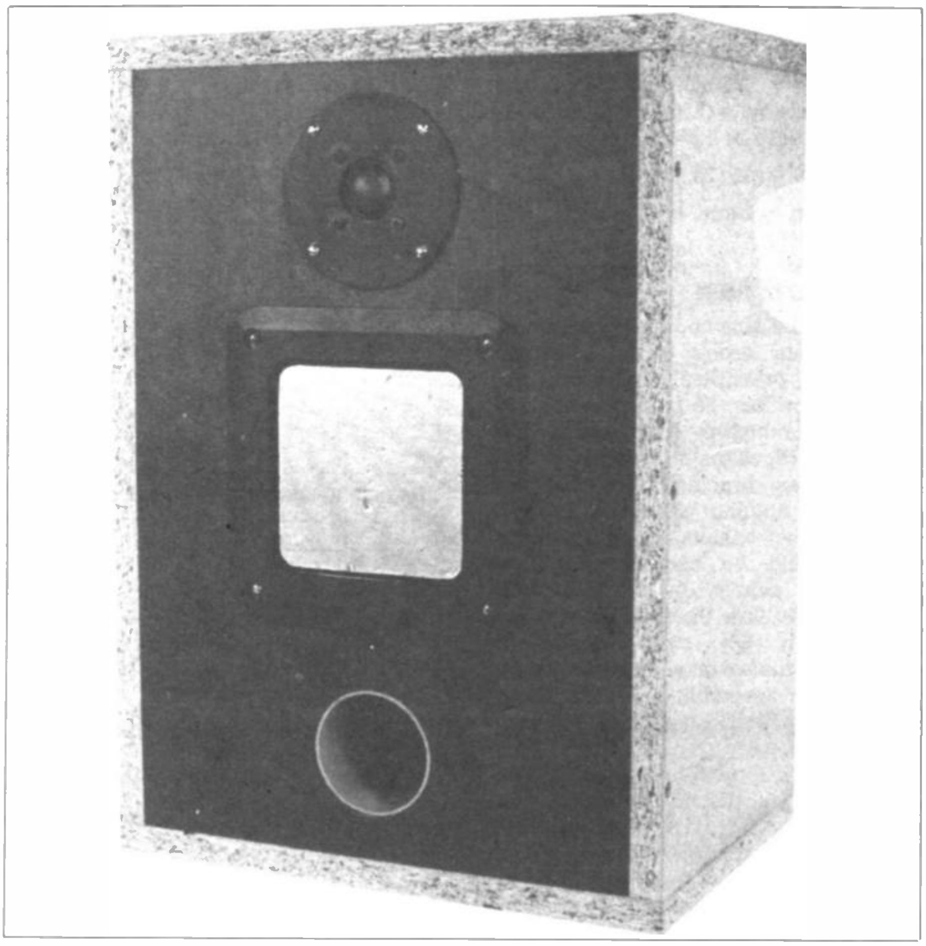
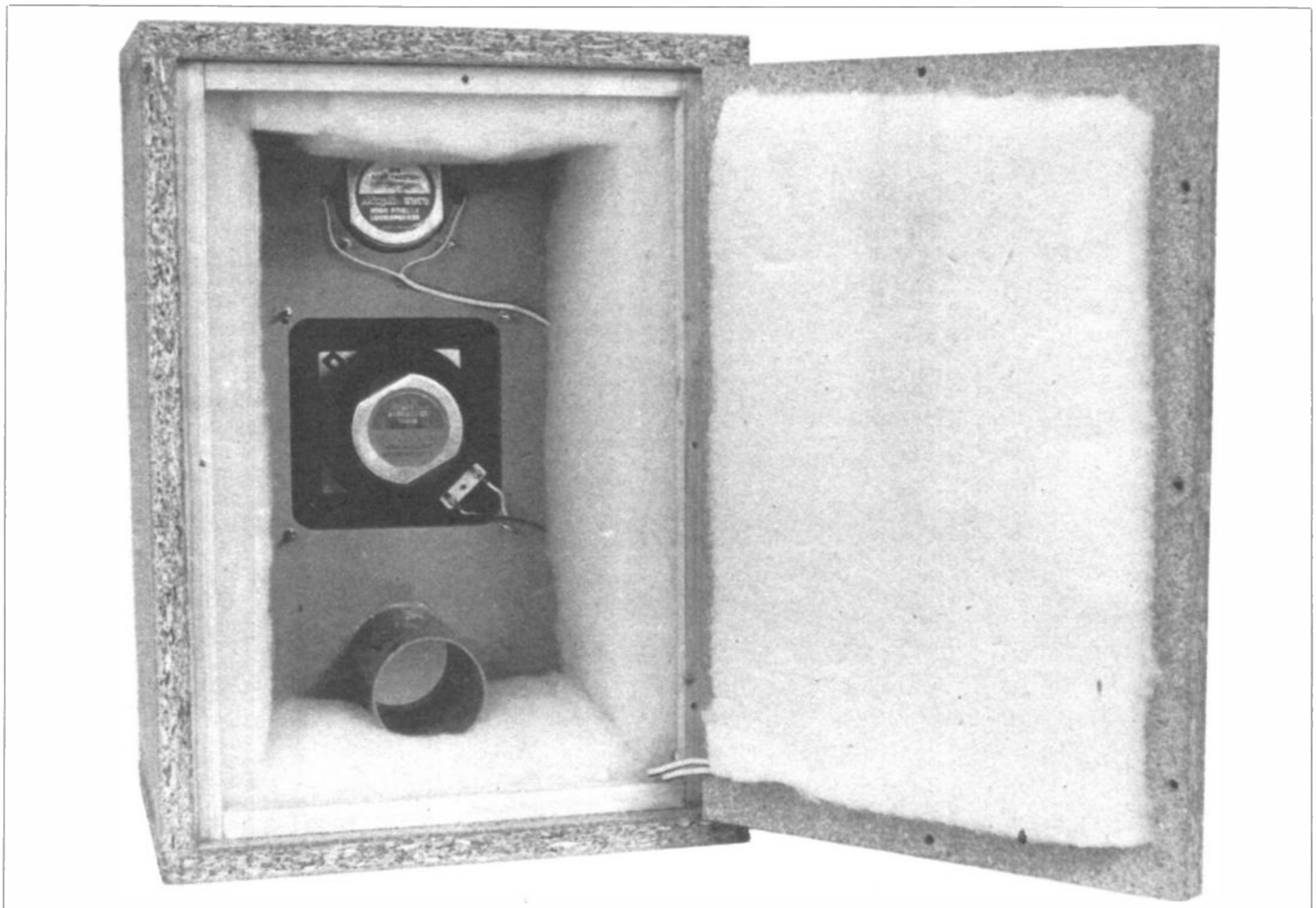


Figure 7. 23 Litre cabinet panels.



23 litre cabinet front baffle.



Inside the 23 litre cabinet.

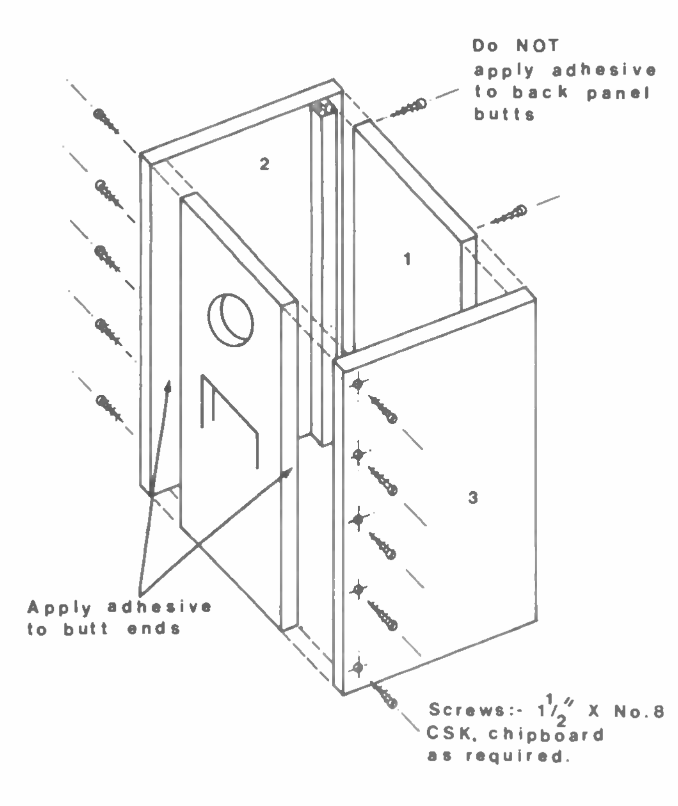


Figure 8. Assembling the panels.

CUTTING LIST (40 LITRE CABINET)

	Material	:	High Density Chipboard 19mm thick
(1)	Back Panel	:	1 off - 500mm x 230mm
(2 & 3)	Side Panels	:	2 off - 500mm x 388mm
(4 & 5)	End Panels	:	2 off - 268mm x 388mm
	Material	:	Soft wood 15mm square prepared.
(6 & 7)	Hor. Frame	:	2 off - 200mm long
(8 & 9)	Vert. Frame	:	2 off - 500mm long

RESIN 'W' wood adhesive.
38mm (1.5") No.8 chipboard screws.
25mm wire nails.

CUTTING LIST (23 LITRE CABINET)

	Material	:	High Density Chipboard 19mm thick
(1)	Back Panel	:	1 off - 420mm x 290mm
(2 & 3)	Side Panels	:	2 off - 420mm x 228mm
(4 & 5)	End Panels	:	2 off - 228mm x 328mm
	Material	:	Soft wood 15mm square prepared.
(6 & 7)	Hor. Frame	:	2 off - 260mm long
(8 & 9)	Vert. Frame	:	2 off - 420mm long

RESIN 'W' wood adhesive.
38mm (1.5") No.8 chipboard screws.
25mm wire nails.

19mm or 3/4in. chipboard is a common variety and dimensions given are based on this. If thinner or thicker board is used then change the end panel (268mm - 40 litre, 328mm - 23 litre) size accordingly. See Figure 6 and Figure 7.

Figure 8 shows assembly details for the panels. Either large 'sash' clamps or chipboard screws can be used for holding panels together while the glue dries, but do not apply glue to the back panel (1). The use of screws is not recommended on pre-finished or laminated panels unless screw heads appeal to the constructor! Also note that plastic laminated edges butting up together cannot be glued successfully, although wood veneer will be O.K. On side panels (2) & (3), drill 5 clearance size holes along the front edge only, approximately 9mm in from the edge, and counter sink each hole. Apply a liberal amount of glue to the long edge of the front baffle on the right hand side and offer up panel (3). Insert screws and repeat the procedure for panel (2). Temporarily place back panel (1) between the side panels to space them apart evenly and tighten all screws. Remove excess glue exuding from the front joints with a damp cloth and while the assembly is drying, drill and counter sink end panels (4) & (5) as before. Do not drill along the back edge, only along the front and sides. Apply glue to the assembled side and front panels along the top edges, but not the back panel and offer up panel (4). Fit all screws and remove the back panel which may now need cleaning, and wipe away excess glue from all but joints. Turn the assembly over and fit panel (5) as before. Figure 9 shows a completed cabinet.

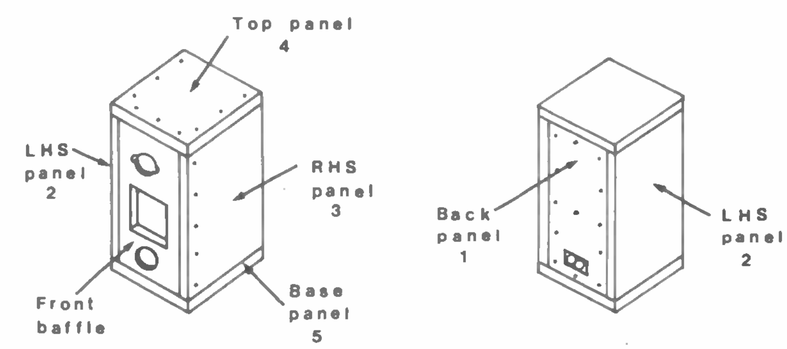


Figure 9. Completed cabinet.

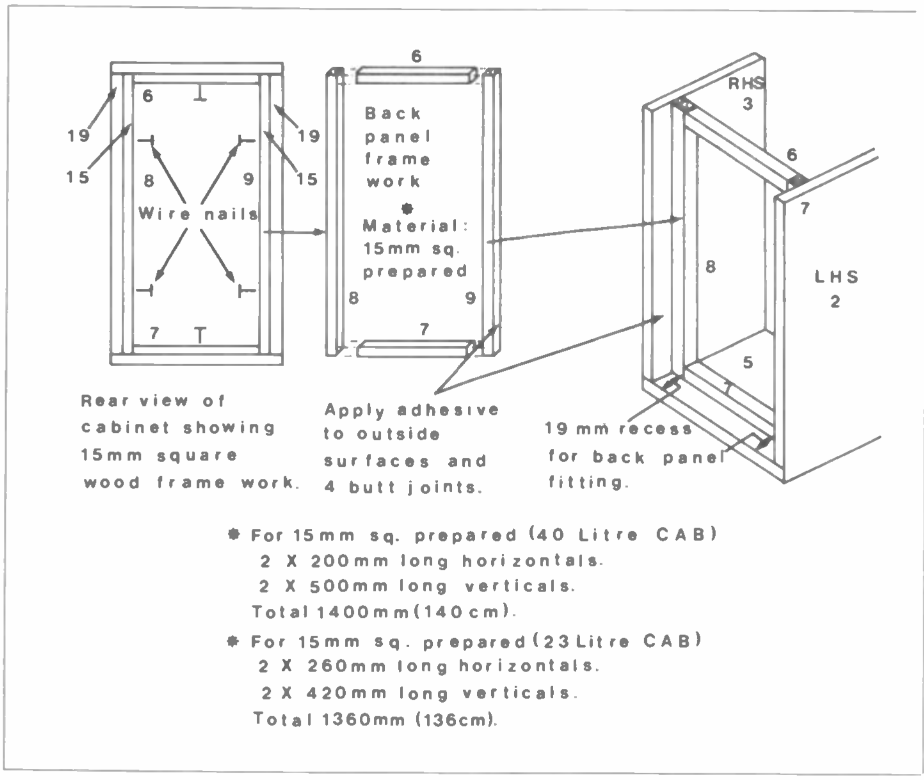


Figure 10. Back panel framework.

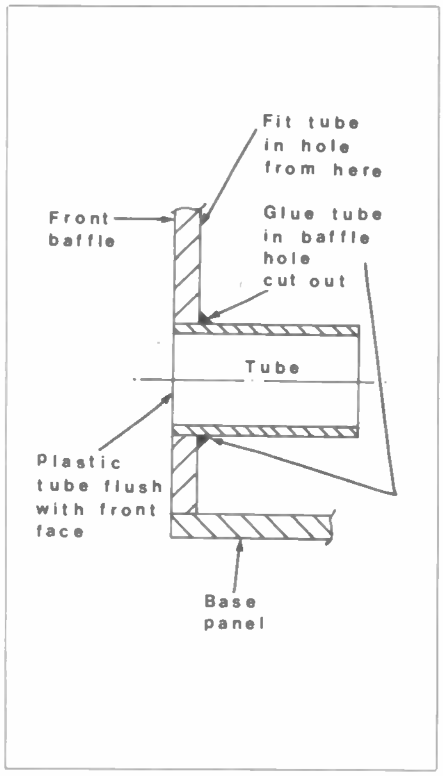


Figure 11. Fitting the port tube.

Figure 10 shows a simple wood framework which is glued and pinned inside the cabinet, and holds the back panel (1) in place. Both longer (8 & 9) verticals are the same length as panels (2 & 3) but horizontals (6 & 7) must be cut to lengths determined by their thickness. Dimensions given are for 15mm square prepared and should be the thinnest material used; thicker material will mean shorter lengths for (6 & 7) accordingly.

Draw a reference line inside the cabinet either 19mm in from the back edges or to suit the back panel thickness. Glue both verticals (8 & 9) to this reference line and use wire nails to hold in position. Do the same for (6 & 7) spreading glue over each cut end. Wipe away any excess glue and re-measure the recess between frame and panel edges, make any adjustments to ensure the frame is square.

Baffle Mountings

Figure 11 shows the port tube fitted in the baffle hole cut-out below the square woofer. Spread a thin layer of glue around the inside of the baffle port hole and insert the tube from behind. Run a thin filler of glue around the tube on the inside face of the baffle keeping the tube flush with the front face and leave to dry.

Before mounting loudspeakers, solder connecting wires to each +V and −V terminal on all units; this can be an awkward job to do with the speakers in place! Insert speakers into the baffle from the front and secure with 4BA x 1.5" bolts, shakeproof washers and 4BA nuts.

40 Litre Baffle - 3-Way System

Refer to Figure 12. Fit the rectangular tweeter FD95D into the topmost position and the mid-range speaker YP13P into the centre hole. Fit the bass driver YN24B into the square cut-out position. and mount the plastic trim cover over the top. Be careful not to force any cones during installation and take precautions while tightening up with a screwdriver. It may be found advisable to cover the speakers with thick card whilst doing this, just in case the screwdriver should slip!

23 Litre Baffle - 2-Way System

Refer to Figure 12. Fit the dome tweeter YN43W into the topmost position and insert the bass driver YN24B into the square cut-out. Mount the plastic trim cover over the top and follow the same precautions during installation as before. If required, a protective grille can be fitted over the dome tweeter to prevent dust and damage from spoiling its performance. The dome is very soft and sticky by design and should not be handled. To fit the grille, very carefully remove all 4 star-head screws, place the grille over the hole positions and replace the screws.

Cross Over and Wiring

When wiring speakers to the crossover module, use a separate cable pair to each unit, connecting terminal 'W' to bass speaker positive, 'T' to tweeter positive, and if used,'M' to mid-range positive. The positive terminal on each speaker will be marked either by a red dot or a + symbol stamped into the plastic housing. Speaker negative or return cables should be terminated to the crossover module terminals marked 'C'.

On the 2-way module only, it is necessary to remove the bass speaker by-pass capacitor. This component is not marked, but can be identified by placing the module with input terminals 'IN' and 'C' facing to the left and output terminals 'N', 'C' and 'T' facing to the right. The capacitor to be removed is then the bottom one which is soldered to the track areas marked with a 'W' and 'C' on the copper side. De-solder both capacitor leads and remove carefully. If required, the capacitor can be left in position, but this has the effect of emphasising the mid-range response on the bass speaker which sounds quite raucous in this particular set-up.

Cabinet Wadding

Cut five pieces of fibre wadding to fit inside the cabinet and fix to the walls with adhesive. Both sides, top and bottom panels and the back panel should be covered, but not the baffle panel. Keep the port tube clear of any obstructions and do not cover the crossover module. Depending on where the module is fitted in the cabinet, cut out a section of wadding so that it fits around the module and not over it. Also, allow clearance for the wood frame when cutting the back panel piece; the wadding should not be sandwiched in the recess when the panel is screwed in place.

Finally drill a small hole in the back panel for the connecting cable to your amplifier. If the speaker is to be sited some distance from the amplifier, then use a fairly thick cable, such as 2-wire mains cable, and not the thin bell-flex variety. On the input side of the crossover module, 'IN' is the positive terminal and 'C' the return terminal. Ensure correct polarity connections to the amplifier on stereo speakers, to keep speakers in phase with each other. If you are not sure about polarity, connect a

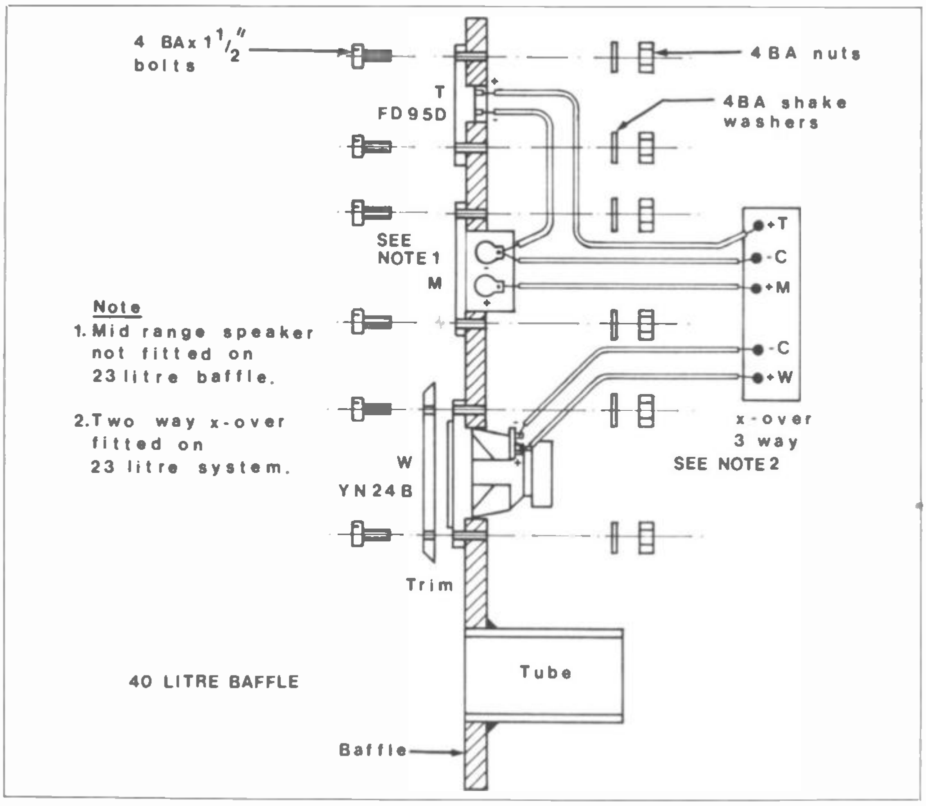


Figure 12. Baffle mounting.

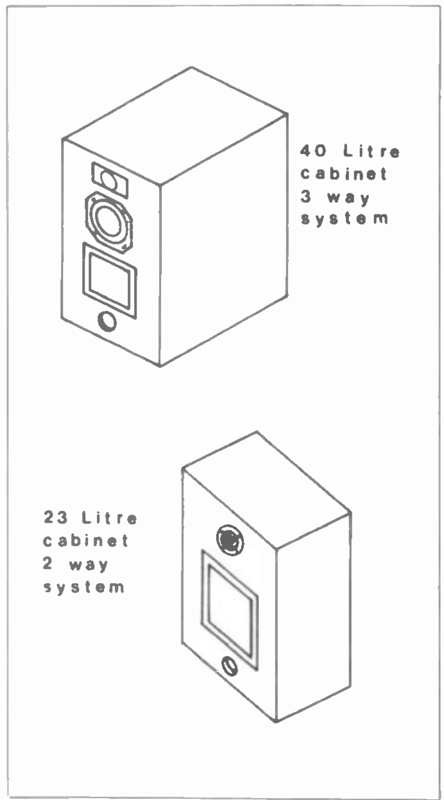


Figure 13. 40 and 23 Litre cabinets.

1.5V battery with positive to 'IN' and negative to 'C' on the module. The woofer cone-panel should pop outward, if not then the polarity is incorrect and the woofer (or crossover) wiring should be reversed. Figure 13 shows the two types of cabinet discussed in this article.

Amplifiers vary in their power output specifications and often 'MIDI' systems rated at 40 Watts per channel refer to peak output power. Both of these designs have a 50W peak continuous sine wave rating which should be adequate for most domestic listening environments.

FINAL SPECIFICATIONS

23 Litre Cab, 2-Way System, Reflex Port

Cross Over	:	2.75kHz (Modified)
Power Rating	:	50W peak, 25W RMS Continuous Sine Wave
Maximum Signal	:	40V peak, 14.2V RMS Sine Wave
Frequency Response	:	50Hz to 16kHz, 4dB peak at 60Hz
Impedance	:	8Ω

40 Litre Cab, 3-Way System, Reflex Port

Cross Over	:	1kHz and 6kHz, −6dB
Power Rating	:	50W peak, 25W RMS Continuous Sine Wave
Maximum Signal	:	40V peak, 14.2V RMS Sine Wave
Frequency Response	:	45Hz to 23kHz
Impedance	:	8Ω

23 LITRE CABINET PARTS LIST

MISCELLANEOUS

Hi-Fi Bass Driver	1	(YN24B)
Hi-Fi Dome Tweeter	1	(YN43W)
Dome Tweeter Grille	1	(FD93B)
Plastic Tube (130 x 69mm O/D)	1	(YP15R)
2-way Crossover	1	(WF02C)
Baffle 2W23L	1	(XJ09K)
4BA x 1½in. Bolt	1 Pkt	(LR52G)
4BA Nut	1 Pkt	(BF17T)
4BA Shake Washer	1 Pkt	(BF25C)
No.4 Self Tap Screw x ½in.	1 Pkt	(BF66W)
Loudspeaker Wadding	2 Mtre	(RY06G)
Loudspeaker Cable	1 Mtre	(XR72P)

A kit of parts is available:
Order As LM21X (23 Litre Cabinet Kit) Price £29.95
The following are also available separately, but are not shown in the 1987 catalogue:
Plastic Tube 130 **Order As YP15R Price 48p**
Baffle 2W23L **Order As XJ09K Price £2.75**

40 LITRE CABINET PARTS LIST

MISCELLANEOUS

Hi-Fi Bass Driver	1	(YN24B)
70W 3½in. Mid-range Speaker	1	(YP13P)
Mini Dome Tweeter Rectangular	1	(FD95D)
Plastic Tube (180 x 69mm O/D)	1	(YP14Q)
3-way Crossover	1	(WF03D)
Baffle 3W40L	1	(XJ08J)
4BA x 1½in. Bolt	2 Pkts	(LR52G)
4BA Nut	2 Pkts	(BF17T)
4BA Shake Washer	2 Pkts	(BF25C)
No.4 Self Tap Screw x ½in.	1 Pkt	(BF66W)
Loudspeaker Wadding	3 Mtre	(RY06G)
Loudspeaker Cable	2 Mtre	(XR72P)

A kit of parts is available:
Order As LM20W (40 Litre Cabinet Kit) Price £35.95
The following are also available separately, but are not shown in the 1987 catalogue:
70W 3½in. Mid-range Speaker **Order As YP13P Price £7.95**
Plastic Tube 180 **Order As YP14Q Price 60p**
Baffle 3W40L **Order As XJ08J Price £2.95**

Keypad for the Z80

★ Type in your own code easily
★ Visual display aids checking
★ Simple construction

by Graham Dixey C. Eng., M.I.E.R.E.

Introduction

The Maplin Z80 CPU card which was published in Issue 15 of 'Electronics' offers an inexpensive way to get to grips with computerised control systems for those who can write their own control programs and put them into an EPROM. The provision for 8K of on-board memory is generous for such applications, and input/output decoding for peripheral chips is also provided. Unfortunately the module is totally devoid of any kind of resident software and is completely inaccessible to the 'user' in its basic form. Provision is made for a keyboard to be added however, the suggested device is the 8279 programmable keyboard/ display interface IC, which can look after a variety of input sources (keypads, full keyboards, sensor arrays, etc.) and can control up to sixteen 7-segment displays if required. Thus, it is obviously possible to produce a small computer which can be programmed directly from a HEX keypad, with a 7-segment display to monitor addresses, status and data, both in and out.

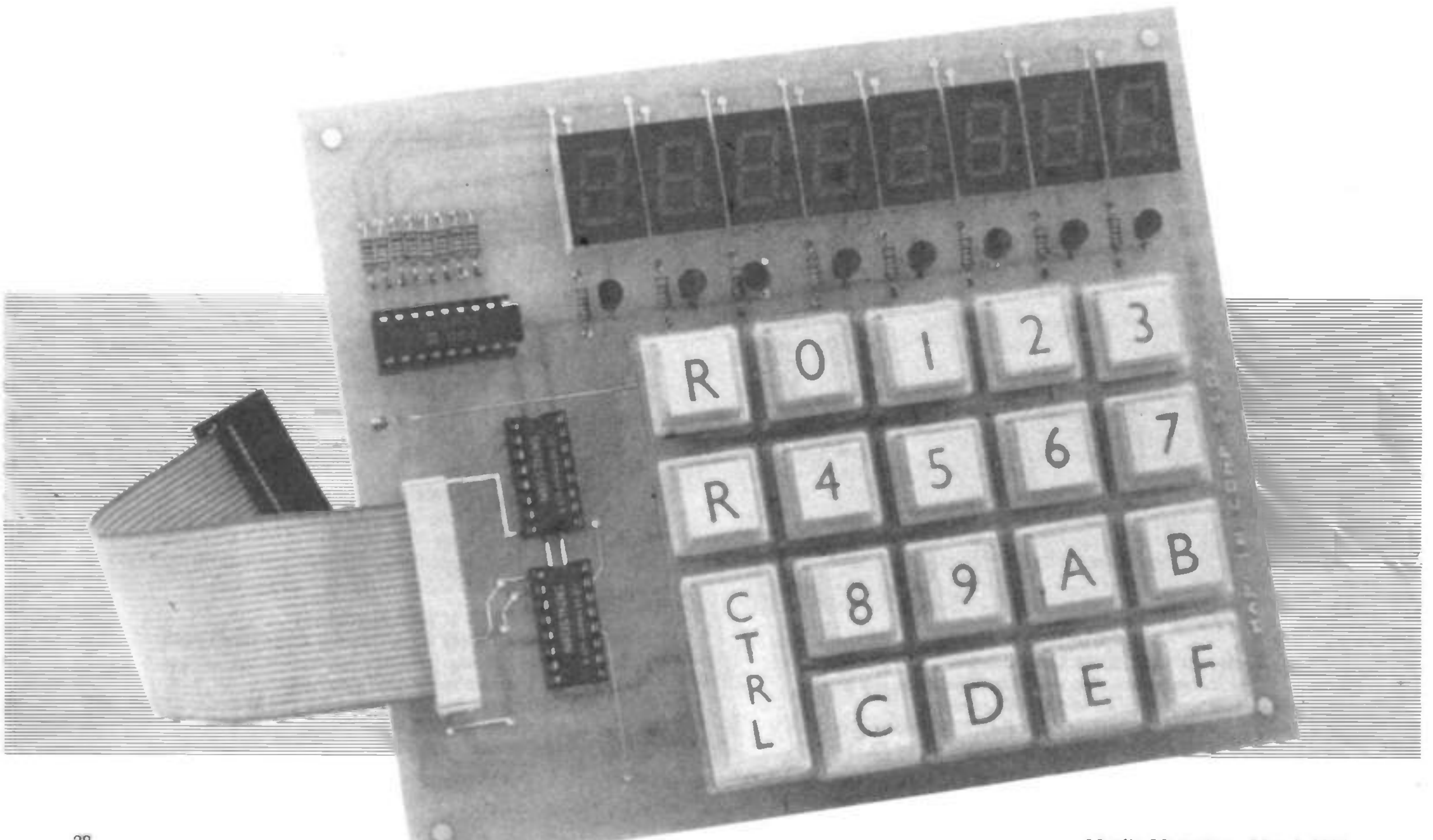
In the design presented here, there are eight 7-segment displays, from left to right, the first four form the 'address field', the next two the 'status field' and the two on the right, the 'data field'. What is needed to achieve this simple objective is the module described here, a monitor resident in EPROM (which has been developed and is available - see Parts List), and some knowledge of Z80 machine code or the desire to acquire it, which can be assisted by my current series on the subject.

Note that it is advisable to obtain a copy of Issue 15 of 'Electronics' to be sure exactly what is provided in the Z80 CPU kit and what is otherwise 'optional'.

The Keyboard Display Circuit

The circuit is shown in Figure 1, and is quite straightforward, largely due to the built-in sophistication of the 8279 IC.

The display is multiplexed at a rate determined by the system clock and a control word sent by the monitor. As a result, a binary counter output appears



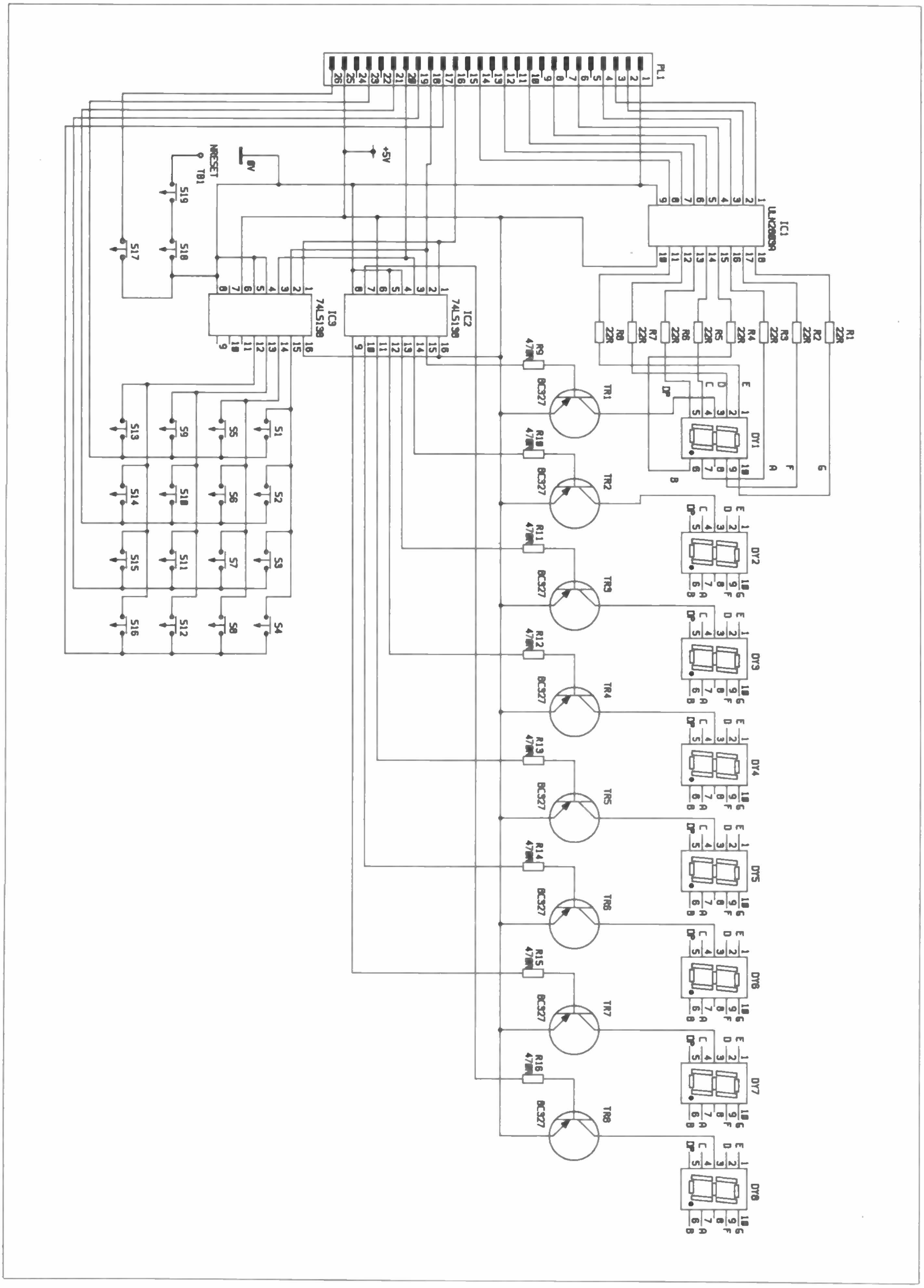


Figure 1. Circuit Diagram.

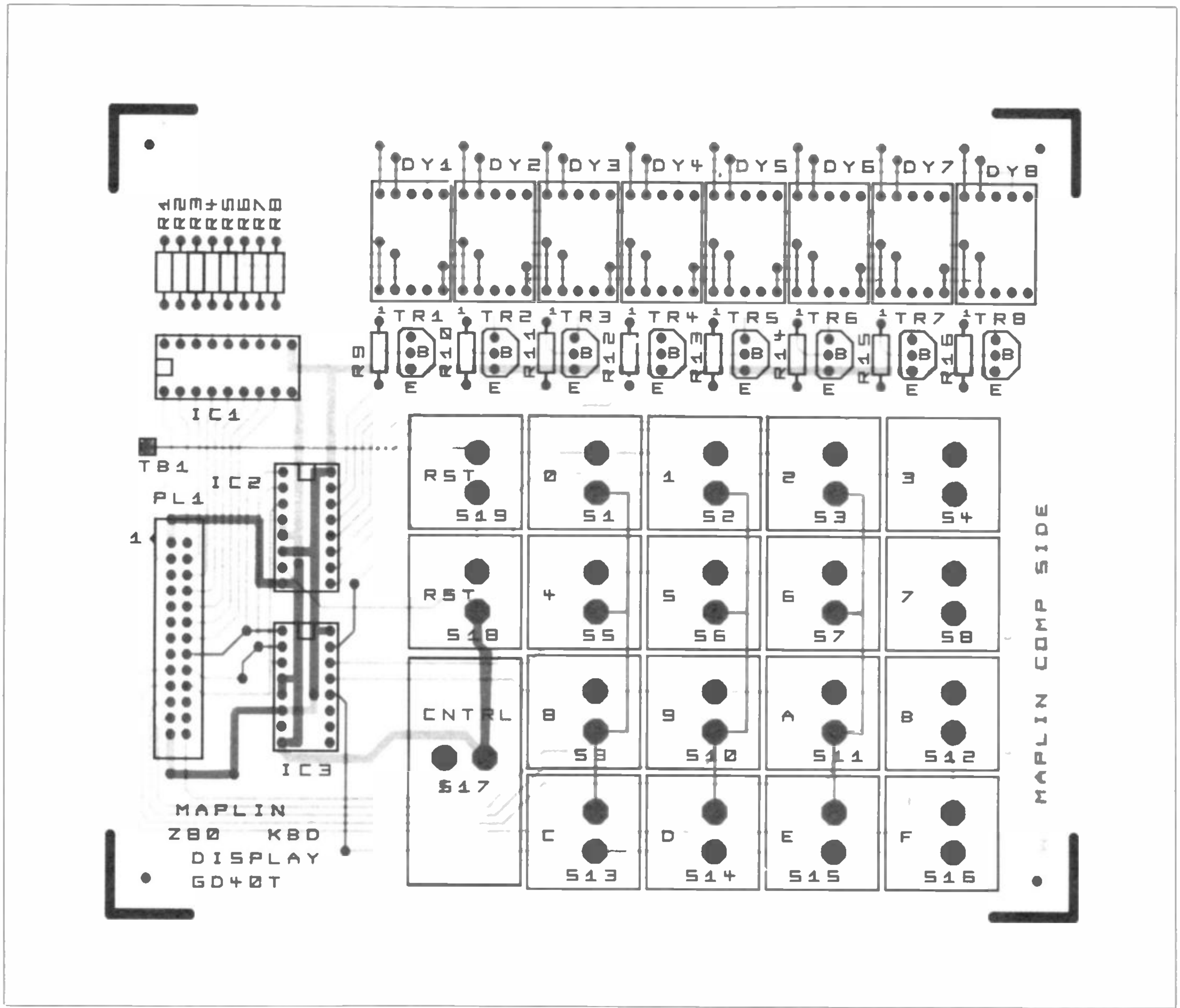


Figure 2. PCB Layout.

on the scan lines SL0-SL2, which is applied to both 74LS138 3-8 line decoders, IC2 and IC3. The eight output lines of IC2 drive the bases of driver transistors TR1-8, which are PNP types since common-anode displays are used. The ULN2803A, IC1, is an octal inverting buffer, that can sink more than enough current for the 7-segment displays. Its input is a set of eight data lines A0-A3, B0-B3 from the 8279 internal display RAM. The 22Ω resistors, R1-R8, limit the segment current to a value that will ensure reliability and long life for the displays.

The keypad consists of a 16-key HEX matrix and, to obtain additional functions, a further key, CTRL, is provided. This, used together with any other key, allows up to 16 *control* functions. Some of these are used in the system monitor, described later. The keypad returns four lines RL0-RL3, plus CTRL, to the 8279, which scans them to detect a key press and to identify its position in the matrix. It then sends an 'interrupt' signal to the Z80, to initiate a 'read keyboard input' routine.

Construction and Testing

No problems should be encountered provided that you negotiate the usual hazards of dry joints, bridged tracks, wrong polarity for IC's and transistors, etc. Refer to Figure 2 for assembly and afterwards carry out a visual examination for such defects and check with a meter for shorts across the supply. Some resistance checks with the power off will give an indication whether all is well or not. Where there are semiconductors in circuit, the reading will be different depending upon which way round the meter leads are applied to the circuit.

For example, a measurement between the 0V line and any of the lines A0-A3, B0-B3 should show high resistance one way and approximately 22Ω the other way. Similar results should be obtained between 0V and the lines SL0-SL2, but RL0-RL3 to 0V should show open circuit until a key is pressed, when the results are much the same as for the others.

These are all static tests, carried out with the chips in place but no supply connected.

When the CPU and keyboard/display modules are connected together (a suitable cableform is available and its pin-outs are shown in Figure 3), and power is applied, the Z80 sends clock pulses to the 8279 IC which then generates the scan voltages on SL0-SL2. These can be detected by using a logic probe in the 'pulse' mode. Naturally, on power-up the display could show almost anything, unless the monitor ROM is fitted, in which case, if all is well, you'll see eight dots to tell you that the monitor's running. Pulse trains should also be found on pins 7, 9-15 inclusive of IC2 (and hence on the bases of TR1-8), and on pins 12-15 of IC3.

Pressing a key in any of the four vertical rows causes pulses to appear on RL0-RL3 respectively. Both CTRL and RESET should send logic low to the CPU card when pressed. To avoid the embarrassment of accidentally resetting the computer, two Reset Keys are provided, which have to be pressed at the same time to force a reset.

The Monitor EPROM

A simple monitor occupies rather less than half of a 2716 EPROM and provides the following facilities:

(a) Access to any memory location to examine and/or modify data,
(b) Step backwards or forwards through memory to examine, edit or enter program data,
(c) Run a program from a given start location.

No sophistication is claimed for the monitor, but it is easy to use with a little practice. It operates as follows.

On power up, eight dots appear on the display to indicate that the monitor is running. Now press CTRL-A. CTRL-A means 'CTRL key plus A key, press down together'. OA now appears in the 'status field' to indicate 'address mode'. Type in an address, which you'll notice goes into the display in 'typewriter' mode, i.e. left entry. If you now enter CTRL-D, the status field changes to Od (data mode), though the dots remain in the data field. However, anything typed on the keypad now will appear in the data field and is entered into memory at the location stated in the address field. Entering CTRL-F takes you forward to the next location, while CTRL-B takes you back to the previous location. CTRL-F and CTRL-B only operate in data mode and always refresh the display, in other words, an address must be entered first before you can move forward or backward from that location. You can use this facility to only examine or edit memory rather than entering a program. Instead of typing in the actual start address, type in the one 'before it'; enter data mode and then use CTRL-F. This takes you to the location you want and brings up the data actually at that location on the display. Now as you step forward or back through memory, you will have a simultaneous display of memory and data. You can look anywhere in ROM or RAM in this way. CTRL-A and CTRL-D allow you to 'toggle' back and forth between the two modes, so you can nip about in memory quite niftily.

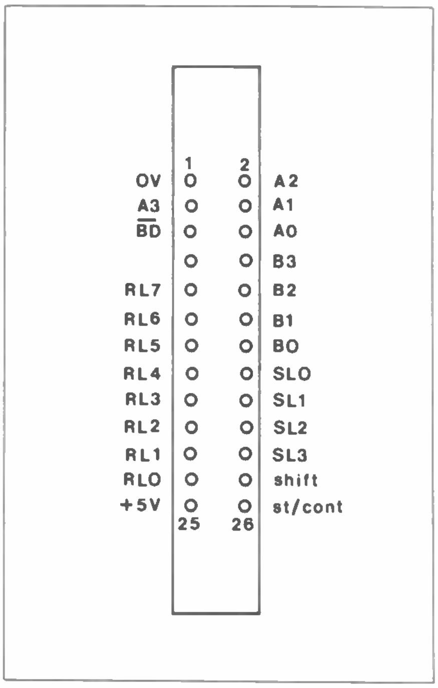


Figure 3. Connections to Z80 CPU.

Note that the data display is only refreshed by CTRL-F or CTRL-B, which means that whenever you toggle back to 'data' mode from 'address' mode the data shown is arbitrary. To see the correct data at the new location, type CTRL-F followed by CTRL-B (or vice-versa). Thereafter, any memory locations examined by use of either of the latter control keys is correct.

To run a program that you have entered, type CTRL-E and OE appears in the status field. Enter the start address of the program, and operate CTRL-C. The program will now run and eight dashes on the display is the sign that it is doing so. If you put a HALT instruction at the end of your program, it will wait and you can then leave the program by using the 'reset' keys, which will take you back into the monitor. This, of course, allows you to examine any memory locations that might have been modified by the program simply by re-entering the sequence via CTRL-A.

Scratchpad RAM

As with all monitors, this one requires a small amount of RAM for its own use. This it uses for the storage of variables and also as a 'stack' during the running of certain monitor routines. The monitor ROM occupies the addresses &0000 to &07FF; the following area of the memory map is normally occupied by RAM, starting at address &0800. The monitor claims the bytes from &0800 to &085F for its scratchpad. This means that the lowest address at which user programs should be stored is &0860.

Summary of Control Functions

Command	Status Code	Mode & Action
Power-on	8 dots	Monitor ready
Reset	8 dots	Monitor ready
CTRL A	0A	Address mode. Enter address.
CTRL D	0d	Data entry mode, following Address mode only. Enter data.
CTRL F	0d	Step forward one location and refresh display. Data mode only.
CTRL B	0b	Step backward one location and refresh display. Data mode only.
CTRL E	0E	Enter start address of program to execute.
CTRL C	8 dashes	Execute program.

Z80 HEX KEYPAD PARTS LIST

RESISTORS: All 0.6W 1% Metal Film			
R1-8	22Ω	8	(M22R)
R9-16	470Ω	8	(M470R)
SEMICONDUCTORS			
TR1-8	BC327	8	(QB66W)
IC1	ULN2803A	1	(QY79L)
IC2,3	74LS138	2	(YF53H)
DY1-8	7-segment Display	8	(FR39N)
MISCELLANEOUS			
	Hex Keypad PCB	1	(GD40T)
S1-19	Keyboard Switch	19	(FF61R)
	Veropins 2145	1 Pkt	(FL24B)
	Keytop 1 Position	18	(FF62S)
	Keytop 2 Position	1	(FF63T)
	DIL socket 16-pin	2	(BL19V)
	DIL socket 18-pin	1	(HQ76H)
	Constructor's Guide	1	(XH79L)
OPTIONAL			
PL1	Keypad Cableform	1	(FP63T)
	EPROM 2716/M12	1	(UH87U)

A complete kit of all parts, excluding optional items, is available for this project:
Order As LM18U (Z80 Hex Keypad Kit) Price £34.95
The following items included in the above kit list are also available separately, but are not shown in the 1987 catalogue:
Keypad PCB **Order As GD40T Price £11.95**
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4½ DIGIT COUNTER

★ General Purpose Counter ★ Low Power Consumption
★ Buffered Inputs Accept Wide Signal Range
★ LCD Display ★ Schmitt Trigger Count Input

by Mark Brighton

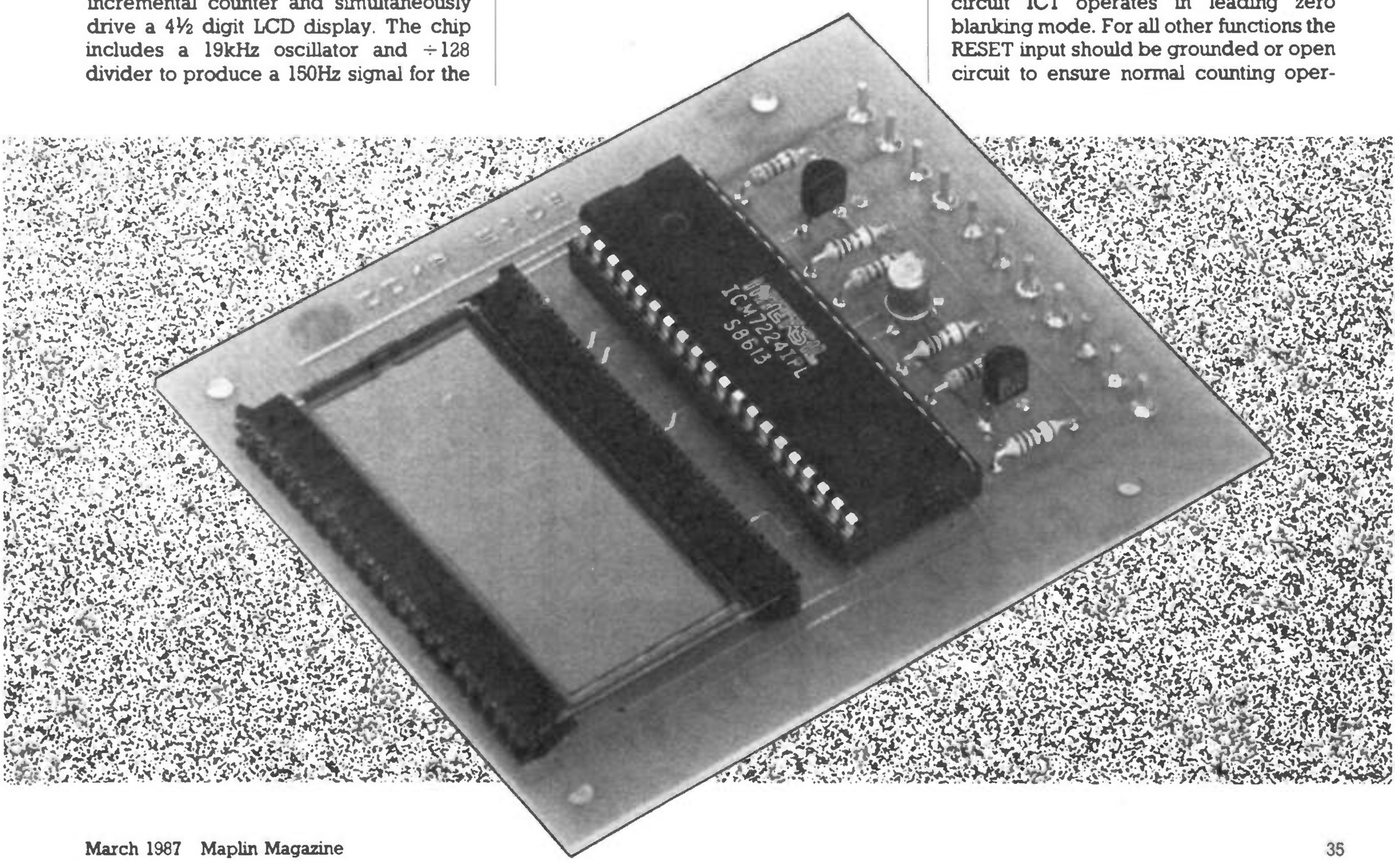
This article describes a simple 4½ digit counter for general purpose applications, either as it stands or in the form of a 'building block' module where a counter function is required as part of a larger system. Please note however that it is not a complete frequency counter or a timer in its own right, although it could be used in these applications if provided with the necessary external gating and timing circuitry.

The counter is built around the ICM7224 IC, which actually contains all essential circuitry to operate as an incremental counter and simultaneously drive a 4½ digit LCD display. The chip includes a 19kHz oscillator and ÷128 divider to produce a 150Hz signal for the display's AC backplane, making it very easy to use, and requiring only a regulated +5V supply and the display to function.

Circuit Description

The 7224 is shown as IC1 in Figure 1. This is a minimum circuit configuration for this device, and makes use of just three inputs to the chip for the functions COUNT, COUNT/INHIBIT and RESET. Inverter stages TR1 to TR3 have been added to the minimum circuit to provide a measure of protection against over-voltage signals, by buffering the chip from the board inputs, and enabling the counter to operate over a wide range of input voltage peaks from approximately +2 to +20V. This is a desirable precaution, given that 'general purpose' usage may require signal voltages to be anything but standard logic levels.

To reset the counter to zero the RESET input at TB9 is taken to >+0.7V, which also blanks the display - in this circuit IC1 operates in leading zero blanking mode. For all other functions the RESET input should be grounded or open circuit to ensure normal counting oper-



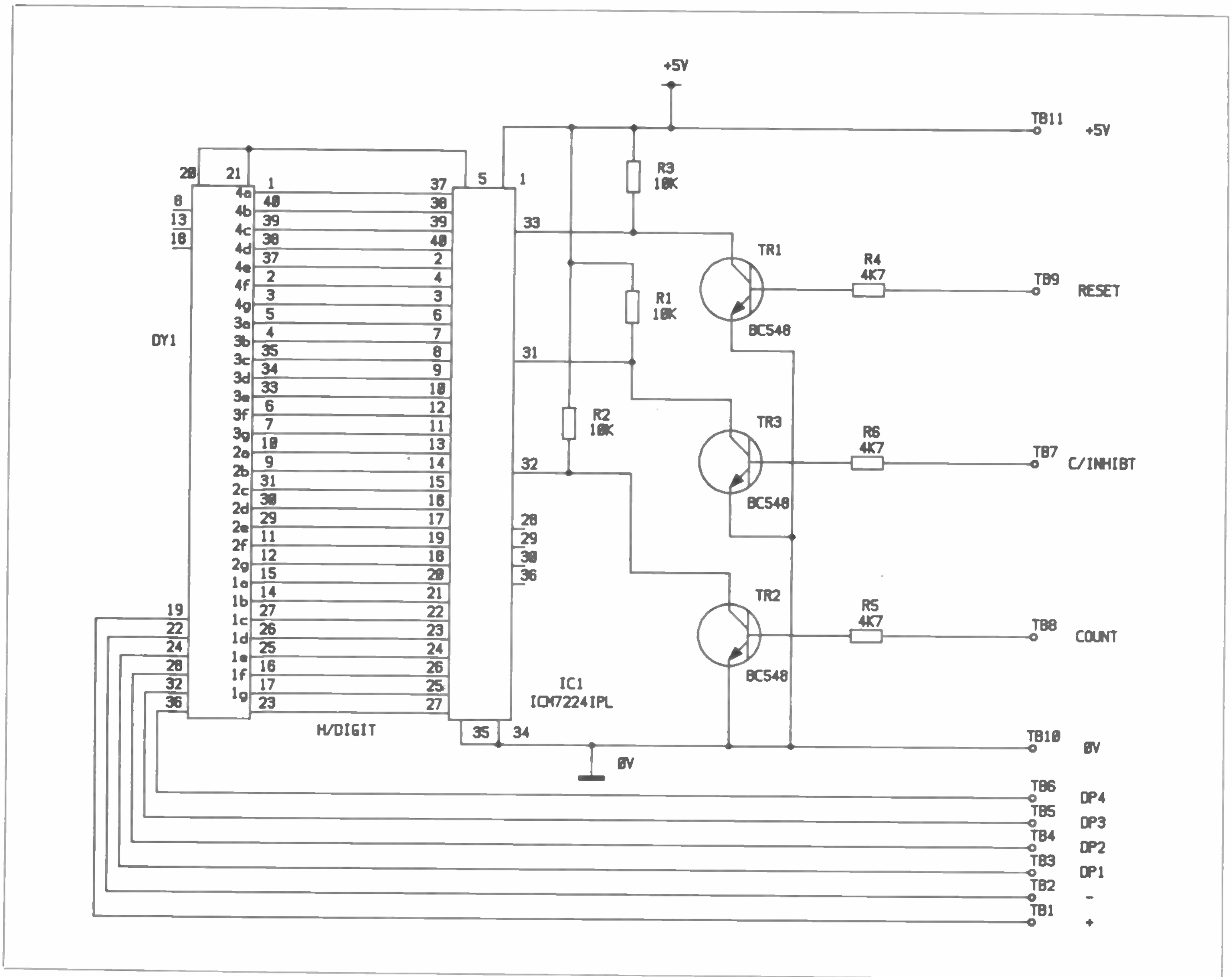


Figure 1. Circuit.

ations. The COUNT input, TB8, is negative going, and requires a positive voltage falling to zero at which point a count of one will be incremented in the counter. This input need not necessarily be hard-edged pulse or square waveforms, since the COUNT input of IC1 incorporates a schmitt trigger input stage, which together with the gain of TR2 will allow slower voltage transitions. For example, a low level sine wave signal (less than 5V peak) alternating about 0V can be used to trip the counter on each falling positive half-cycle. Moreover, the schmitt trigger operation offers some immunity to interference and noise injection, thus preventing erroneous and erratic behaviour of the counter. This flexibility allows a wide variety of COUNT input sources, including various types of sensors.

The COUNT/INHIBIT input at TB7 is used to defeat normal counting operation so that the display remains static without the need to remove the signal at the COUNT input. To do this COUNT/INHIBIT is taken to >+0.7V. In this condition the current count can be retained and displayed indefinately, or cleared to zero with RESET. COUNT/INHIBIT must be grounded or open circuit to enable, or resume, normal counting. In this way the counter can be 'gated' by a means based

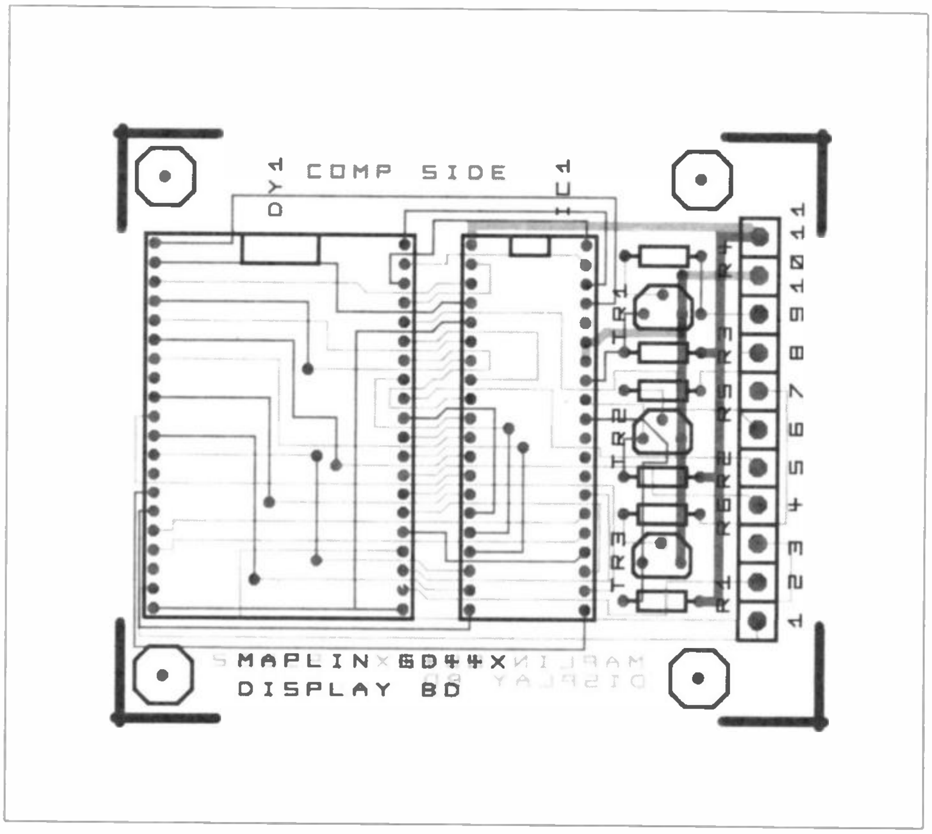


Figure 2. PCB Layout.

on a time period or a specific condition (e.g. counting allowed provided condition is true, etc.).

Some additional terminals are provided on the board, which are direct connections to the LCD display, brought out and made available to the user. These are the four decimal point positions TB3 to TB6, the plus sign TB1, and the minus sign TB2. If the counter module is to be incorporated into a system for a particular task, then these can be hard-wired to 0V as required, or temporarily connected for some general purpose use to clarify the display. The decimal points may be switched if the module is to form the basis of some sort of frequency or period counter, over several switched ranges. If these terminals are not to be used they should be left floating.

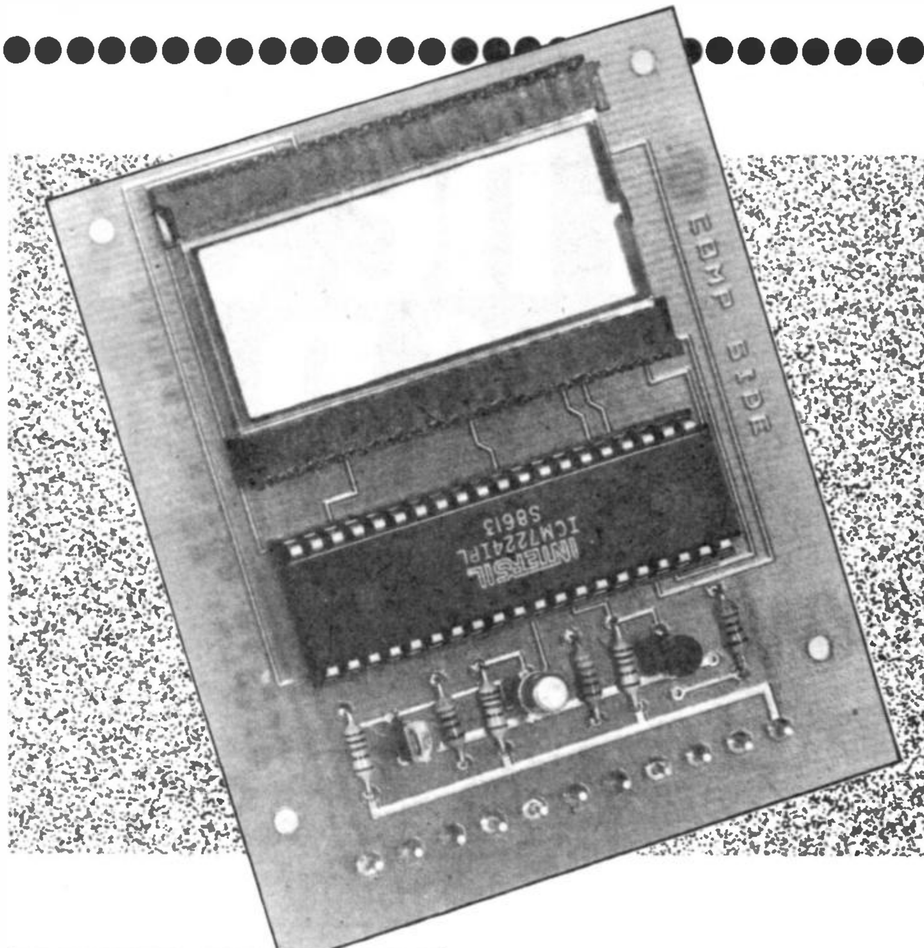
Construction

With reference to the Parts List, and the board layout and legend shown in Figure 2, insert and solder all six resistors. Insert and solder TR1 to TR3, making sure orientation is correct. Carefully fit the LCD display DY1, ensuring that all pins line up with their respective holes, and that the glass pip at one end of the display must align with the rectangular marker on the legend. Be very careful when soldering that the display is not allowed to get hot; if so then wait between soldering operations until it cools. Insert and solder the 40-pin DIL socket at IC1 position with the end notch adjacent to the rectangular marker on the legend. Upon completion check your work for possible short circuits and incomplete solder joints. In particular closely examine the areas between the pins of the DIL socket and the display. When you are satisfied that all is well then carefully insert IC1 into its socket ensuring that its end notch aligns with that of the socket, and commence testing the module.

Testing

Note that due to the nature of the plated through holes used for the General Purpose Counter PCB, it is not possible to fit veropins in the holes TB1 to TB11 in the normal way. However small pins such as type 2145 (FL24B) might be used if the holes are drilled out to 1mm, and the pins soldered on both sides, but this must be done carefully, if required. The module requires a regulated +5V DC supply to operate – do not attempt to connect anything other than +5V to the supply pin or damage may occur. Upon switching on a random number may appear on the display. Operate the RESET input by connecting TB9 to TB11 with a test lead. The display should clear to give a blank display.

Similarly, pulsing the COUNT input in the same manner should cause the module to count up. Link the COUNT/INHIBIT pin TB7 to TB11 and the module should not respond to further input at TB8. The display should be



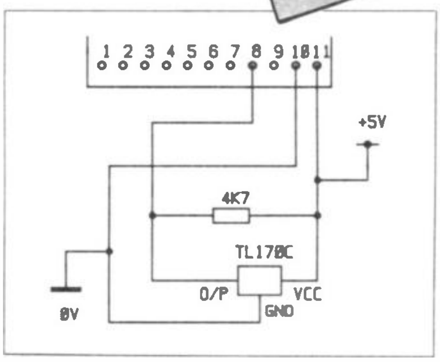


Figure 3. Hall Effect Device.

'frozen' with the last value incremented before COUNT/INHIBIT was taken high.

Pins TB1 to TB6 on the board access the plus and minus signs and the decimal point symbols of the display. Earthing each in turn to 0V should cause these to appear.

Using The Module

How the module should be employed is entirely up to the constructor, but the most obvious applications include those of the event counting type. Means of electrical input to the COUNT pin have already been mentioned, and a mechanical switch can also be used between TB10 and TB8, with a pull-up resistor between TB8 and TB11 to cause an increment of one whenever the switch is closed. The switch may be a thumb operated push-button for counting items by hand or a micro-switch on a machine. Note however that some form of 'debouncing' is desirable and a minimum requirement would be a 100nF capacitor connected across the switch terminals. Figures 3 and 4 show alternative arrangements which replace TR2, utilising a magnetic hall effect device (with a magnet) and an opto-coupler respectively as sensors. Either of these latter two methods can produce a counter for a hand operated wire winding machine, or with a wheel to become an odometer etc.

Some more sophisticated functions are available if desired, but involving some 'customising' of the General Purpose Counter PCB if this is used. A wire link to pin 28 of IC1 gains access to the chip's CARRY output (active low), which can be used to drive an overflow indicator, or perhaps even a second, cascaded counter module.

Connecting pin 29 of IC1 to ground via a wire link defeats the leading zero blanking mode, causing the display to show zero on RESET.

Isolating pin 34 of IC1 from 0V and attaching a wire link gains access to the chip's STORE input (active low). The STORE function controls internal latches which transfer decoded display data from the count decoders to the display drivers; whilst pin 34 is low the latches

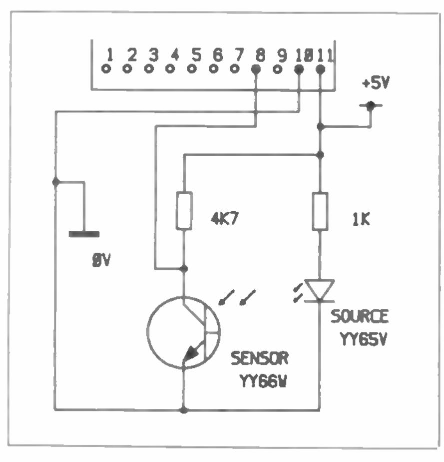


Figure 4. Opto-coupler.

Continued on page 42.

The Story of Radio

by Graham Dixey

C.Eng., M.I.E.R.E.

Part Six– The Golden Age

The 1930's was the 'Golden Age of Wireless'. Even with the Depression (or perhaps because of it), more people turned to the wireless receiver in their leisure time. When the BBC was founded in 1922 there were just over two million licence holders in the UK – by 1939 there were over 9 million. By the middle of the decade, 1935, 98% of the population of this country could listen to one BBC programme and 85% had a choice of two. The listening public crossed all social boundaries. Even the very poorest (and there were plenty of those in pre-war Britain), felt the need for a cheap wireless set to entertain them. The Philco People's set, introduced at the 1936 Radiolympia, sold for 5 or 6 guineas (£5.25 - £6.30). The hire purchase companies did well out of the growing interest, for the cost of a receiver was beyond the cash resources of many, especially if it was of the type that included a gramophone, the popular 'radiogram'. Nearly half of the licence holders of 1939 had incomes of less than £4 per week; some had less than £3.

Wireless on the move!

Radiolympia was the highlight of the 'wireless year', being held in the autumn. At the 1930 show, one of the most noticeable developments was in the number of mains operated receivers. These were classified as 'table models' or 'transportables', that could be moved from room to room. The dials of these receivers were marked with the wavelengths to which they could be tuned. It was only later that the station names were included as well because, at this time, there was still a lot of discussion going on around the conference tables as to what each country should have in the way of wavelength allocations.

It may seem obvious to us that sets which were to be used exclusively in the home should be able to operate from the domestic mains supply, but the fact is that there were many homes still without electricity, and those that were connected might have either AC or DC mains, depending upon the whim of the local board! As recently as the 1950's it was possible to take an AC mains receiver from one part of the country to another and be unable to use it because the supply turned out to be DC. Many a mains transformer primary went up in smoke because of this incompatibility! An obvious advantage of having a receiver capable of operating from the mains was its negligible operating cost in terms of power consumption. Batteries were then, and still are now, expensive items.

Superhet

The 1930's saw the widespread adoption of the 'superhet' receiver. To give it its full name, it was a 'supersonic-heterodyne' receiver and it has remained the standard type ever since. Its great advantages were, a substantial increase in both 'sensitivity' and 'selectivity', compared with the T.R.F. (Tuned Radio Frequency) or 'straight' receiver. The greater sensitivity resulted from the larger number of stages of amplification (at r.f.) that could be achieved without encountering the instability problems that often resulted with T.R.F. receivers. The improved selectivity (the ability to discriminate against stations on a wavelength close to that of the desired station) followed more or less automatically, because more r.f. amplification implied more resonant circuits, each tending to reject adjacent channels. The problem with the T.R.F. receiver was the extreme difficulty of achieving high gain and variable tuning at the same time without the whole thing bursting into oscillation. High gain meant several r.f. stages, each with its own tuned circuit that had to be 'ganged' to the others – an unwieldy arrangement. The superhet got around the problem by producing an 'intermediate frequency' (the i.f.) that was always the same no matter what the incoming frequency. Most of the amplification was carried out at this lower, fixed radio frequency, and was much easier to do in consequence.

Figure 1 shows block diagrams of both types of receiver. In the case of the superhet, the i.f. is produced by a process known as 'heterodyning', in which the incoming signal is mixed with the output of a local oscillator. The i.f. is one of four frequencies output from the mixer, and is the difference between the r.f. signal and local oscillator frequencies, the other three being the received r.f., the local oscillator frequency and the sum of these

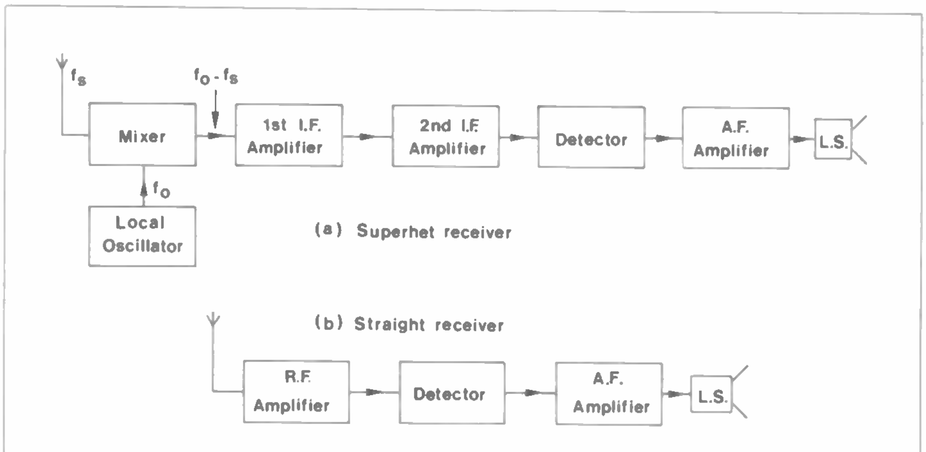
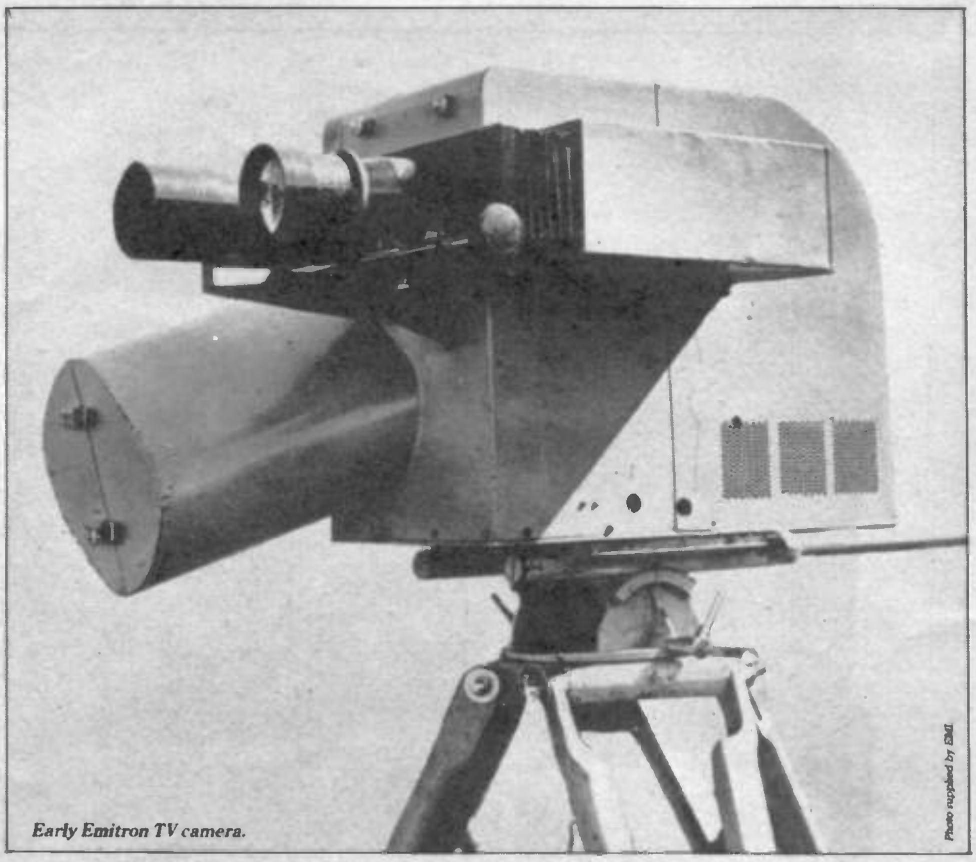


Figure 1. The superior complexity of the superhet against the simplicity of the straight receiver; both popular designs in the 1930's.



Early Emitron TV camera.

Photo supplied by EMI

Alexandra Palace, London, 1937.

Photo supplied by the Trustees of the Science Museum (London).

Baird Disc Model Televisor 1930.

two. A tuned circuit immediately follows the mixer output which filters out all but the required i.f. which is passed on to successive stages. This precludes that the local oscillator output frequency must 'track' the received r.f. and so two ganged, tuned circuits are required. Since the local oscillator and r.f. signal tuning are ganged, their difference is always the same. A typical value of i.f. for a modern AM receiver is 470kHz though, in the past, it has been anything from 110kHz to 550kHz, for MW/LW wavebands.

Apart from the benefits of having a receiver that was less prone to 'adjacent channel interference', the owner of a superhet receiver no longer needed the elaborate aerial system that had previously been considered vital. At worst he could probably get by with a piece of flex strung along the picture rail, and so the skyline of a 1930's town became somewhat cleaner than it had been in the previous decade, as the forest of swaying masts was gradually dismantled.

Radio gets Style

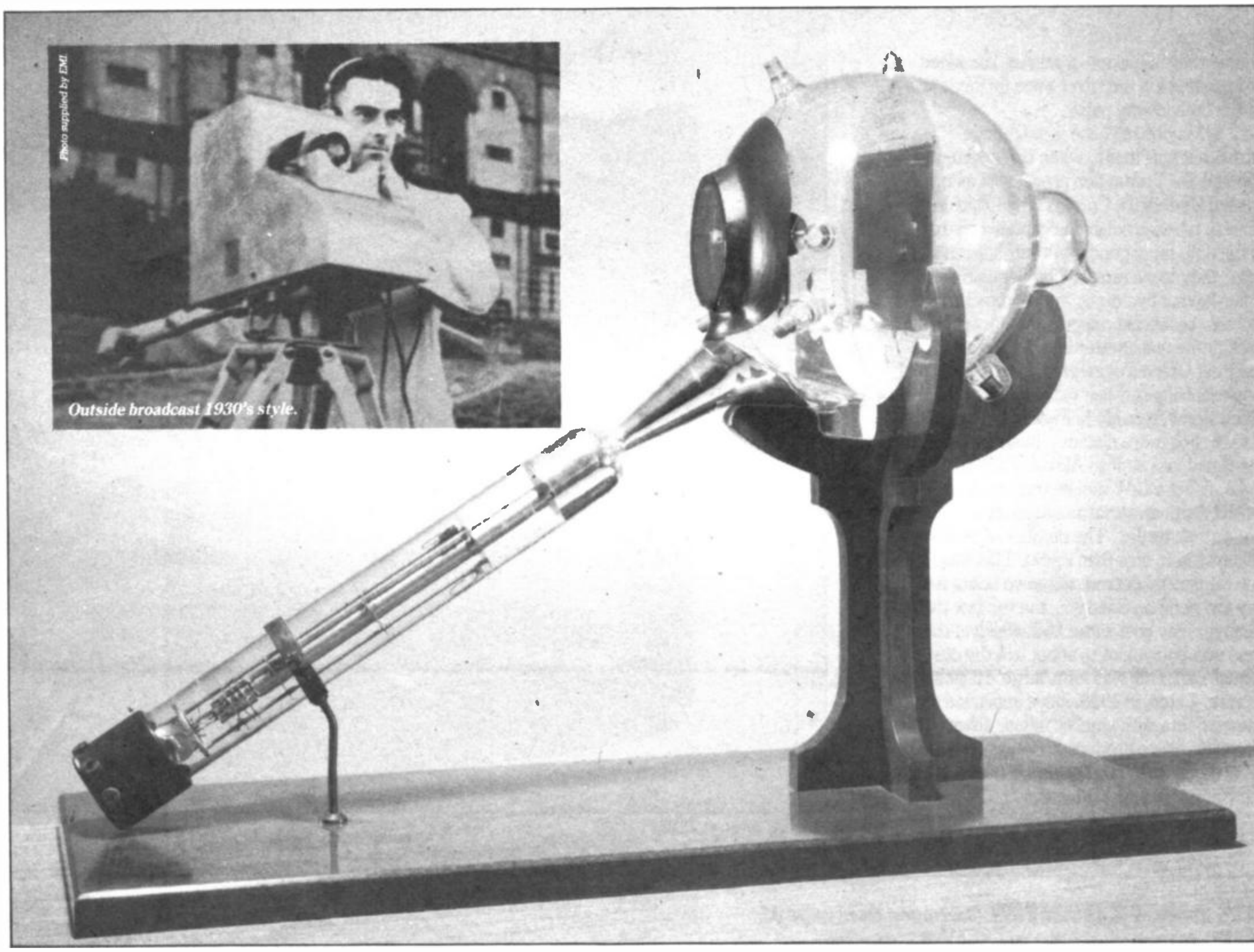
Styles in receiver cabinets underwent changes in the 1930's, one significant line of development being the exploitation of plastics, in the form of Bakelite. One company, Ekco, produced a receiver in 1934 called the AD65, which used a Bakelite moulding that broke away (not literally!) totally from traditional furniture styles. This was designed by the architect, Wells Coates, designer of some of the interior of the BBC's Broadcasting House. The use of the term 'furniture' to describe the style of a radio cabinet may seem slightly odd; nonetheless that is how cabinets were viewed up till then, as extensions of existing furniture, subject to the same limitations of wooden construction as sideboards, bookcases, and so on, since a typical receiver of this time (let alone a 'radiogram') could be as large as a modern good sized colour TV or bigger! Another handsome and significant design in Bakelite was the Philco 'Peoples' Set, Model 444 of 1935.

The domestic wireless scene was big business in the 1930's. The well-known firms of GEC and HMV were a far cry from the garden shed businesses of a few years earlier. The latter company employed a workforce of 12,000, had their own foundry, timber yard and sawmill, Bakelite moulding facility, generating station and even their own railway siding.

Various innovations were adopted in domestic receivers in the years leading up to World War Two, some successful, some not so. One of the latter category was a 'voice-operated' receiver from the Marconi Company, in which there were no knobs; the tuning was effected by the receiver's response to the human voice. It was combined with a television receiver that was similarly controlled. More successful ideas included visual tuning indicators, an example being the neon indicator, another the cathode ray 'magic eye' indicator valve (which was used much later as the level meter for valve driven tape recorders). Tuning a receiver by ear alone did not always get the best results. In the desire for portability, very small receivers were produced, such as the Empire Portable weighing less than two pounds. Otherwise the main variations were found in the lines of the cabinet, which were sometimes rounded, sometimes angular. However, 1938 saw another trend, in the form of push-button tuning. Here the onus for proper tuning was placed on the set maker rather than the user. A deft stab with one's finger was all that was needed to change stations. An example of this type of receiver was the 1938 Defiant MSH 938, which had a motorised tuner and no less than twenty push-buttons!

Air Travel

Imperial Airways, the British state-owned national airline, was formed in 1923 and continued in existence until the beginning of World War Two. During the two decades preceding this conflict, great pioneering flights opened up the air routes



Outside broadcast 1930's style.

The Emitron TV Camera Tube.

linking the British Empire and the world's capitals. The greater ranges and higher speeds of the current generation of aeroplanes necessitated improved performance in both airborne and ground wireless units, especially those used for the vital role of direction finding. This led to increased use of the h.f. wavebands (as opposed to the lower frequencies) for airborne communication. As a demonstration of the effectiveness of h.f. for long range communication, in December 1928, the transmissions from an airliner flying over England were picked up in Cairo.

March 1930 saw the introduction of another valuable service, air-sea rescue, which originated when the National Lifeboat Institution (later Royal) fitted the new Dover lifeboat with a Marconi XBM1 transmitter-receiver. Other lifeboats were gradually similarly equipped and this led eventually to the RAF Air-Sea Rescue service, which saved so many lives in World War Two.

Television

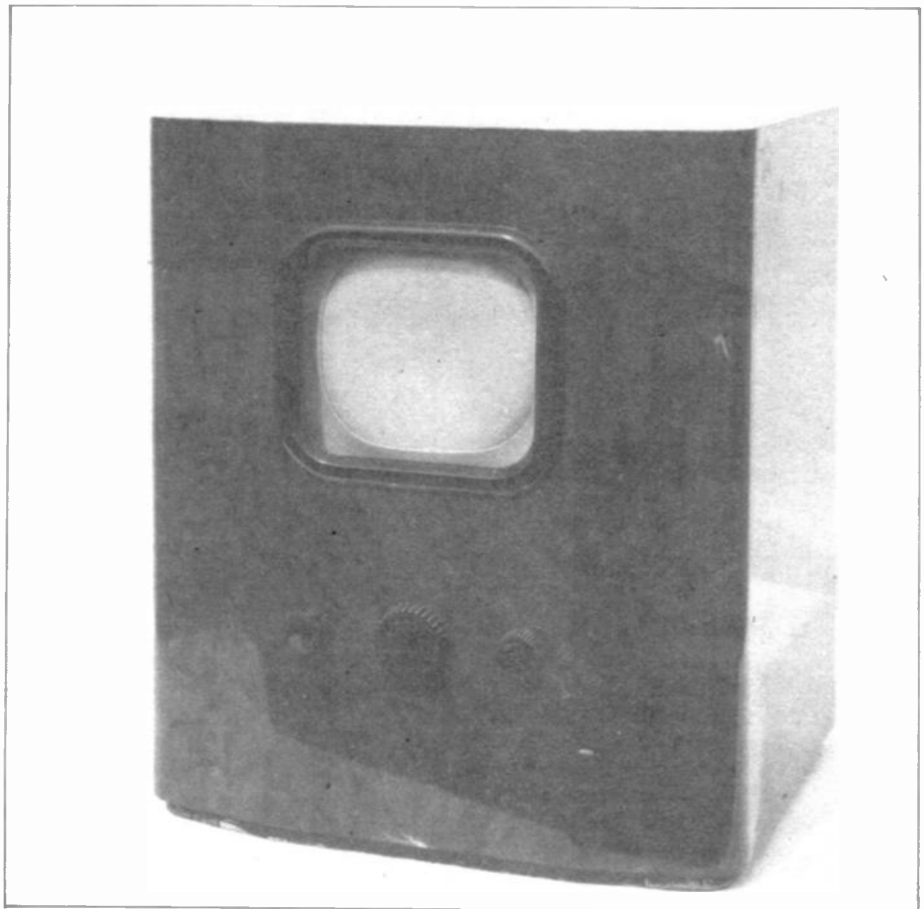
Any discussion of radio in the 1930's would be incomplete without some mention of television. Was it a companion to wireless or a competitor? In the 1930's the question was a bit academic; very few people owned a TV set. Television is, in a sense, merely 'radio with pictures'. It uses the same principles of modulation, transmission, reception and demodulation of a carrier, though the signal is more complex and two separate components can be identified - video (including sync.) and sound. So it is part of the story of radio, an offshoot, as is radar.

Associated with the 'invention' of television is the name of John Logie Baird, who was certainly an ingenious man but, ultimately, his work ended in a technological blind alley. His first crude 'televisor' consisted of an old tea chest, supporting an electric motor that drove a cardboard scanning disk, cut from an old hat box. The spindle was a darning needle. The projection side of it comprised a lamp in a biscuit tin and lenses borrowed from bicycle lamps. Even so, he was able to transmit an image over a distance of 2 to 3 yards and this led to the Baird 30-line system.

By 1928 Baird had convinced the BBC that his system was sufficiently developed to be put into service, but it wasn't until the following year that any transmissions were made. The first transmitted pictures were appalling, barely recognisable as the human face they purported to be. Even picture and sound were unsynchronised. Afterwards, the system was improved to a point where a recognisable picture with fully synchronised sound was transmitted. Televisors then went on sale at a cost of 25 guineas (£26.25) but there were few takers. The picture quality was about the same as the early movies and look how they had improved! Experiments continued and there were notable broadcasts, including the 1931 Derby and, in November 1932, a transmission was made from Broadcasting House in London to the Arena Theatre in Copenhagen, 600 miles away! But the Baird system was ultimately doomed; it just couldn't offer the picture definition that a viable system demanded.

Company movements are complex operations at best, but in 1934 the Marconi Company joined with EMI to form the Marconi-EMI Television Company Ltd, combining the technology of the two companies, which included experience of high power transmitters and the Emitron TV camera. The important aspects of this were the use of electronic instead of mechanical scanning techniques at the studio end and the cathode-ray tube at the receiver. This put the development of television on a totally different footing although much pioneering work needed to be done to produce a high definition system that would capture a wide audience. The world's first 'regular' television broadcasts were begun by the BBC on November 2nd, 1936. Advance publicity of the event was given by test transmissions between Alexandra Palace and the 1936 Radiolympia exhibition. At this time both the Baird and EMI systems operated side by side, but in February 1937 the Baird system was at last dropped. Not only had there been a disastrous fire at the Crystal Palace, which had destroyed a major part of the Baird Television Company's equipment, but the EMI equipment, which was based on the 405-line standard, was undoubtedly superior. It merely remained now to develop the latter even further and to widen the viewing public.

In May of 1937 the first Outside Broadcast was made, when three cameras showed the Coronation procession as it passed Hyde Park Corner. The Emitron camera tubes produced acceptable pictures in the dull, rainy conditions but, later in the year, they were replaced by Super Emitron tubes having five times the sensitivity. Outside broadcast meant some form of link back to the transmitter and, for this purpose, the Post Office Engineering Department laid a special balanced-pair cable to carry the video signal from Hyde Park to Alexandra Palace. For more distant outside broadcasts the signal was sent to Alexandra Palace by radio, using a 1kW mobile transmitter at 64MHz with an aerial mounted on a fire-escape ladder. The number of receivers sold was low, less than 2,000. This was due to low transmission time, only two hours per day and none on Sundays, and the fact that a receiver may cost some £60, which at the time was equivalent to about half the cost of a small car! This was for a 'large' 12 inch picture. Later, in 1938, sales improved as cheaper sets with smaller tubes, down to 5in. diameter, were produced. By September 1939 there were 20,000 sets in use, but now the Nation was again at war.



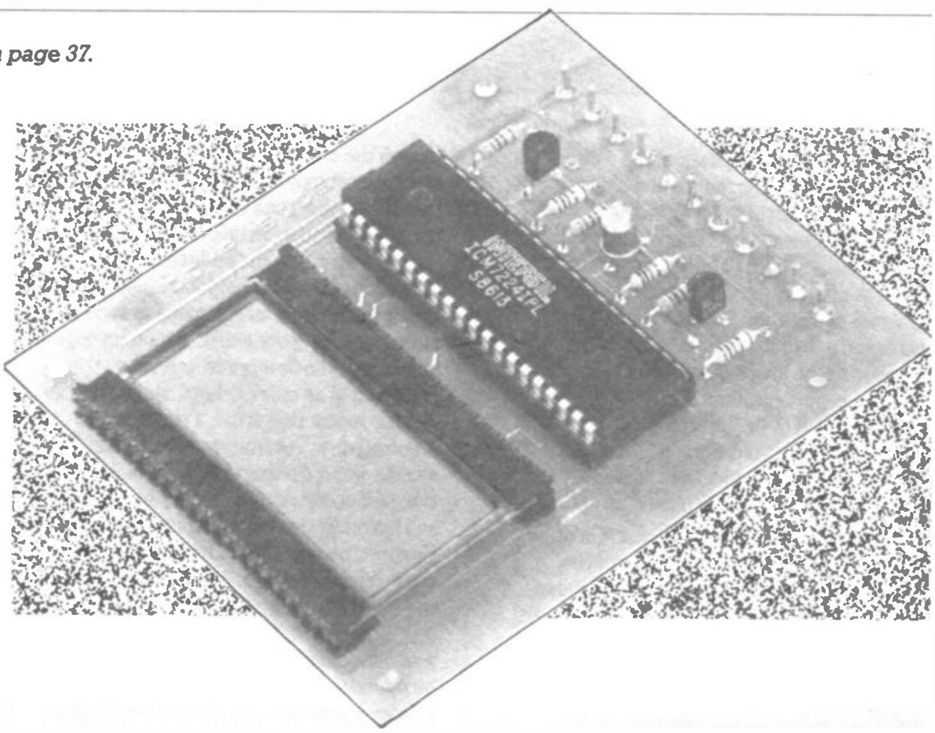
Ekco TV receiver 1938.

Photo supplied by the Trustees of the Science Museum (London).

4½ DIGIT COUNTER *Continued from page 37.*

are 'transparent' and the display reflects real time counting. On pin 34 being high the last count value is latched causing the display to hold this value, even though the counting is continued. Pulsing pin 34 low will show updates of the count value, remaining static between times. RESET does not effect the display in this condition.

A simple frequency counter can be made in this way, where a suitable clock and logic can produce, in sequence, COUNT/INHIBIT low for the gating period, followed by STORE (IC1 pin 34) low to update the display, then RESET to clear the counters for the next gating period. Signal input is to COUNT continuously. If a gating period of 1 second is used, the module can become an AF frequency counter with a resolution of 1Hz and an upper display limit of 19,999Hz with no range switching necessary.



4½ DIGIT COUNTER PARTS LIST

RESISTORS: All 0.6W 1% Metal Film

R1-3	10k	3	(M10K)
R4-6	4k7	3	(M4K7)

SEMICONDUCTORS

IC1	ICM7224IPL	1	(FP62S)
DY1	Display 4½ Digit	1	(FP61R)
TR1-3	BC548	3	(QB73Q)

MISCELLANEOUS

4½ Digit Counter PCB	1	(GD44X)
DIL Socket 40-Pin	1	(HQ38R)
Constructor's Guide	1	(XH79L)

A complete kit of all parts is available for this project:
Order As LM19V (4½ Digit Counter Kit) Price £25.95
The following items in the above kit list are also available separately, but are not shown in the 1987 catalogue:
4½ Digit Counter PCB **Order As GD44X Price £8.95**
4½ Digit Display **Order As FP61R Price £5.95**
ICM7224IPL **Order As FP62S Price £11.95**

MACHINE CODE PROGRAMMING WITH THE Z80

by Graham Dixey C.Eng., M.I.E.R.E. Part Six

Introduction

The interrupt facilities provided with microprocessors enhance their computing power enormously. However, since they are initiated by a voltage level transition, they are essentially hardware orientated. Obviously most readers of 'Electronics' will have such a bias, so it can be assumed that among the applications of a computer that they might consider are those that involve control of external devices. In this case a sound understanding of interrupt methods in general, and of the specific facilities of the Z80 in particular, is essential.

To understand what an interrupt is, consider the purpose of the 16-bit register that we call the Program Counter. This holds the addresses of the program as it runs. For example, if a program is loaded to run from the address &A000 then, on running it, the Program Counter is first loaded with this address. Since this register automatically increments it will hold the program addresses in sequence, i.e. &A000, &A001, &A002, etc. However, the sequence can be broken by special instructions, such as 'jumps' and 'calls'. In the case of these, the Program Counter is loaded with a new address and carries on executing instructions from this new address. In the case of a jump the Program Counter will not, in general, return to the point following the jump since its purpose was to give the program a completely new direction. Such is not the case with a call, however, since this is used to fetch a sub-routine. The last instruction in a sub-routine is the RET (RETurn from sub-routine) and this ensures that the program re-commences from exactly the right point, immediately after the call was encountered. How does it manage to do this? Well, of course, the way it 'remembers' where it was is by 'pushing' the relevant program address onto the stack and, when RET is encountered, 'popping' it off again, back into the Program Counter. This reminder of the way in which the Program Counter contents can be changed and restored at will is included because the action is relevant to an understanding of interrupts.

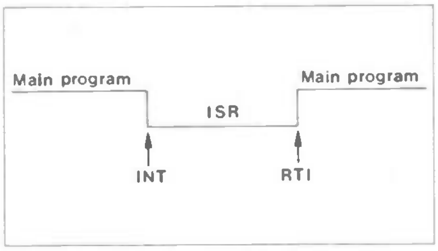


Figure 1. Single Interrupt during a Program.

So now to define an interrupt, which can be done by saying that it is a means whereby a main program running on a microcomputer may be interrupted by some external device in order to provide that external device with some 'service'; the action that initiates this interrupt is known in general terms as an 'interrupt request', and it is accomplished by applying logic 0 to one or other of two special pins on the Z80 CPU.

For now it is worth noting that these two interrupt inputs to the Z80 are known as INT (Interrupt Request) and NMI (Non-Maskable Interrupt); the former of these is the general purpose interrupt input. The idea of an interrupt is shown diagramatically in Figure 1.

The Interrupt Vector

The word vector implies direction and that is precisely what is meant in this context. There is nothing mysterious about the interrupt vector. It merely provides the essential information as to where the program should go when an interrupt occurs. Essentially, it is a pair of memory locations at which the start address of the Interrupt Service Routine can be found. In fact, the sequence of running the Interrupt Service Routine is easily seen as a series of jumps. As an example, suppose that on receipt of an interrupt, the program is sent to location &0038. At this, and the two succeeding locations, it finds the three bytes:

C3 1B 08

C3 is a jump instruction, so the three bytes mean 'jump to location &081B'. Now the memory location &0038 is in the operating ROM of the computer (it is in fact one of the restart addresses), whereas the location &081B is assumed to be in RAM. This allows the programmer to write whatever he likes into this location that will direct the program to the start of the Interrupt Service Routine. Suppose that this is to begin at location &0900. Then at &081B, and the two following locations, we find:

C3 00 09

Now let's look at the complete sequence.

(a) The interrupt line goes low and the program counter is loaded with &0038. Here, it finds a jump to &081B. The program counter now holds the latter address.

(b) At &081B it finds a jump to a specified location (the interrupt vector); in this case it is vectored to &0900. It is here that the first instruction of the Interrupt Service Routine is located.

(c) The computer runs the Interrupt Service Routine, at the end of which it encounters a 'return' instruction. This takes it back to whatever it was doing before the interrupt occurred.

Thus, it is quite possible for the computer to be interrupted as often as necessary, provided that it is always ensured that any interruptions always allow the computer to carry on with its main task, after such an interruption, just as if nothing had occurred. Upon reflection this must mean more than just pushing the Program Counter on the stack. If we assume the obvious, that is that any interrupt can occur at any totally unpredictable instant of time, then literally any of the registers involved with the main program could be in use. If the return from the interrupt is to leave matters just as they were prior to the interrupt, then all registers used by the main program must be pushed onto the stack also, unless we can absolutely guarantee that they are not used by the Interrupt Service Routine. The instructions that carry out the operations of saving and retrieving data in these situations are known as PUSH and POP.

The stack is known as a Last In First Out device, which means that the order of popping registers is always the opposite of the order of pushing them. Suppose that we know that the Interrupt Service Routine uses the following registers: A, F, IX, B and HL. The first instructions in the ISR must include:

```
PUSH AF
PUSH IX
PUSH BC
PUSH HL
```

And, at the end of the ISR, we will have:

```
POP  HL
POP  BC
POP  IX
POP  AF
```

The PUSH and POP instructions are classed as 16-bit loads, which means that registers are always pushed or popped in pairs if they are 8-bit registers. Thus, although register C is not actually likely to be corrupted by the ISR, it is still pushed along with register B since it is the other half of this particular register.

INT, NMI and Priorities

If it is possible for several devices to interrupt the computer program, the natural question that arises is, 'what happens if two interrupts arrive so close together that one ISR is still running when the second interrupt is received?' Then, of course, there also arises the question of whether one interrupting peripheral might be more important than another. This leads to the idea of 'interrupt priorities'. What must happen in practice is as follows:

If there are two Interrupt Service Routines, known as ISR1 and ISR2, where ISR1 is the more important, then if: (a) ISR1 arrives first it will 'mask off' ISR2 to prevent it interrupting it in turn, but if: (b) ISR2 arrives first it will be unable to mask off ISR1 since it has a lower priority. These cases are illustrated by Figure 2.

In the simple case of just two ISRs with these priorities, ISR1 would use the NMI interrupt facility, while ISR2 would

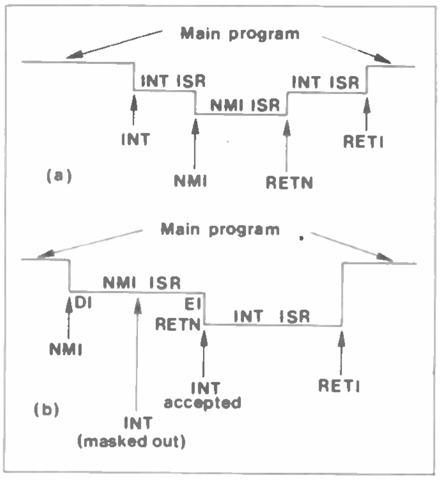


Figure 2. Multiple Interrupts when (a) INT arrives before NMI and (b) NMI arrives before INT. NMI assumed priority.

use the INT facility. This is obvious when it is remembered that NMI actually stands for 'Non-Maskable Interrupt'. The question is then, 'how is the masking effected?' The answer is that it happens automatically. In the Z80 there is a flip-flop, known as the 'Interrupt Mask Bit Flip-flop IFF1'. When this is reset all INTs are disabled (masked out); when it is set they are accepted. On receipt of an NMI this flip-flop is automatically reset but, before it is, its status (i.e. whether set or reset) is copied into a second flip-flop, IFF2, so that the Z80 can 'remember', at the instant that the NMI was received, whether further INTs were to be accepted or not.

To put this in perspective, suppose that at some point in time, an INT had been received and accepted but, before its routine was complete, an NMI was also received. At the beginning of the INT routine there would have been an instruction DI (Disable Interrupts), put there for the express purpose of masking off further INTs. This would have reset IFF1. Obviously, since NMI was received during the first INT routine, the latter must be completed immediately after the NMI routine and before any further INT routines are accepted. For this reason, at the end of the NMI routine, IFF2 will be copied back into IFF1 to restore the latter's status. The instruction that performs this is RETN (RETurn from Non-maskable Interrupt), which also pops the PC from the stack.

Interrupts versus Polling

Before looking at interrupts in more detail, it is worth looking at an alternative known as 'polling'. This is a software method of determining if a peripheral (or which peripheral of several) requires attention. There must be a status line between the peripheral and the computer so that the former can send a logic level, signifying status, to the computer. For example, it might be decided that if a peripheral requires service, it shall signal this fact by sending a 'logic 1' to the computer. It is then a question of how the computer will recognise that a demand exists. This is where polling comes in. A special polling program regularly checks the status line to see if it is high. When it finds that it is, it jumps to a routine to service that peripheral. If several peripherals are involved, the polling program will have to establish which peripheral is signalling for attention and jump to the service routine for that particular peripheral. There are two disadvantages of this method of servicing peripherals:

(a) If the polling program checks the peripheral status too often, it wastes time that could be used for other processing tasks.

(b) If the polling is carried out too infrequently, the peripheral may actually be left waiting for service, thus effectively limiting the speed of response.

However, it is quite easy to write a polling program so it is worth looking at what is involved. The basic segment is:

```
POLL    IN     A,(DATA)   ; Read input from
                            port
        BIT    ★,A        ; Test bit ★ in A
                            register
        JR     Z,POLL     ; Poll again if zero
```

```
00003  5C00  (5C00)              ORG  &5C00
00004  5C00  (0000)      INPUT   EQU  &00
00005  5C00  DB 00       .POLL   IN   A,(INPUT)    ;Read input register
00006  5C02  CB 47               BIT  0,A          ;Test bit 0
00007  5C04  C2 50 5C            JP   NZ,SRA       ;Go to SRA if equals 1
00008  5C07  CB 4F               BIT  1,A          ;Test bit 1
00009  5C09  C2 60 5C            JP   NZ,SRB       ;Go to SRB if equals 1
00010  5C0C  CB 57               BIT  2,A          ;Test bit 2
00011  5C0E  C2 70 5C            JP   NZ,SRC       ;Go to SRC if equals 1
00012  5C11  20 ED               JR   NZ,POLL      ;Keep polling if all 0
00013  5C50  (5C50)              ORG  &5C50
00014  5C50              .SRA                      ;ISR (Peripheral A)
00015  5C60  (5C60)              ORG  &5C60
00016  5C60              .SRB                      ;ISR (Peripheral B)
00017  5C70  (5C70)              ORG  &5C70
00018  5C70              .SRC                      ;ISR (Peripheral C)
00019
```

Listing 1.

In the first line the data word is fetched from the port and tested in line two to find out if a particular bit is 1 or 0. The BIT instruction does this, which it may be remembered affects the status of the Zero Flag in the F register. If the bit is 0 the flag is set and the JR Z,POLL recognises this and loops back to the label POLL. This can be easily extended to several peripherals as the assembled Listing 1 shows. Now consider how interrupts would deal with the same situation. The peripheral (or peripherals) is connected to the CPU via an interrupt line, say INT. If there are several peripherals, each will have to be able to indicate separately that it required service. One method of allowing several devices to share a common interrupt line is by use of the 'wired-OR' connection, shown in Figure 3. Any of the peripherals can take this line low to initiate the interrupt but the service routine so called must interrogate the status lines in turn to find which one is SET. This has the advantage that it is possible to establish priority on the basis that the status lines are checked in a chosen order of importance. For example, if there are three peripherals A, B and C, that being their priority order, then if two were to interrupt simultaneously, say A and C, A would be serviced first.

It is, of course, quite easy to establish a similar order of priority using the polling method, by checking the status lines in the required order of priority. However, the real advantage of using interrupts instead of polling is that it is faster and less wasteful of time. The computer carries out no checking at all; it occupies itself with its main computing task until requested to do otherwise. When an interrupt request is received, it completes its current instruction, saves PC and other registers on the stack and jumps to the relevant ISR.

The Z80 Interrupts

Three interrupt mechanisms exist in the Z80; the bus request BUSRQ, the non-maskable interrupt NMI and the usual interrupt INT.

The Bus Request

This is the highest priority interrupt on the Z80. Whereas both NMI and INT allow the CPU to finish its current instruction before taking control, the BUSRQ only allows the current machine cycle to finish before it takes over; this may well not be the end of an instruction. Its use is for Direct Memory Addressing (DMA). Any NMI or INT requests received during this time are stored, pending the end of the DMA state, when they will then be handled. Most programmers will not be concerned with DMAs so no further discussion of them will take place here.

The Non-maskable Interrupt NMI

This cannot be inhibited by the programmer. Unless there is a BUSRQ in operation, it will be accepted immediately after the current instruction has been completed. The value of the PC will be pushed onto the stack automatically and there will also be an automatic vector to location &0066. It is the responsibility of the programmer to use this to access the Interrupt Service Routine. However, since &0066 is in ROM, bytes will have been installed at &0066 and subsequent locations to vector the program into the area of RAM where the ISR resides. The exception might be in a small dedicated system where the ISR is actually resident in the ROM at &0066. But, taking an example where a vector into RAM is required, the following disposition of these memory bytes might be found.

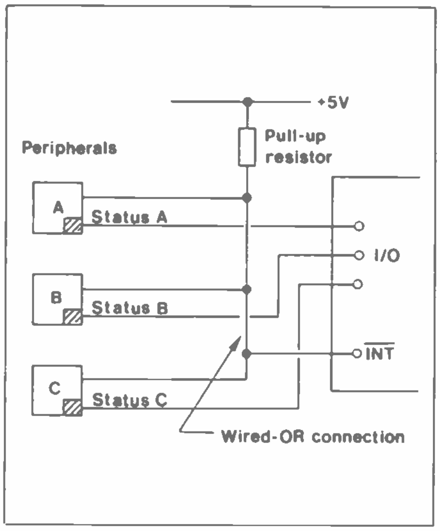


Figure 3. Multiple Interrupts on a common line using 'wired-OR'.

Memory location	0066	0067	0068
Data bytes	C3	1E	08

From this we deduce that, whenever NMI is received, a jump into RAM location &081E is performed. At this point the programmer has two choices; either he starts his ISR at &081E or he installs a further jump instruction (C3) here, followed by two bytes into a further area of RAM. The latter is very flexible because the two bytes mentioned can change with the program, allowing access to a variety of ISRs from the same interrupt source, namely NMI, according to requirements. This idea was described in general terms earlier when discussing the interrupt vector. The effect of NMI on the flip-flop IFF1 has already been covered, as has the use of RETN at the end of an NMI routine.

The General Purpose Interrupt INT

There are three distinct maskable interrupt modes in the Z80, all accessible by the INT input. In each case they can be disabled by the DI instruction and enabled by an EI (Enable Interrupts) instruction. These instructions will reset or set IFF1 respectively.

Interrupt Mode 0

The Z80 CPU was developed from the 8080 CPU and retains some of its instructions and characteristics. One of the latter is this mode of interrupt operation. The mode is selected in one of two ways:

(a) whenever the machine is reset.

(b) when the mode is programmed by the IM0 instruction.

In this mode, on receipt of an interrupt, the Z80 will do nothing except generate a pair of signals, IORQ (Input/Output Request) and M1 on the control bus; these constitute the signal INTA (Interrupt Acknowledge). It will then wait for the peripheral to place a byte of data on the data bus, which it must do in the next cycle. This data byte will then be executed by the CPU to run the Interrupt Service Routine. This byte will usually be a RST or a CALL, either of which will push PC as a matter of course.

It may be remembered that there are eight 'restarts' (see Table 12 in Part One), which are located at the bottom of Page 0. The lowest of these, RST0, is a complete system reset but the others can be loaded with vectors to any address in memory. Alternatively, the CALL instruction accesses the routine directly with a three-byte instruction. Thus, suppose the required routine is in RAM at &08E0, then the machine code for the two alternatives is:

(a) using RST38, FF is the peripheral response to INTA, giving:

Memory location	0038	0039	003A
Data	C3	E0	08

i.e. jump to location &08E0.

(b) Using CALL, CD is the peripheral response, followed by the bytes E0 08 i.e. call routine at &08E0.

An interrupt in Mode 0 automatically disables further interrupts. The programmer must remember to insert an EI instruction at the end of the ISR. The final instruction in the ISR will be RETI (RETurn from Interrupt). Beware of confusion with RET (RET from subroutine) and RETN.

It is possible to establish a priority order among peripherals using the INTA signal associated with this mode. This signal is sent to each peripheral in turn; only the peripheral that initiated the interrupt will respond. If two did so, the higher priority peripheral will respond first. This principle, known as 'daisy chaining', is illustrated in Figure 4.

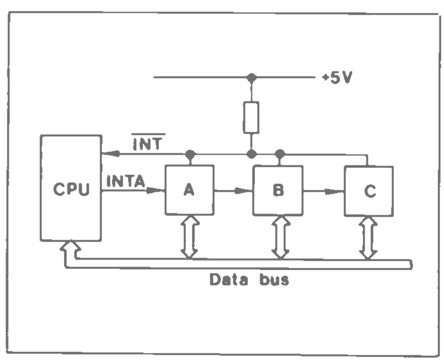


Figure 4. The 'daisy chain' principle.

Continued on page 50.

Weather Satellite Down Converter

by Robert Kirsch Part 1

A system for receiving and decoding data from polar orbiting weather satellites in the 137MHz band has been described in previous issues of 'Electronics'. This article describes a Down Converter that may be connected directly to this receiving system to enable it to receive S band signals from Meteosat 2, a geostationary weather satellite.

The Meteosat System

Meteosat forms one of a chain of five geostationary weather satellites located above the equator that cover the entire world, see Figure 1. Meteosat 1 was launched during November 1977 by the European Space Agency (E.S.A.) and continued to work until November 1979, being replaced in June 1981 by Meteosat 2, which is still in service.

This satellite is located on the Greenwich meridian, nearly 36,000km above the equator (0 degrees N, 0 degrees E) and orbits on the same axis as the Earth at a speed that maintains it in a fixed position above the Earth (geostationary orbit).

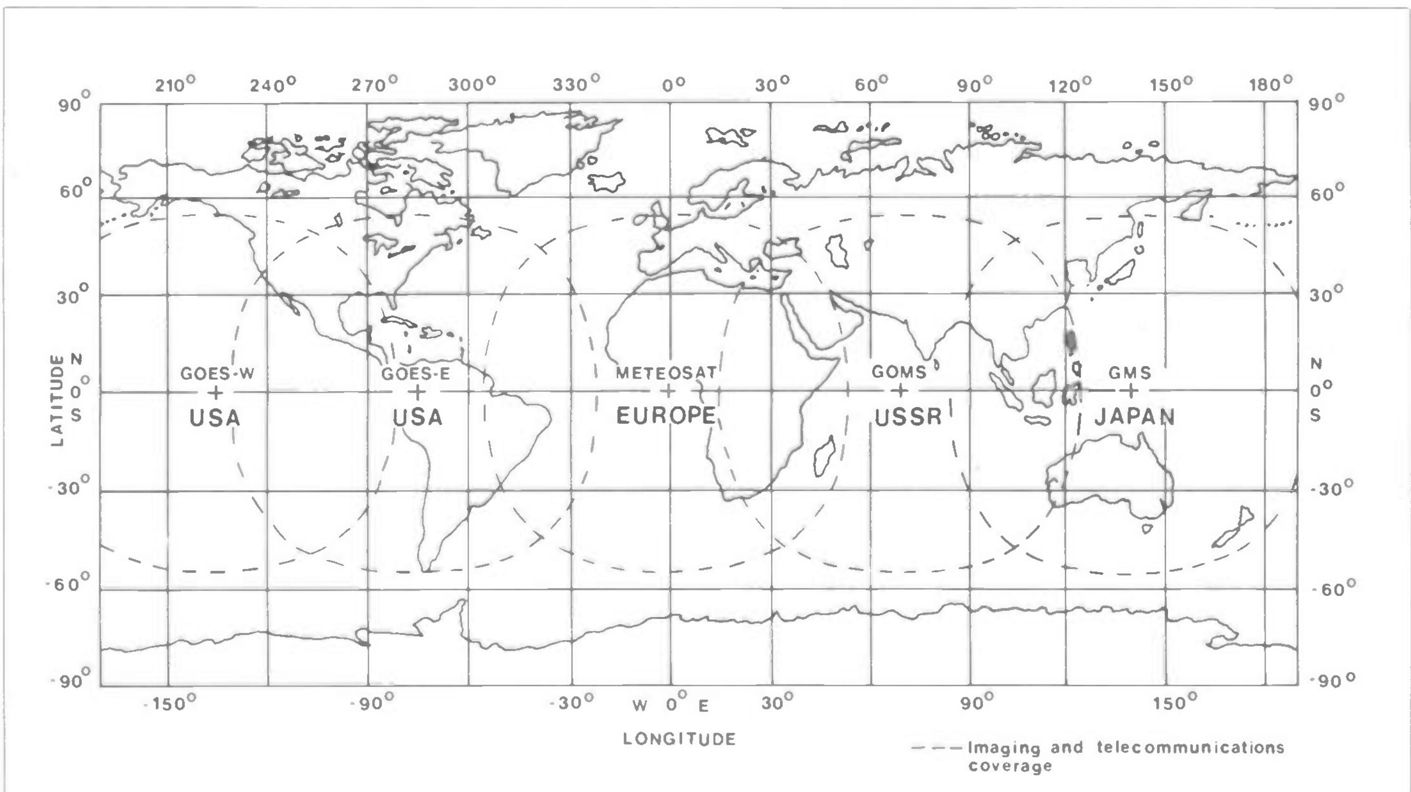
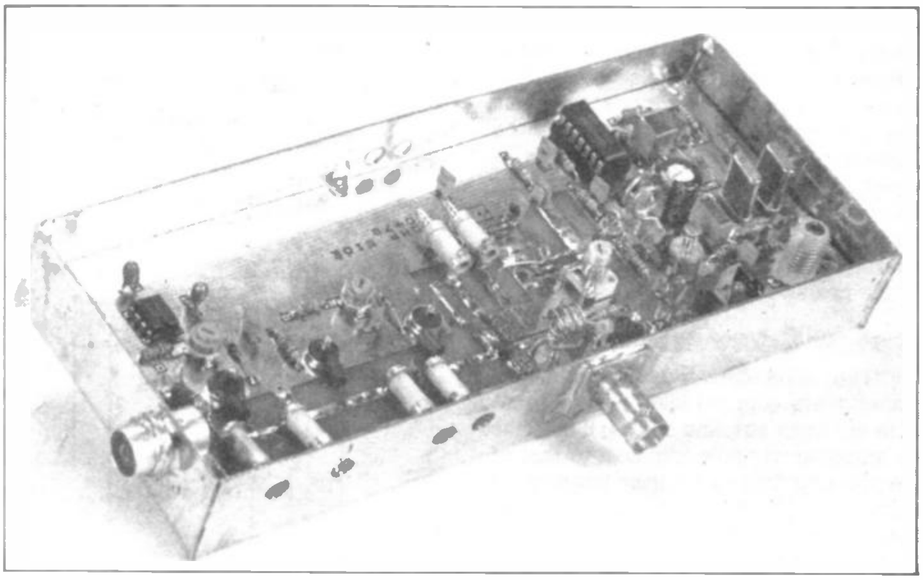


Figure 1. Weather Satellite system.

The Meteosat satellite system differs from the polar orbiting satellites in that the higher orbit of Meteosat enables it to see the whole disk of the Earth at once, thus it can make constant observations of the area covered. The satellite looks at the Earth through a device called a multispectral radiometer which provides four separate images, two visible and two in different infra-red spectral bands. One infra-red channel gives a thermal image of the Earth, the other responds to the water vapour absorption band giving an indication of the levels of atmospheric humidity.

The raw data from the satellite's radiometer is transmitted to the Earth for processing in the S frequency band (1670-2110MHz). The receiving station for these signals, called the DAATS (Data Acquisition, Telemetry and Tracking Station), is located in the Federal Republic of Germany, about 50km from Darmstadt. Signals received are fed to the Meteosat Ground Computer System at the European Space Operations Centre in Darmstadt, see Figure 2.

The data from the satellite is processed by a pair of large mainframe Siemens computers from which information is fed by land-line to world wide users and also back to the DAATS for re-transmission to the satellite in WEFAX format with coastline added. The satellite re-radiates this information on two S band frequencies, channel A at 1694.5MHz and channel B at 1691MHz, these are the signals received by the Down Converter described in this article. These signals are then translated to 137.5MHz by the Down Converter ready for detection and decoding by the Mapsat receiving system.



The Down Converter.

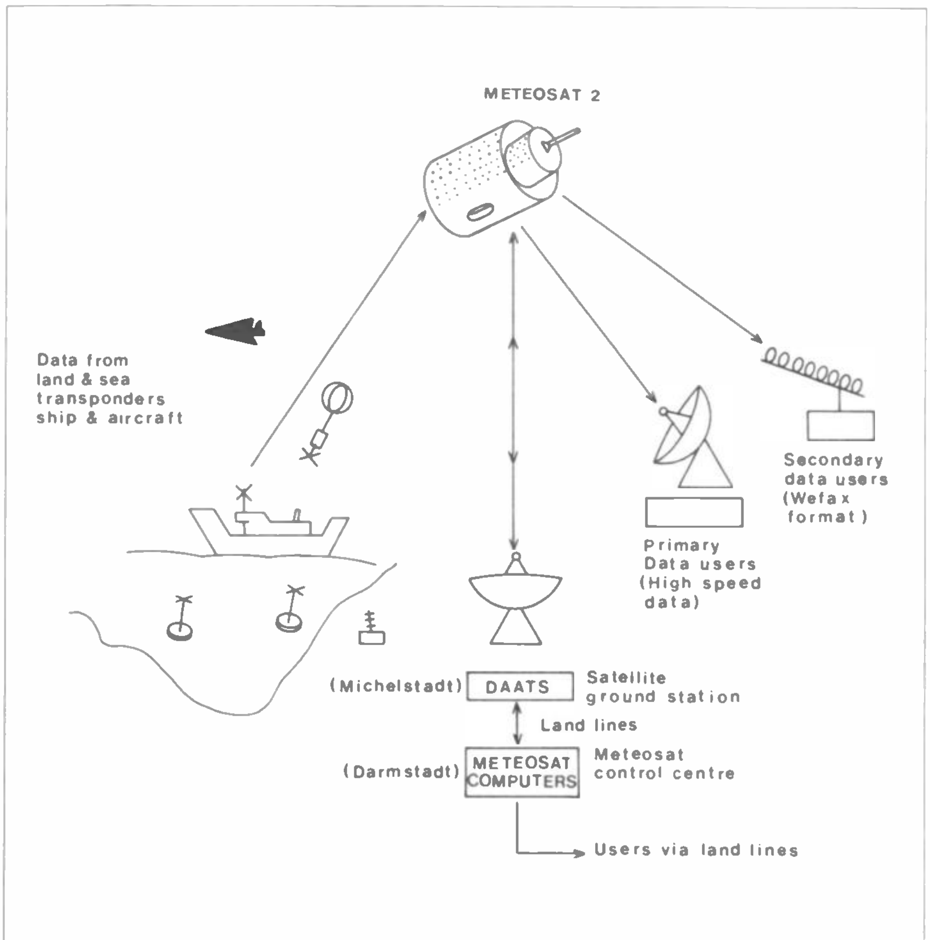


Figure 2. Meteosat 2 receiving station.

The Complete System

Figure 3 shows a block schematic of the complete receiving system, details of the Pre-amplifier, Down Converter and Channel Switching Unit are shown. Information on the Mapsat receiver and decoder can be found in issues 18 and 20 of 'Electronics' (XA18U and XA20W), which are available as back issues, see inside back cover.

Aerial

The aerial used is of the loop-yagi type which is fairly unusual for this kind of application, but it has several advantages over more conventional satellite receiving aerials. The relatively small size of this aerial makes mounting it a simple exercise as it can be attached to most types of standard television aerial masts, its small surface area producing a low wind resistance. The beam-width of this system is fairly broad and aligning is quite easy. The complete receiving system may be operated from batteries in the vicinity of the aerial during adjustment and this enables the aerial to be aimed for the best signal from the satellite. This type of aerial is equivalent to a small dish and has a sharp horizontal polarisation. Due to the low level and high frequency of the signals received it is important to keep feeder losses as small as possible and for this reason a high gain low noise pre-amplifier is mounted directly below the receiving element of the aerial.

Pre-amplifier

Referring to Figure 4, it will be seen that the input from the aerial is fed via C1 to the 50Ω stripline L1 which is tuned by VC1 and VC2. The other end of this line is connected to the gate of the GaAs FET TR1. The two source leads of this device are grounded, and its drain is connected to the 75Ω output stripline L3 which is tuned by VC3. The output end of L3 is connected by C9 to the 75Ω coax that in turn connects to the Down Converter. Power for the pre-amp is fed via the centre conductor, with earth return via the screen of the coax from the Down Converter. L5 isolates the power from the signal path by presenting a high impedance to the RF but a low resistance to DC. The GaAs FET requires a negative voltage on its gate, this is generated by the voltage converter IC1, and fed via preset RV1 and the RF choke L2 to the centre of the input stripline L1. The positive voltage is fed to the output stripline in a similar manner via L4. ZD1 and ZD2 are protection diodes to prevent any voltage spikes from damaging the sensitive GaAs FET. The pre-amp is supplied with 4 metres of low loss coax attached, and it should be noted that under no circumstances should this be shortened as this will affect the alignment of the pre-amp.

Down Converter

The incoming signals from the pre-amp are coupled via C1 (see Figure 5) to the input stripline of TR1; this forms an amplifier virtually identical to that of the pre-amp. The output from this stage is coupled to L7, the input stripline of the mixer GaAs FET TR2. This line is tuned by VC4 and VC5. The dual gates of this FET are also fed via C5 with signals from the oscillator/multiplier stages. The resultant output from the mixer at 137.5MHz is tuned by L6 and VC6 and fed to the output socket via C9.

Two crystals are provided to enable both channels of the satellite to be received without re-tuning the 137.5MHz receiver. The switching of these crystals is accomplished by interrupting the power to the Down Converter for set periods. The logic that detects these pulses and switches the crystals is formed by IC2 and its surrounding components. TR5 is the crystal oscillator whose collector circuit, VL1 and C23, is tuned to the overtone frequency of the selected crystal. The output from this stage is fed to the multipliers formed by TR4 and TR5 producing an output of 18 times the crystal frequency. This signal is filtered by L9 and L10 before being fed to the gate of the mixer via C5.

A 9 volt supply is fed from the Mapsat receiver via the channel switching unit and downlead coax and is isolated from the 137.5MHz signal by L5. This supply feeds the oscillator stage direct and the rest of the Down Converter via the 5 volt regulator RG1. The negative supplies for the two GaAs FETs is generated by IC1. The 5 volts required by the pre-amp is fed to SK1 via LK1 and L14 which isolates the signal path from the power supply.

Power Supplies

The power for both the Down Converter and the Aerial Pre-amplifier comes from the power unit in the Mapsat receiver via the same coaxial cable that carries signals to the receiver from the Down Converter. This simplifies the installation of the system as only one cable connects all the units together. The Channel Switching Unit (to be described in the next issue) is connected in series

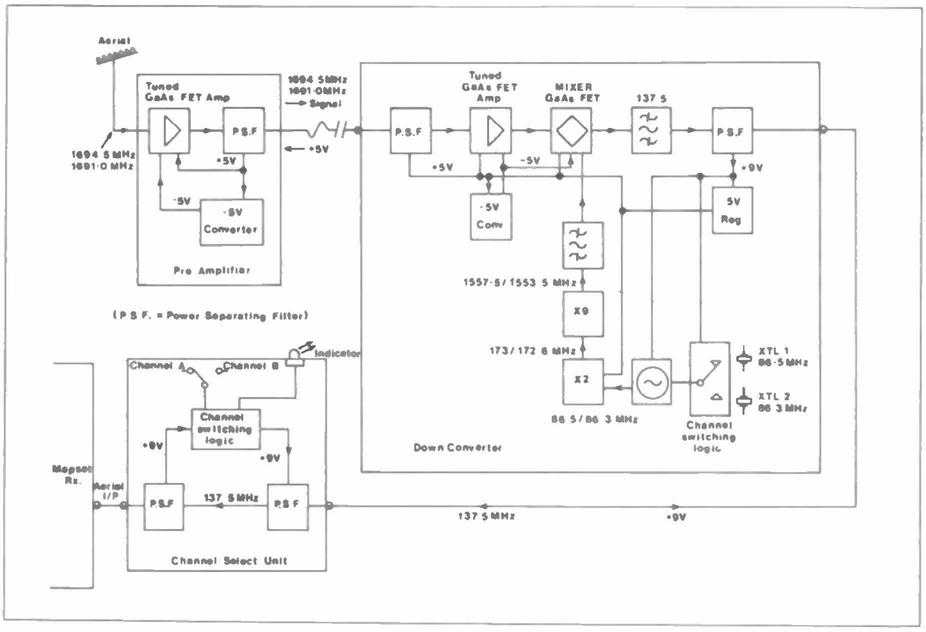


Figure 3. Block schematic of the system.

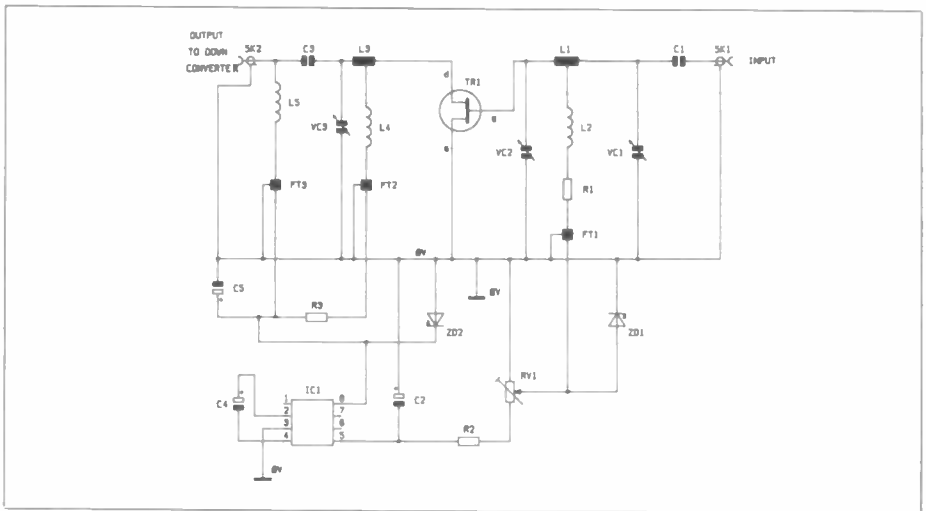
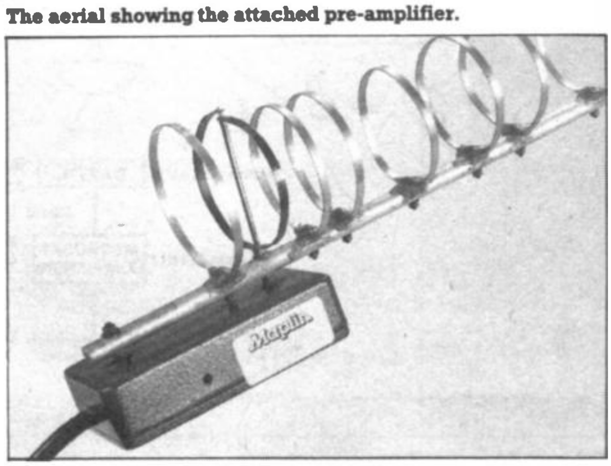


Figure 4. Pre-amplifier circuit.

The aerial showing the attached pre-amplifier.



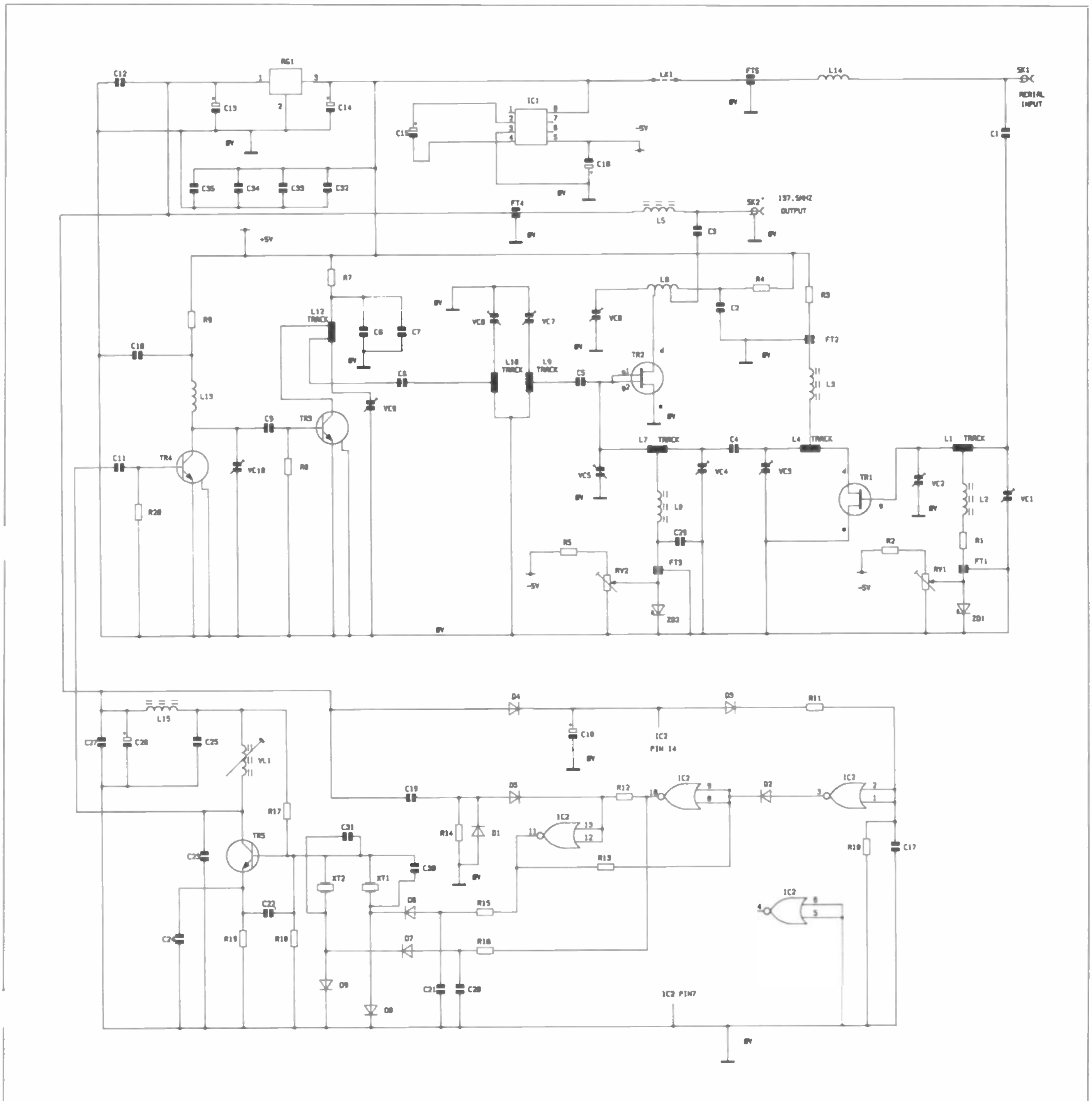


Figure 5. Down Converter circuit.

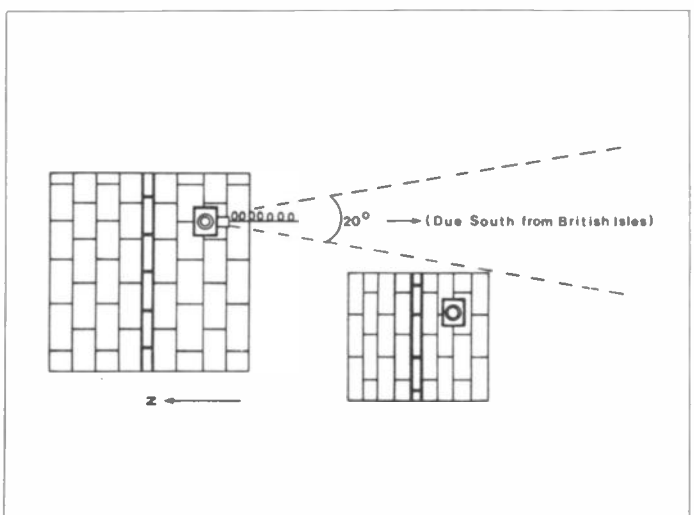


Figure 6. Aerial azimuth.

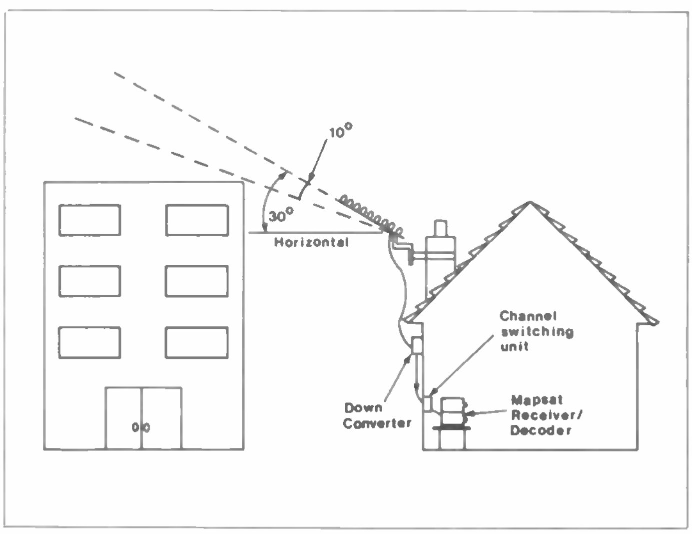


Figure 7. Aerial elevation.

with this cable at any convenient point near the Mapsat receiver.

Sighting the Aerial

The aerial *must* be positioned in such a way that it can point at clear sky in a due south direction (from the British Isles), see Figure 6, at an angle of 30 degrees above the horizon. There should also be no major obstructions below about 10 degrees of the aerial axis, see Figure 7. No mast or other aerial should be within 1 metre of the aerial other than directly behind, where there is no restriction. The angle of elevation is set by the special clamping bracket supplied with the aerial when the support mast is mounted vertically. Small changes in elevation may be affected by setting the mast off vertical in the appropriate direction. The heading and elevation of the aerial when used in other countries may be calculated from the position of the satellite above the Earth and the known height of 36,000km. Note this may require special mounting arrangements to be made. Further details of the aerial assembly and installation will be given in Part 2.

Kits

There are 3 main kits available for this project. The Down Converter kit, an Aerial and Pre-amplifier kit, and the Channnel Switching Unit kit. The Down Converter and Pre-amplifier are supplied ready-built, tested and aligned. The Channel Switching Unit and the Aerial are all that can be constructed by the hobbyist. In addition, other items will be required to complete the installation, these include a mast for the aerial, a water proof box for the Down Converter (if it is to be sited out of doors), various connectors and cable for connecting the Down Converter to the Mapsat receiver via the Channel Switching Unit. The aerial *must* be coated with a good quality polyurethane clear varnish before installation, and this can usually be obtained from your local DIY shop.

The Down Converter may be used with other aerial systems provided they produce a sufficient signal level, and do not have DC continuity across their output terminals as the Down Converter supplies power to the Pre-amplifier via the coaxial cable inner and outer conductors.

Kit parts lists are shown here for the Down Converter kit, and for the Aerial and Pre-amplifier kit; please note however that the kits will not be available until May 1987.

DOWN CONVERTER PARTS LIST

MISCELLANEOUS		
Down Converter Module	1	(YP17T)
OPTIONAL		
Waterproof Box, large	1	(YM92A)
Low-loss Coax white	As req	(XR87U)
HQ Coax Plug	2	(FD85G)

The Down Converter Module is only available ready-built and aligned, and is *not* available as a kit, and is not shown in the 1987 catalogue:
Order As YP17T (Down Converter Module) Price £79.95

AERIAL & PRE-AMPLIFIER PARTS LIST

MISCELLANEOUS		
Boom	1	
Strip D12 - 25	14	
Strip D1 - 11	11	
Strip DE	1	
Strip R	1	
RH Clamp	1	
LH Clamp	1	
Plate	1	
U Bolt and Nuts	2	
Bolt 8BA x ¾in.	3 Pkts	(FP69A)
Washer 8BA	3 Pkts	(BF23A)
Shake washer 8BA	3 Pkts	(LR01B)
Nut 8BA	3 Pkts	(BF19V)
Bolt 2BA x ½in.	1 Pkt	(BF00A)
Shake washer 2BA	1 Pkt	(BF24B)
Nut 2BA	1 Pkt	(BF16S)
Pre-amplifier Module	1	(YP18U)
OPTIONAL		
Mast 1in. to 1¼in. dia.	As req	
Mast Mounting Brackets	As req	
Polyurothane Varnish	As req	

The items listed above, excluding optional, are available as a kit:
Order As LM22Y (Aerial and Pre-amp Kit) Price £64.95
Some items are also available separately, but are not shown in our 1987 catalogue:
Pre-amplifier Module **Order As YP18U Price £35.95**
Bolt 8BA x ¾in. (pack of 10) **Order As FP69A Price 60p**

Z80 MACHINE CODE *Continued from page 45.*

Interrupt Mode 1

This interrupt mode is selected by the instruction IM1. When the INT line goes low an automatic branch is performed to the restart address &0038 and PC is pushed onto the stack. As explained previously, when discussing the use of &0066 in connection with NMI, the ISR may be made from here to an ISR somewhere in RAM.

This vectoring to a single address produces one small problem, which is what to do if there is more than one peripheral that could have initiated the interrupt. In such a case, the program will not be vectored directly to the ISR but to a form of polling program instead, similar to the one discussed earlier.

Interrupt Mode 2

The instruction IM2 sets this mode.

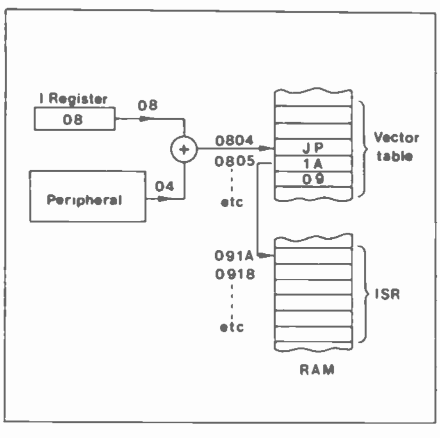
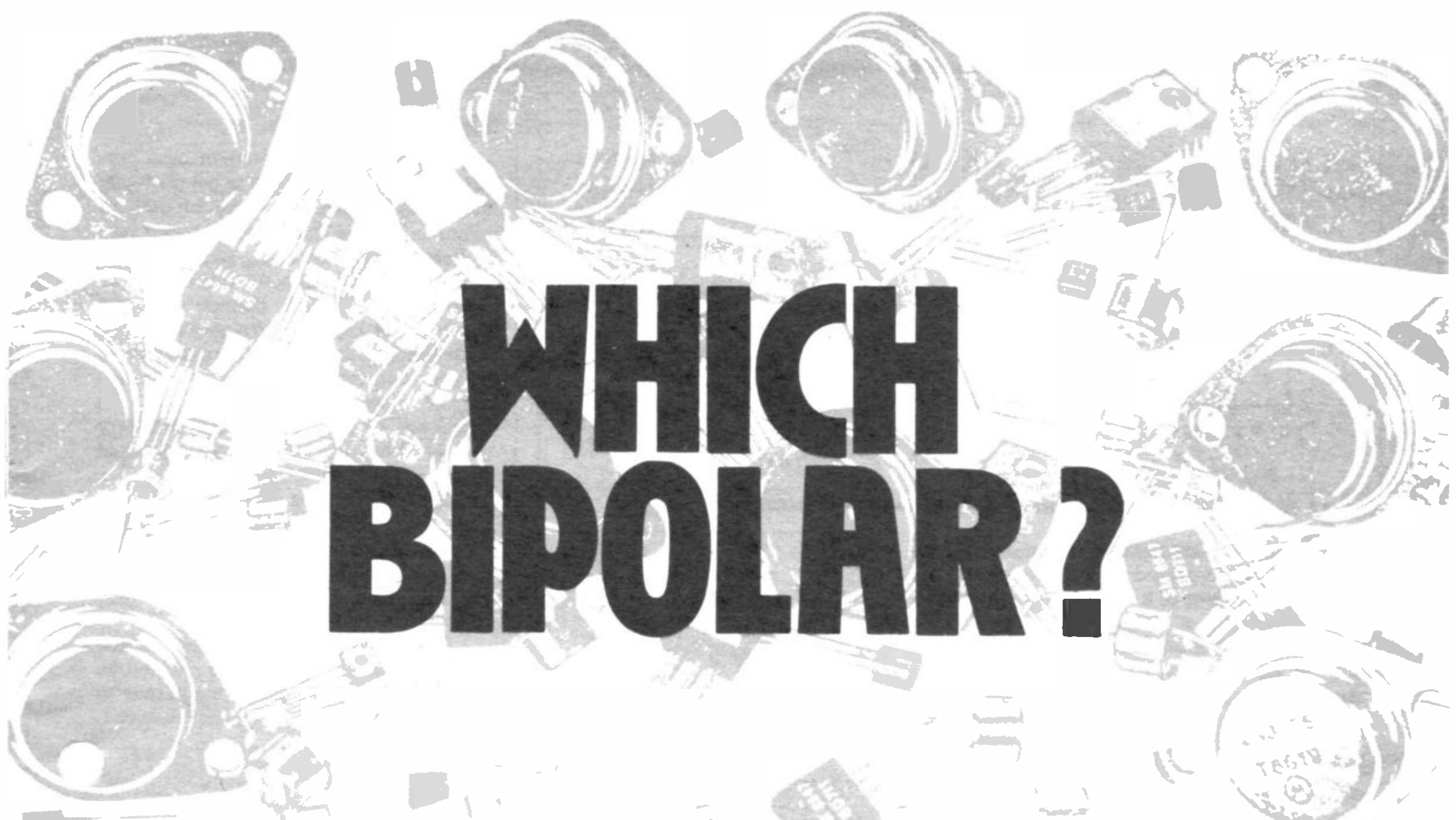


Figure 5. The Z80 'mode 2' for Interrupts.

This is the most powerful means that the Z80 has of performing automatic vectoring of interrupts. One of the special purpose registers of the Z80, the I register, or Interrupt Page Address Register, is used in this mode. It is loaded by the programmer with the high byte of the ISR address. The peripheral itself supplies the low byte, with bit 0 always set to 0. This mode is shown in Figure 5.

The vector formed in this way is one of a number contained in a table of vectors. Each of these points to an ISR elsewhere in memory.

The Z80 may be thought of as the father of a 'family' of related chips. Two others in this family are the PIO (Parallel Input/Output) and the CTC (Counter-Timer Chip). Both of these are involved in interrupt operation. A detailed discussion of programming and applying them will be given in the next part of this series.



WHICH BIPOLAR?

by J.K. Hearfield

Choosing the right transistors for a new circuit is an easier task than it might appear, despite the many thousands of different types available. Transistor manufacturers always define the range of operating conditions their devices can cope with, as well as the operating performance one can expect from them. This article explains what some of the more important parameters mean in practice, and shows how they can be used to select the best transistor for a particular application.

Basic Ideas

Let's start with the fundamentals. A bipolar junction transistor is a tiny scrap of slightly impure semiconductor with three terminals known as collector, base and emitter. A small current flowing between base and emitter controls precisely the much larger current flowing between collector and emitter.

The base of a modern transistor is its collector, which emits current collected by the emitter. The paradoxical names arise from the remorseless march of technology. Early transistors were built outwards from the base (Figure 1a), whereas modern practice is to build downwards into the collector (Figure 1b). Also, the first transistors were PNP types. Conventional current (plus-to-minus current, as opposed to electron current) flows from emitter to collector in a PNP transistor (Figure 2a) so the names are actually quite logical. Most transistors used today are NPN though, in 'negative earth' circuits, and conventional current flows through them in the opposite direction (Figure 2b).

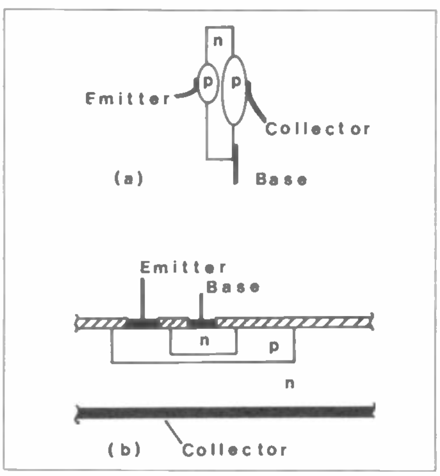


Figure 1. Early and modern transistors.

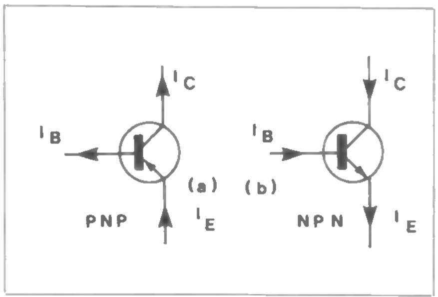


Figure 2. PNP and NPN transistors.

Characteristics

It is possible to design transistor circuits directly from the characteristic curves, but it's a much easier task if the transistor is first modelled as some simple arrangement of resistors and voltage or current generators. One such model views the transistor as an amplifier (Figure 3). The common-emitter configuration is shown here, since this is by far the most widely used. The amplifier has an input resistance of r_{in} and an output resistance of r_o and a current gain of G. The current-generator model is used instead of the more usual voltage-generator model because we happen to know that a transistor's output current is more or less proportional to its input current. Figure 4a shows how the input current (I_B) depends on the input voltage (V_{BE}), whilst Figure 4b illustrates how the output current and voltage (I_C and V_{CE}) are affected by the input current.

The input characteristic is easy to model. Since the current is almost zero when the voltage is less than about 0.7 volts and rises almost linearly when the voltage is more than 0.7 volts, the curve can be approximated as two straight lines (Figure 5a). And since a straight-line graph means that current is proportional to voltage, the graph of Figure 5a leads directly to the component model of Figure 5b. Resistor r_{in} represents the slope of the graph. For AC signals the model becomes simpler still, since the steady 0.7 volt offset can be ignored, see Figure 5c.

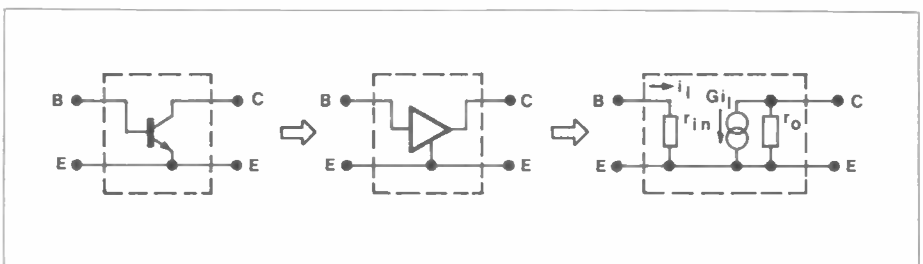


Figure 3. The transistor viewed as an amplifier.

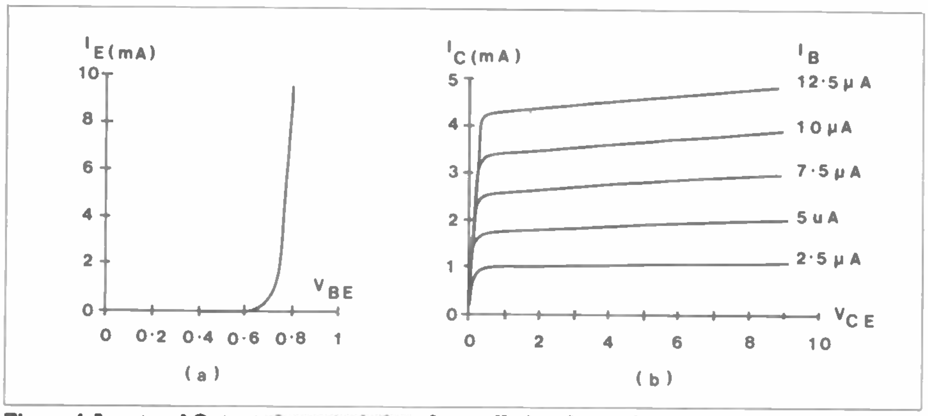


Figure 4. Input and Output characteristics of a small-signal transistor.

The output characteristics are more straightforward. Provided V_{CE} is greater than about a quarter of a volt (which can also be ignored in a simple model), the output current is directly proportional to both the output voltage and the input current. Each characteristic can be approximated as just one straight line (Figure 6a). The output resistance r_c (r_o in Figure 3) is the slope of the line. Its value may be many tens of k-ohms for a small-signal transistor operated at a few mA of collector current, though it is much lower in a power transistor carrying several amps. The current gain (G in Figure 3) is the ratio of output current to input current at zero output voltage (Figure 6b).

The model implies that no collector current flows when the base current is zero. In fact, the collector current is never quite zero. The small residual current is known as the leakage current (I_{CBO} in transistor data sheets) and whilst it is negligibly small in most silicon transistors, it can be great enough to become a problem in germanium types. For example, a BC108 at its maximum junction temperature of 150°C has a leakage current of no more than 15μA, but the leakage of a medium-power germanium device may vary from 10μA at 25°C to 1mA or more at 85°C.

Models

Figures 5c and 6b can be combined to give a perfectly serviceable model of a transistor. It's not too easy, though, because r_{in} (Figure 5c) depends in a complicated way on the base current. To get round this problem, r_{in} is usually split into two components, r_b and r_e. Resistor r_b represents the resistance from the base terminal to the actual base area, and varies from a few tens of ohms in a power transistor to a few hundred ohms in a small-signal transistor. Resistor r_e represents the slope of the base-emitter diode characteristic (I_E versus V_{BE}) at the operating point - that is, at the chosen emitter current. It turns out that the value of r_e is related to the emitter current by the expression:

$$r_e = \frac{30}{\text{Emitter current (mA)}} \text{ ohms}$$

In other words, when the emitter current is 2mA, r_e is about 15 Ω, no matter what type of transistor is being modelled. The final model is shown in Figure 7.

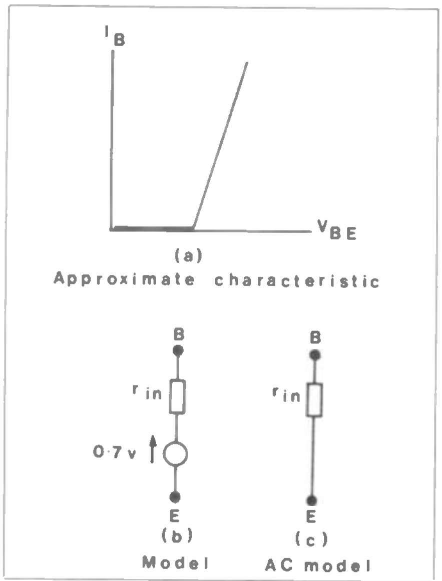


Figure 5. Input characteristic.

It must be admitted that this model is not as elegant or precise as the so-called 'h-parameter' model shown in Figure 8, but it is simple to understand and easy to use. It even accounts for the frequency-dependent behaviour of real transistors, since the current gain (h_{fe}) varies with frequency.

Current Gain

The relationship between base current and collector current is not perfectly linear, so the current gain can be defined either as h_{FE} (the ratio of collector current to base current) or as h_{fe} (the ratio of a small change in collector current to the corresponding small change in base current) see Figure 9. Whichever way it is defined, a transistor's current gain is far from constant. It depends on collector current (Figure 10) as well as on frequency (Figure 11), and it can vary greatly between apparently identical devices (Table 1).

Figure 10 shows why current gain is always specified at a particular collector current. There is no reason to suppose that the gain will be the same as the quoted value at any other collector current.

Figure 11 illustrates the importance of the parameter f_T, which is defined as the frequency at which the magnitude of the static current gain (h_{FE}) has fallen to 1.

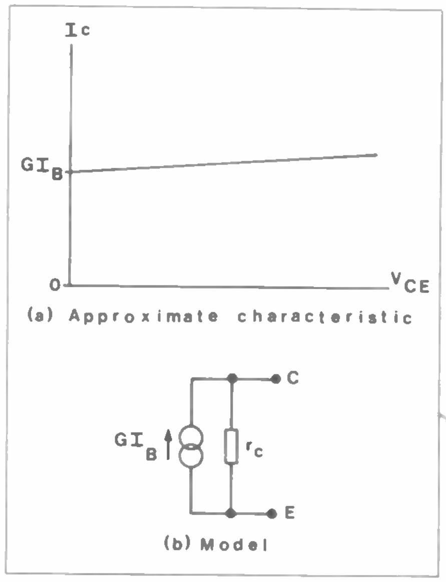


Figure 6. Output characteristic.

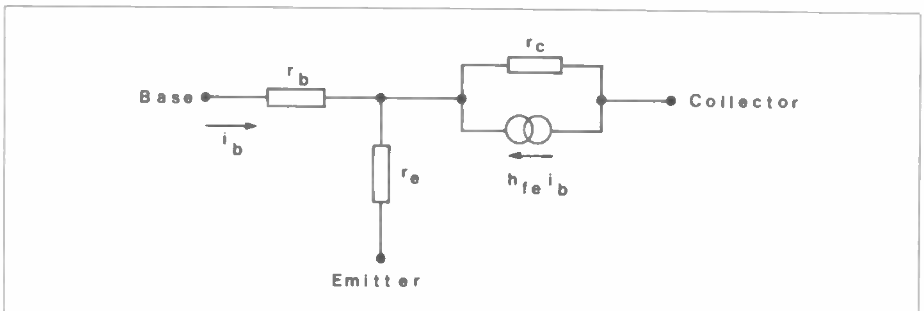


Figure 7. Transistor model.

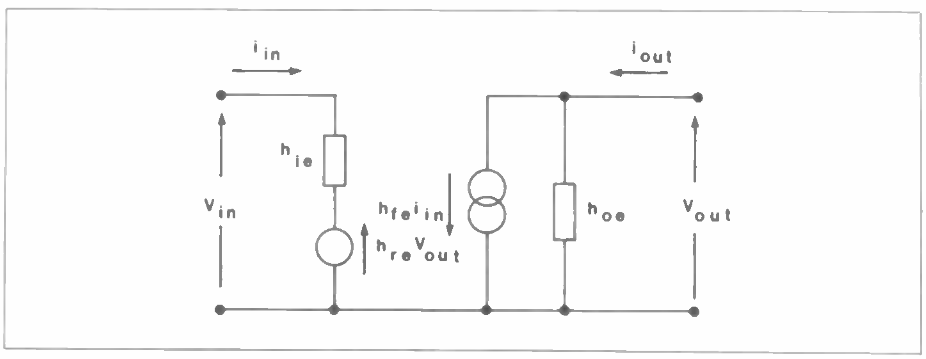


Figure 8. The h-parameter model.

Type	Ic max	VCEO max	P max	Current Gain min	max	hFE @Ic	VCE (sat) max	@Ic	fT	Price (pence)
Low noise amplifier applications										
2N3707	30	30	250	100	400	0.1	1	10	–	15
BC169C	50	20	300	450	900	2	–	–	150	15
BC109C	100	20	300	420	800	2	0.25	10	300	15
ZTX109	100	30	300	240	900	2	0.1	10	350	20
BC549	100	30	500	110	800	2	0.25	10	300	15
BC650	100	30	625	380	1400	2	–	–	300	40
BC239	100	45	300	180	450	2	–	–	280	10
General purpose amplifier and switching applications										
2N3708	30	30	250	45	660	2	1	10	–	15
2N3711	30	30	250	180	660	2	1	10	–	15
2N2926	30	18	200	35	470	2	–	–	200	10
2N706	100	20	300	20	–	10	0.6	10	150	30
BC209C	100	20	300	420	800	2	0.25	10	200	40
BC108C	100	20	300	420	800	2	0.25	10	300	15
BC168C	100	20	300	450	900	2	0.2	10	85	15
BC548	100	30	500	110	800	2	0.25	10	300	15
ZTX108	100	30	300	125	900	2	0.1	10	350	15
BC171	100	45	300	110	450	2	0.6	100	250	20
BC107B	100	45	350	200	450	2	0.25	10	300	15
BC547	100	45	500	110	800	2	0.25	10	300	15
ZTX107	100	50	300	125	900	2	0.1	10	300	15
BC183L	200	30	300	125	800	2	0.6	100	150	10
BC184L	200	30	300	200	800	2	0.6	100	150	10
2N3903	200	40	310	50	150	10	0.2	10	200	20
2N3904	200	40	310	100	300	10	0.2	10	300	20
BC182L	200	50	300	125	450	2	0.6	100	150	10
Higher current applications										
ZTX300	500	25	300	50	300	10	0.4	10	150	15
PN3643	500	30	350	100	300	150	0.22	150	250	30
ZTX302	500	35	300	100	300	10	0.3	50	200	20
ZTX304	500	70	300	50	300	10	0.4	50	150	30
2N3706	800	20	300	30	600	50	1	100	100	10
2N3705	800	30	360	50	150	50	0.8	100	100	10
2N3704	800	30	360	100	300	50	0.6	100	100	10
Higher voltage applications										
BC117	20	120	300	30	–	30	2	50	40	30
2SC2547	100	120	400	400	–	2	–	–	90	50
Darlington										
MPSA14	300	30	500	10000	–	10	1.5	100	125	35

Table 1: NPN small-signal low-frequency silicon transistors

Since h_{FE} rolls off at 20dB/decade, it follows that the current gain is constant at its lowfrequency value only up to a frequency of h_{FE}/f_T, and this can be surprisingly low. The current gain of (for example) a ZTX300 with a h_{FE} of 100 and an f_T of 150MHz begins to fall off at a signal frequency of about 650kHz.

The f_T figure is the gain-bandwidth product for the transistor. It is sometimes used as a figure-of-merit: the higher f_T the 'better' the transistor.

Switching Characteristics

A perfect switch has infinite OFF resistance, zero ON resistance, and can be switched OFF or ON in zero time. A bipolar transistor is a somewhat less than perfect switch. Leakage current flows even when the device is off; the collector-emitter voltage is never quite zero when collector current is flowing; and it takes the device a finite time to move between its conducting and non-conducting states. Transistor manufacturers specify the important switching parameters as follows:

I_{CBO} is the collector cutoff current with the emitter open-circuit. Leakage current rises exponentially with temperature. It may be a hundred times larger at a junction temperature of 90°C than at 25°C, though in silicon devices it is usually too small to worry about.

V_{CE}(sat) is the collector-emitter saturation voltage. This is the lowest value to which V_{CE} can fall at the quoted collector current (I_C) and base current (I_B). When I_B is increased to the point that any further increase makes V_{CE} only marginally smaller, the transistor is said to be saturated. The quoted values of I_C and I_B for $V_{CE\,(sat)}$ are important too, since h_{FE} may here be 10 or less. $V_{CE(sat)}$ increases with collector current.

The switching-time characteristics are best explained graphically, see Figure 12.

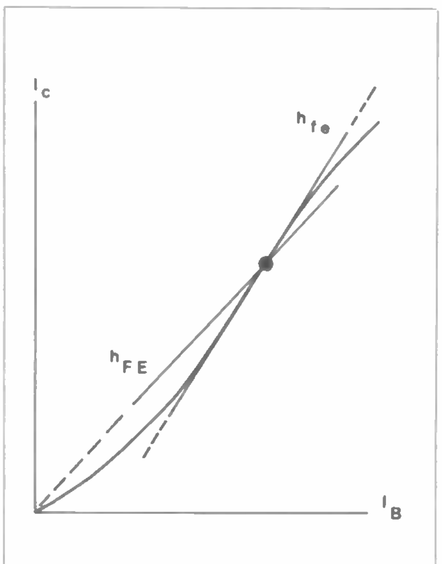


Figure 9. The difference between h_{fe} and h_{FE}.

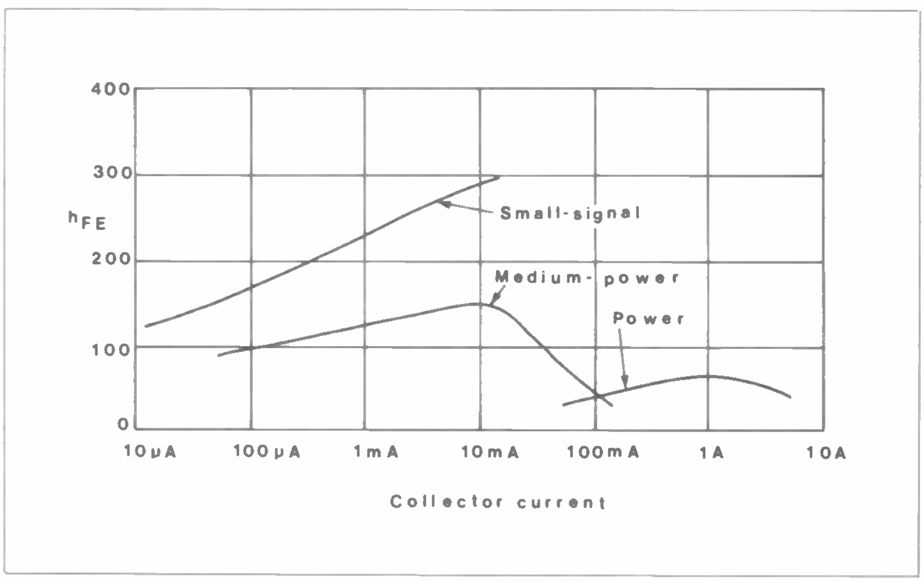


Figure 10. h_{fe} varies with collector current.

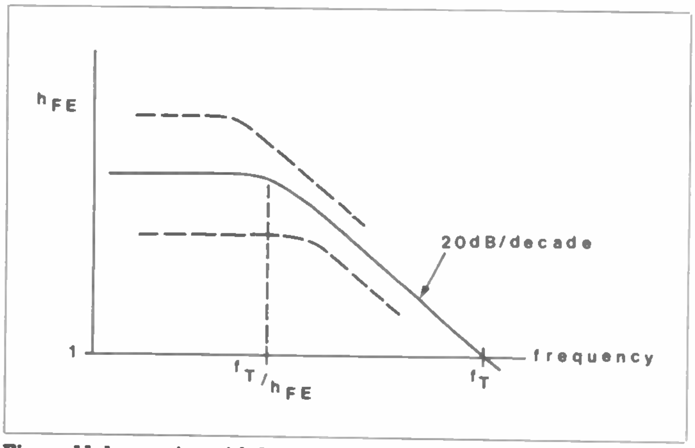


Figure 11. h_{FE} **varies with frequency.**

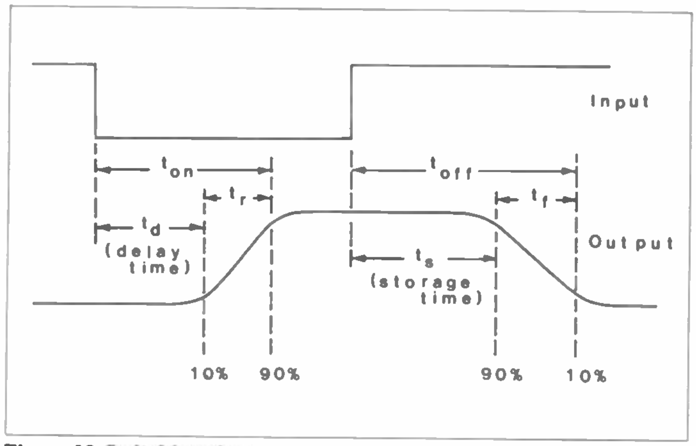


Figure 12. Switching-time parameters.

Absolute Maximum Ratings

The two junctions in a transistor (collector-base and base-emitter) each have the general characteristics shown in Figure 13. When forward-biased, a junction should not be called on to carry too much current, and when reverse-biased, it should be prevented from going into avalanche breakdown. It should also not be allowed to get too hot.

Transistor manufactuers helpfully publish figures for the highest voltage, current and power level a device can be exposed to and still work properly. It is prudent not to exceed these maximum ratings even momentarily, for even if the device survives it may be damaged, and it may fail prematurely. The more important limits are defined below:

V_{CEO} (max) is the maximum voltage that may be applied between collector and emitter with the base open circuit. This sets an upper limit on the power supply voltage a circuit may safely use, since at switch-on the full supply voltage may appear across the transistor before base current has begun to flow.

V_{CBO} (max) is the highest collector-to-base voltage the transistor can withstand with the emitter open circuit. This is the highest reverse-bias voltage that may safely be applied across the collector-base diode. It is often larger than V_{CEO}.

V_{EBO} (max) is the highest reverse-bias base-emitter voltage the transistor can withstand with the collector open circuit. This is the corresponding figure for the base-emitter diode; it is typically 5V for a silicon device. Fortunately, most circuits don't require the base-emitter junction to be reverse-biased.

I_C (max) is the highest continuous collector current the transistor can tolerate. This current is specified under pulsed conditions for some devices. The maximum safe continuous current may be less.

P_{TOT} (max) is the amount of power the transistor can safely dissipate when its case is at 25°C. This power level corresponds to the highest temperature the collector-base junction should be allowed to reach. The case is most unlikely to be at 25°C, of course.

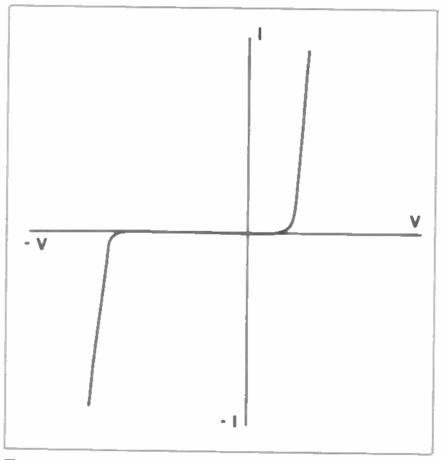


Figure 13. Junction characteristics.

Power Dissipation

Power dissipated at the collector-base junction raises its temperature. This causes heat to flow through the body of the transistor to its case, and from the case to the outside air. The temperature difference across each of these interfaces (junction-case, and case-ambient, depends on the amount of heat flowing, and also on how well each transfers the heat - that is, on the thermal resistance of each interface.

Typical figures for the thermal resistances (in °C/watt) of some common transistor packages are quoted in Table 2.

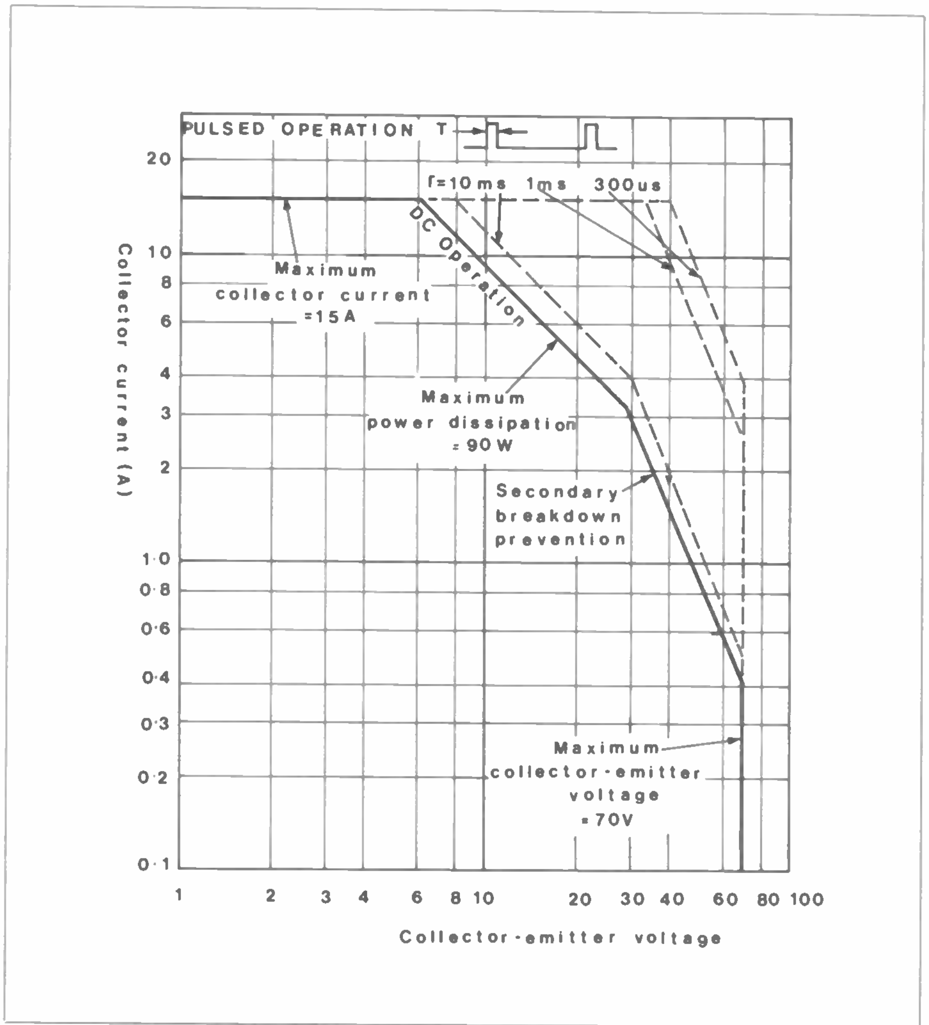


Figure 14. Safe Operating Area for a power transistor.

To see what these figures mean in practice, suppose a BC108 (in a TO-18 package) is dissipating 150mW in air warmed to 30°C. The case temperature will be:

$$T_{case} = 30 + (0.15 \times 300) = 75°C$$

And so the junction temperature will be:

$$T_j = 75 + (0.15 \times 200) = 105°C$$

Heat is transferred much more effectively from the case to the ambient air if the transistor is in good thermal contact with a heatsink. It is not difficult to see the importance of an efficient heatsink for a power transistor dissipating many watts of power.

Second Breakdown

The Safe Operating Area for a typical power transistor is shown in Figure 14. As well as specifying limits for the maximum voltage, current and power the device can handle, the graph warns of one further restriction.

Power transistors can suffer from a phenomenon known as 'second breakdown', in which the collector-emitter voltage drops abruptly to a small value and the current rises sharply (and often fatally). The problem is caused by the emitter current concentrating itself in one small area and so creating a local hotspot. The solution is to set limits for how large the current may safely be at any given collector-emitter voltage. The limits are less stringent when the transistor is switching short current pulses than for normal DC operation.

Type Numbers

Transistors are identified by means of a group of letters and figures. European practice is to use a two-letter, three-digit code (e.g. BC650). The prefix letters define the semiconductor material and the likely application area, see Table

Germanium	A	C	Low frequency, small signal
Silicon	B	D	Low frequency, power
		F	High frequency, small signal
		L	High frequency, power
		S	Switching, small signal
		U	Switching, power

Table 3. Prefix codes.

Sometimes three prefix letters are used instead of two (e.g. BCY71). The third letter indicates that the device is intended for more specialised and demanding industrial applications. The suffix letter which is also sometimes added (e.g. BC109C) identifies the device's gain (h_{FE}) range:

A	110 to 220
B	200 to 450
C	420 to 800

		Junction-Case	Case-Ambient
Metal can:	TO-18:	200	300
Plastic:	TO-92:	100	100
Metal can:	TO-39:	35	200
Plastic:	TO-220:	2	60
Metal can:	TO-3:	5	35

Table 2. Thermal resistance.

American practice is to use the JEDEC system: a four-digit code number, prefixed by one digit and one or two letters (e.g. 2N3707). The '2' indicates that the device has two junctions - in other words, that it is a bipolar transistor.

Selection

How do you choose the best transistor from the vast range on offer? Obviously, only you can decide what (if anything) is special about the application. Is it a fast switch for interfacing to TTL? Is it an RF power amplifier? The current Maplin catalogue groups together devices intended for similar applications, and Figure 15 is a guide to the 23 categories available.

Field-effect transistors are a subject all on their own, and there isn't sufficient space in this article to discuss them too (we shall do this next time), so let's assume that on this occasion only a bipolar device will do. Further, unless there is some compelling reason for choosing a germanium device - perhaps as a replacement for a failed transistor in some sensitive part of an existing circuit - it would be better not to.

The remaining bipolar silicon transistors are amplifiers and switches of varying power-handling capability, intended for either audio or RF designs. Having narrowed the choice down to one or two categories, the next step is to decide the voltage, current and power stresses the device must withstand in service. If you are not sure about these figures, some rules-of-thumb may help to guide you:

V_{CEO}(max) should be greater than the power supply voltage;

I_C(max) should be greater than the standing collector current - that is, the power supply voltage divided by the load resistance;

P_{TOT}(max) should be greater than half the product of the power supply voltage and the standing collector current.

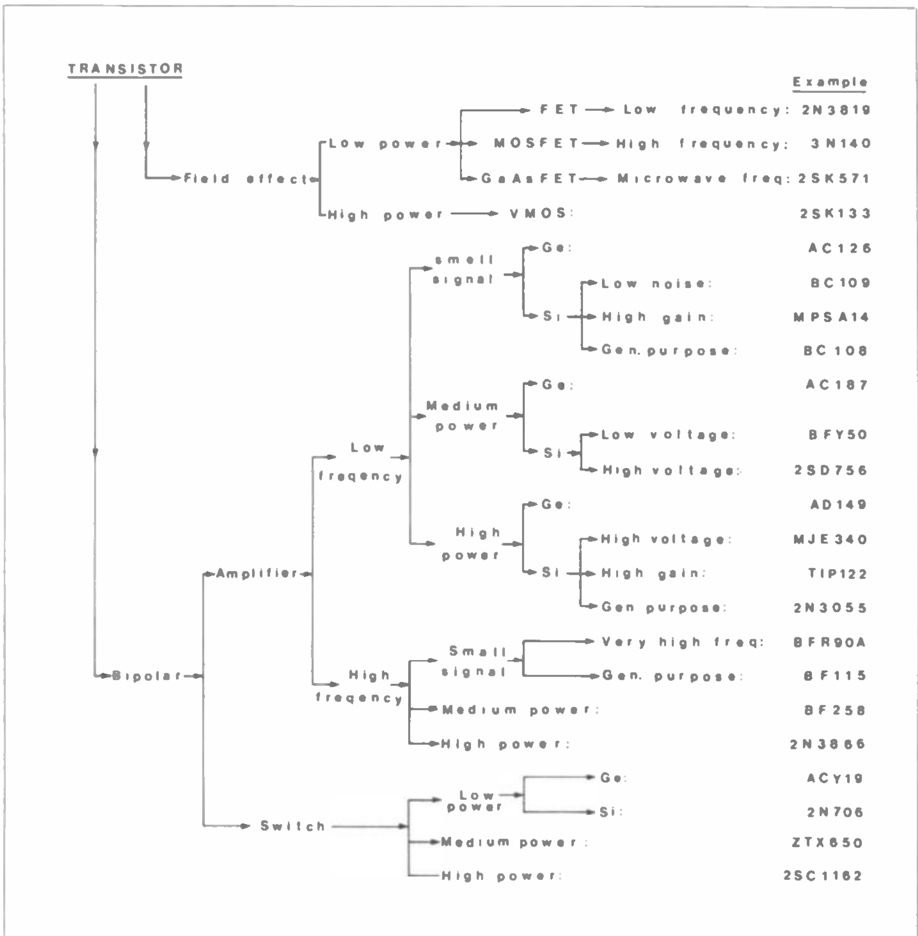


Figure 15. Choosing a transistor.

The number of possible choices should now be down to a handful, and it's time to consider the trade-off between price and performance. If the transistor must amplify small signals, how important is its noise performance? If it must switch current, how important are its turn-on and turn-off times?

Choosing a Small-signal Transistor

To illustrate these ideas, suppose a transistor must be chosen for the straightforward common-emitter amplifier shown in Figure 16.

First, what are the minimum acceptable values of V_{CEO} (max), I_C (max) and P_{TOT} (max)? The transistor is powered from +24V, so it would be reasonable to choose a device with a V_{CEO} (max) of 30V or more.

The collector current can't be more than:

$$\frac{24}{(39 + 2.4)} \text{ mA} = 0.58\text{mA}$$

In fact, since the base voltage is held at:

$$24 \times \frac{82}{(82 + 1000)} = 1.82\text{V}$$

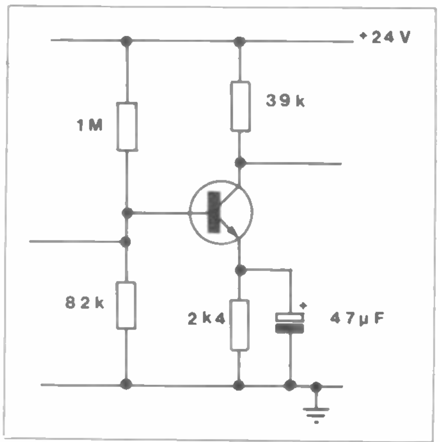


Figure 16. A common-emitter amplifier stage.

The emitter current is more likely to be around:

$$\frac{(1.82 - 0.7)}{2.4} = 0.47\text{mA}$$

So the collector-emitter voltage will be:

$$[24 - 0.47 \times (39 + 2.4)] = 4.5\text{V}$$

And the average power dissipation will be:

$$[0.47 \times 4.5] = 2.1\text{mW}$$

It's clear that I_C (max) and P_{TOT} (max) are not important criteria in this circuit.

Next, what devices are available to choose from? Table 1 lists the Maplin range of small-signal low-frequency NPN transistors, arranged in ascending order of collector current. It appears that any of the following devices would be rugged enough for the job:

2N3707, ZTX109, BC459, BC650, BC239, 2N3708, 2N3711, BC548, ZTX108, BC171, BC107B, BC547, ZTX107, BC183L, BC184L, 2N3903, 2N3904, BC182L.

Finally, how large must h_{fe} be? The bleed current through the 82k and 1M base resistors is about:

$$\frac{24}{(82+1000)} = 22\mu\text{A}$$

And this must be at least ten times the base current. It follows that the transistor's current gain must be at least:

$$\frac{0.47}{0.0022} = 214$$

So the choice boils down to either ZTX109 or a BC650. The ZTX109 is half the price of its rival, so this is the one to go for.

In the next part of this series we shall set about choosing the right Field Effect Transistor.

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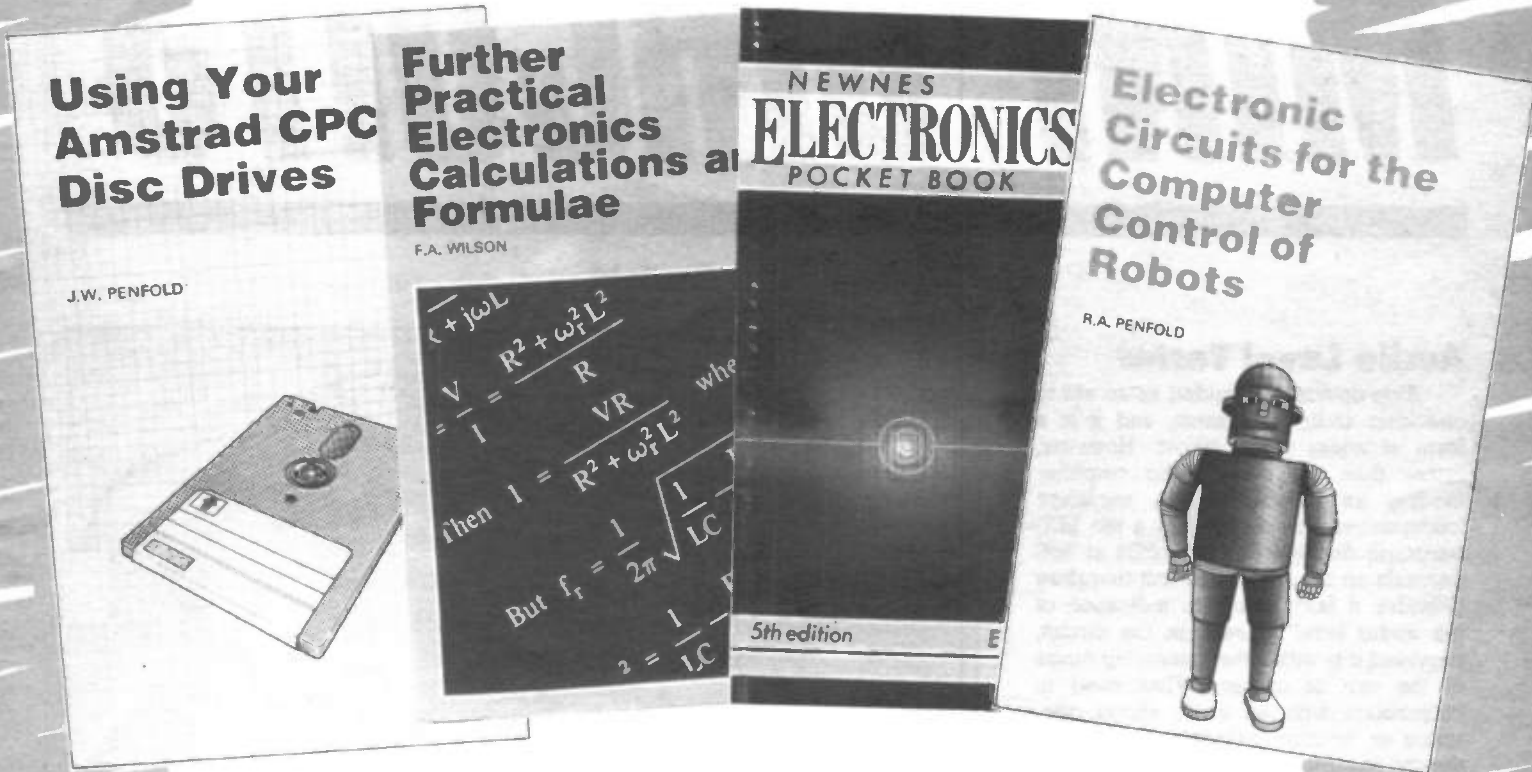

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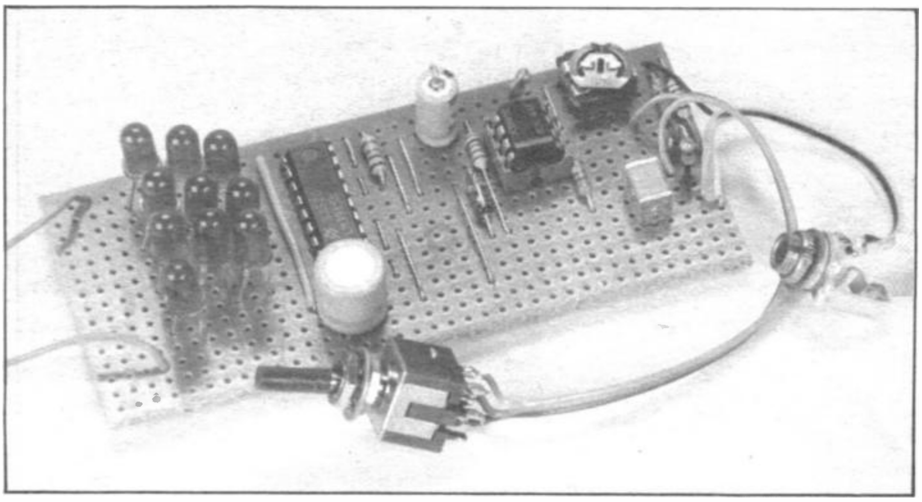
MINI-CIRCUITS

from Robert Penfold

Audio Level Tester

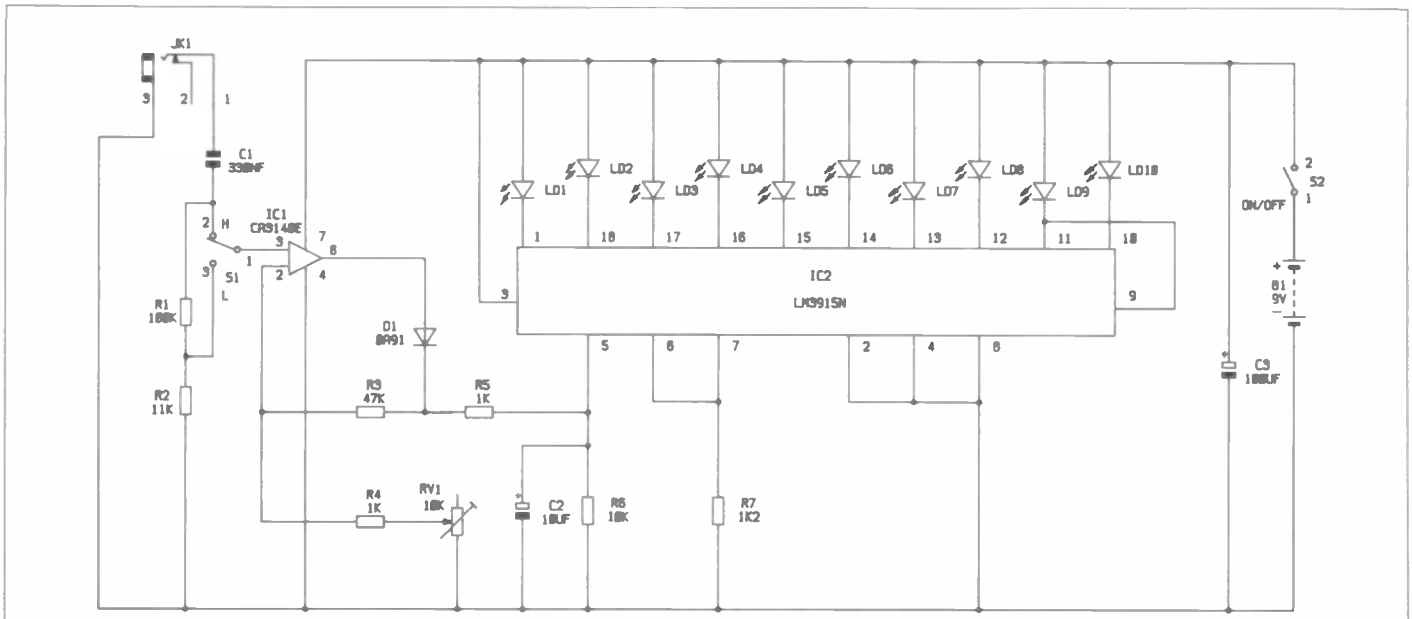
This device is intended as an aid to checking audio equipment, and it is a form of audio signal tracer. However, rather than the usual audio amplifier feeding an earphone or a miniature loudspeaker, this design has a ten LED bargraph display with the LEDs at 3dB intervals on the scale. The unit therefore provides a fairly accurate indication of the audio level present in the circuit, provided it is within the measuring range of the unit of course. When used in conjunction with an audio signal generator or function generator this makes the unit suitable for such things as voltage gain measurement and frequency response testing. In other words, it is in many ways more like a very basic audio millivolt meter than a conventional audio signal tracer, and it can often provide more meaningful results than an ordinary signal tracer. The user should be aware of the devices's weaknesses though, and these are mainly that it will not detect very low level signals, and it does not give any idea of the waveform that it is measuring. It is therefore useless trying to test something like a low impedance dynamic microphone (with its sub 1 millivolt RMS output level) using this tester, or searching for the stage in an amplifier which is producing clipping. Like virtually any simple piece of test gear, it can be very helpful and worthwhile if used thoughtfully and in the right context, and worse than useless if it is not.



Circuit Operation

The circuit is similar to that of a LED audio level indicator, and it could actually be used in this role if desired. Basically the unit comprises a precision half wave rectifier driving a smoothing circuit and a bargraph driver.

Looking at the circuit in more detail, IC1 is the active device in the precision rectifier, which is a simple half wave type. For reasonably accurate results with low level signals, it is essential to use some form of active circuit in order to overcome the inherent non-linearity of semiconductor diodes. This lack of linearity is most severe with silicon devices which require a forward bias of about 0.5 volts or so before they will start



Audio Level Tester

to conduct significantly. In this circuit a germanium type is used, and although these offer much improved performance on low level signals, they still need some external assistance in order to give really good results.

In this circuit, the standard approach of including the diode in the negative feedback look of an amplifier has been adopted. This boosts the output voltage of the amplifier by an amount which is equal to the voltage drop through the diode, and this exactly compensates for the forward voltage drop. The gain of the amplifier has been made variable by means of RV1 to permit calibration of the unit. R1 and R2 form a simple 0dB/−20dB attenuator at the input of the unit, and this enables the sensitivity of the unit to be cut by a factor of ten so that relatively high level signals can be accommodated.

The bargraph driver is an LM3915N logarithmic type which has 3dB increments between the LEDs. Here it is in red in the 'dot' mode and it does not provide a true bargraph display. This gives slightly less clear results, but the current consumption is substantially reduced so that the unit can be powered from a small 9 volt battery if desired. C2 smooths the input signal to the bargraph driver, and this is important as the signal would otherwise be varying at a very fast rate making the display dim and blurred. R7 sets the LED current at approximately 10 milliamps.

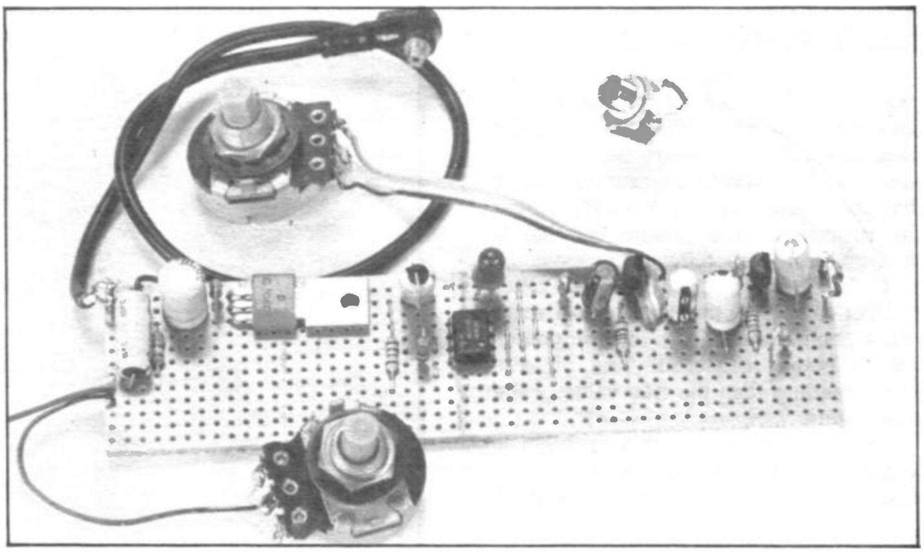
Construction

There are two basic constructional forms that can be used with a device of this type. The first method is to build it as a conventional instrument with a set of screened test leads which connect to JK1. The second approach, and perhaps the better one, is to build the unit as a probe, with C1 connecting to the probe tip and an earthing lead fitted with a crocodile clip connecting to the negative supply rail (JK1 then being omitted). The gain of the circuit is not particularly high, and at 111k the input impedance is only moderately high, and the component layout is not all that critical, although reasonable care needs to be taken with the layout of any fairly sensitive audio circuit. On the prototype the LEDs are ten separate 5 millimetre types. A proper bargraph can be used if perferred and will give the unit a neat appearance, albeit at a greater cost.

RV1 is adjusted to give the desired full scale sensitivity, which can be anything from under 100 millivolts peak to peak, to over 800 millivolts peak to peak with S1 in the 'H' position. With it set to the low sensitivity 'L' position the full scale voltage is boosted by a factor of ten. The best setting to use is to some extent a matter of personal preference, and also depends to some degree on the equipment that will be tested, but a full scale value of about 200 millivolts peak to peak with S1 at the 'H' setting probably gives coverage of the most useful dynamic range.

Sound Triggered Flash

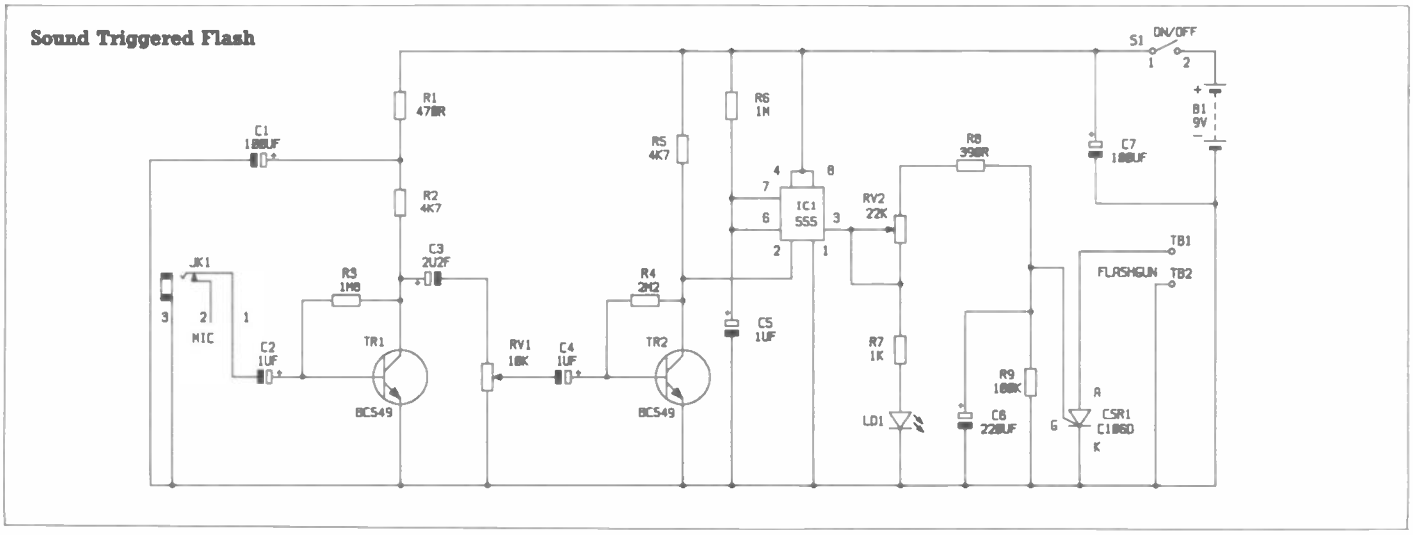
With the aid of an automatic flashgun trigger, it is possible to take a variety of action shots that would be practically impossible by any other means, and which would take innumerable attempts in order to catch just the right moment. The most popular form of automatic trigger is probably the sound triggered type. These are suitable for shots such as balloons in mid-burst, water splashes, champagne corks 'popping', etc., and the very short duration of the output from an electronic flashgun usually 'freezes' the action well enough to give a sharp image. Of course, shots of this type must be taken under quite dark conditions as the camera's shutter must be set to 'Bulb' and left open for a few seconds while the exposure is made, and shots really need to be carefully set up and rehearsed if a lot of wasted film is to be avoided.



Circuit Operation

This unit is designed primarily for use with a low impedance dynamic microphone (the type used with inexpensive cassette recorders), although it will function reasonably well with crystal, high impedance dynamic types, or types which have similar output characteristics to the latter. With any of these types of microphone the output level is only going to be something in the region of 1 millivolt, and a considerable amount of amplification is needed in order to boost the signal to a level that can drive a switching device of some

Sound Triggered Flash



kind. In this case a two stage common emitter amplifier is used, and this provides over 80dB of voltage gain. RV1 is the gain control, and it is generally advisable to have the gain no higher than is really necessary as this would almost certainly result in frequent spurious triggering of flashgun, and possibly a lot of wasted frames.

The output from the amplifier is used to trigger a monostable based on 555 timer device IC1. This gives a nominal output pulse duration of 1.1 seconds, and it activates LED1 to show that the unit has been triggered properly. This is of little value in normal use when the flashgun will obviously fire if the unit is triggered properly, but it is very useful for 'dry' runs when preparing to take a shot. The output pulse from IC1 is also used to trigger a thyristor which in turn activates the flashgun. RV2, R8 and C6 provide a variable delay before triggering occurs, and this is useful for taking a sequence of shots to show (say) a balloon at the instant it starts to burst and the first tears that start to appear in it, through to the point where it has fully collapsed. Note that the distance from the sound source to the microphone also introduces a small delay, and for rapid triggering this distance should be as short as possible. If very fast triggering is required it would also be advantageous to include a switch to permit C6 to be cut out of circuit.

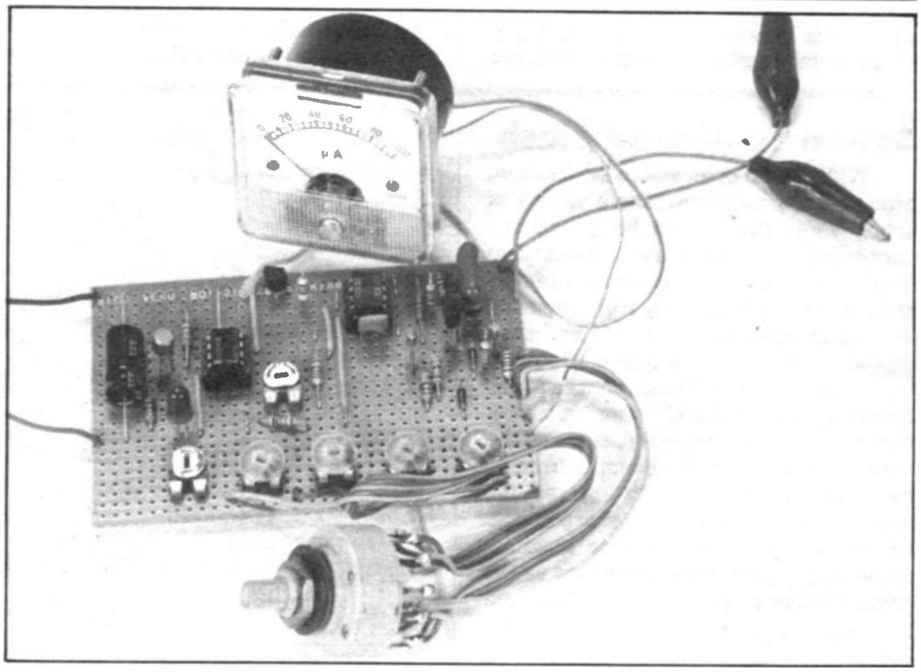
Construction

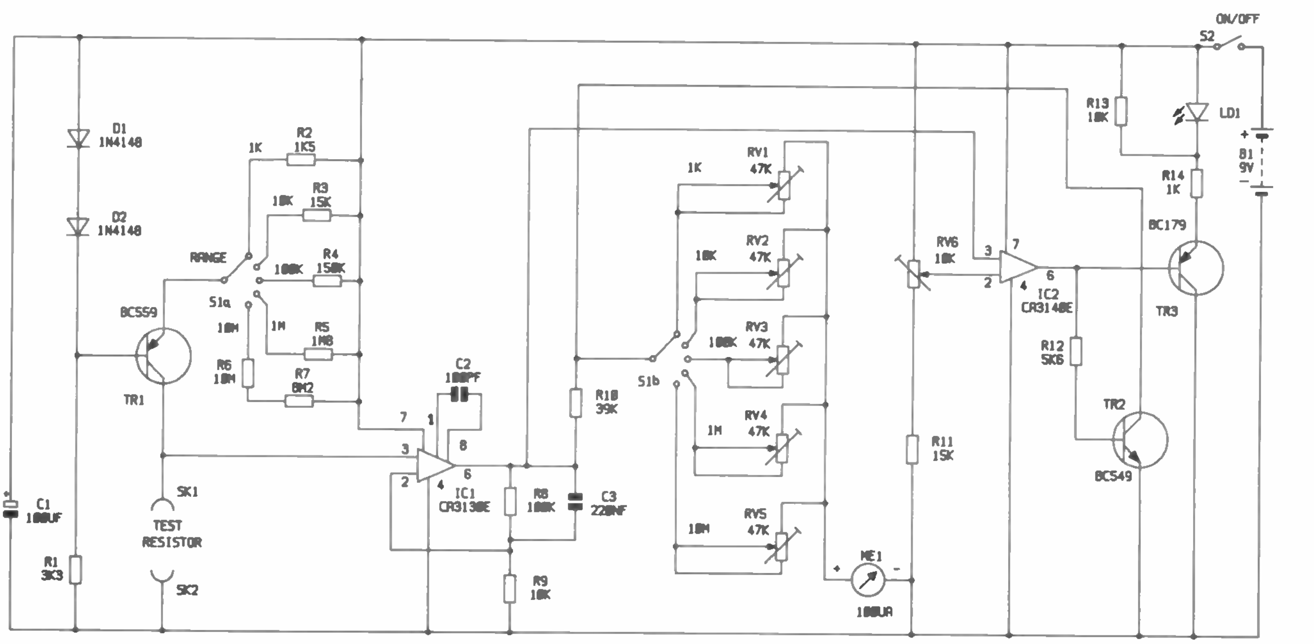
The amplifier section of the unit has quite a high level of voltage gain, and consequently the component layout for this section of the unit needs to be designed with suitable care. An output socket to suit the miniature coaxial plugs fitted to flashgun leads might be obtainable from a large camera accessory stockist, but a simple alternative is to use a socket and short piece of lead cut from a flash extension lead. The lead must be connected through to CSR1 with the correct polarity, and this is something that can be checked using a multimeter set to a high DC voltage range. CSR1 will not be damaged if the lead is connected with the wrong polarity, and it is therefore quite alright to determine the correct method of connection using trial and error. Note that the circuit will only function properly with a sensitive thyristor such as the C106D, which will trigger from a gate current of well under a milliamp, which precludes most other devices from use in the unit.

In-Circuit Resistance Meter

Accurately measuring the value of a resistor that is out of circuit usually presents no great problem, and even the most basic of multimeters usually has a number of resistance measuring ranges that cover most likely values. Measuring the resistance of a component that is in-circuit is a very different proposition, and there is the problem of other components in the circuit placing resistance in parallel with the component that is being measured. This gives a lower reading than the true value of the component.

In modern circuits this problem is largely due to the semiconductors in the circuit rather than other resistors.





In-circuit Resistance Meter

Semiconductor junctions (which can be in diodes, transistors, integrated circuits, or practically any semiconductor component) are often forward biased by the voltage source in the multimeter, and this results in a very low reading. Sometimes simply reversing the test leads will cure the problem, but although this might eliminate the original junction by reverse biasing it, it may well forward bias a second junction and re-introduce the problem.

The most simple solution to the problem is to use a resistance measuring circuit that operates with a maximum voltage across the test resistance that is too low to bring a silicon semiconductor junction beyond the threshold of conduction. This means keeping the voltage down below about 0.4 volts, which is substantially less than that used by most resistance measuring devices. It must be stressed that this system should eliminate the shunting effect of semiconductor junctions, but it will not cut out any pure resistance in parallel with the component under test. Very often there will be no significant resistances of this kind, but if a low reading is obtained one lead of the resistor should be disconnected from the board to isolate the component from any parallel resistance, and the check then repeated. Of course, if an excessive resistance reading is obtained this certainly means that the device under test is a 'dud' (or you have forgotten to switch off the supply before starting work on the equipment!).

Circuit Operation

The unit operates on the well established principle of supplying a constant current to the test component, and then measuring the voltage developed across it (which is proportional to its resistance value). A point in favour of this system is that it gives a forward reading linear scale rather than the reverse reading logarithmic type of a conventional analogue instrument.

In this circuit TR1 operates as a standard constant current source, and the five switched emitter resistances provide five output currents. These give the unit measuring ranges having full scale values of 1k, 10k, 100k, 1M and 10M. Normally with circuits of this type low resistance ranges cause problems as they require quite high test currents. In this case the currents are relatively low, and it would be acceptable to add a 100Ω range if desired by using the otherwise unused position of S1 to switch a 150Ω resistor into circuit. This still only gives a test current of about 4.3 milliamps. An advantage of the low test currents and voltages is that there is little risk of damaging anything in the circuit under test. On the other hand, it does mean that the voltmeter section of the unit must have an extremely high input impedance in order to give good accuracy, particularly on the higher ranges. This requirement is fulfilled by using an operational amplifier having a MOSFET input stage to provide buffering and a certain amount of voltage amplification. C3 rolls off the frequency response of this stage to avoid problems with stray pick-up of mains 'hum' and other noise. There is a separate preset resistor for each range in the voltmeter circuit (switched by S1b) so that each range can be individually calibrated.

With no test resistance the meter will be driven beyond full scale deflection. In order to avoid this, IC2 is used to detect an excessive output voltage from IC1 and to switch on TR2 which diverts the output current from the meter. This could cause confusion, where it is unclear whether the meter is showing a low and valid reading, or an overload is being suppressed. LED1 avoids this by lighting up when a valid reading is present.

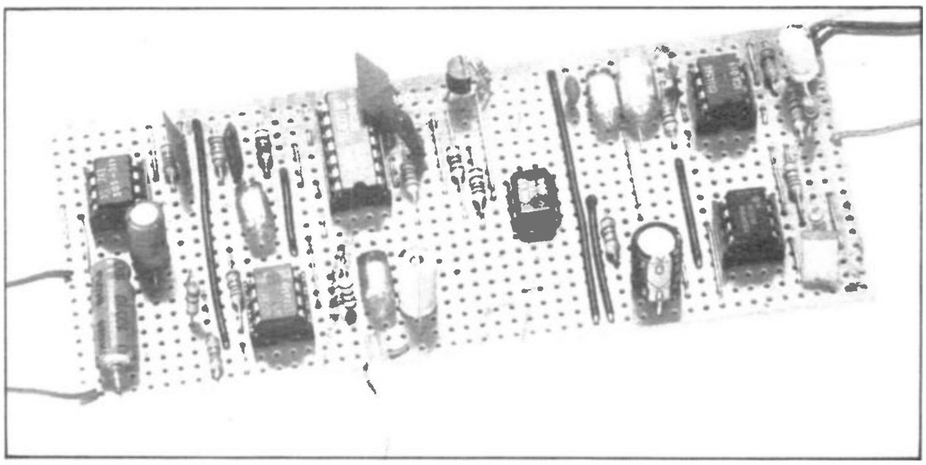
Construction

The unit offers little that is difficult as far as construction is concerned, but bear in mind that both integrated circuits are MOS types and consequently require the usual antistatic handling precautions. For calibration purposes five 1% resistors are required, and these should have values equal to the full scale values (1k, 10k, etc). It is just a matter of connecting the appropriate resistor for the range that is being calibrated, and then adjusting the correct preset for precisely full scale reading on the meter. RV6 is given any setting that permits a full scale reading to be obtained, but which also suppresses the meter with no test resistor connected, and its exact setting will probably not be critical.

Audio Isolator

It is sometimes necessary to couple an audio signal from a piece of equipment without making any direct connection to the equipment. The most common example of this is where a headphone or tape output is required from a television or other item of gear which has a 'live' chassis, and the isolation is required to avoid problems with electric shocks and short circuits to Earth. Another use for an audio isolator is where (say) a number of musical instruments are connected together and there are problems with 'hum' loops. the easiest solution to the problem is to use an isolation transformer, but in practice suitable components seem to be unobtainable. Where an output is required from a circuit that has a 'live' chassis, even if a transformer with the right input/output characteristics could be obtained, that is not to say that it would necessarily guarantee to withstand a few hundred volts without breaking down.

What is generally a more satisfactory solution to the problem is to use an opto-isolator plus some simple electronics to provide the signal transfer, and that is precisely what this circuit does. It has to be emphasised that if the unit is to be used to provide an isolated output on equipment which has a 'live' chassis, it is essential that the person installing it knows exactly what they are doing and have the requisite experience to undertake this task. This is quite definitely not a beginners project, and is potentially very dangerous if used incorrectly with 'live' chassis equipment.



Circuit Operation

The obvious method of using the audio input signal to vary the input current to the LED in the opto-isolator, and then taking the audio output from a load resistor on the transistor side of the device does not generally work well in practice. The two problems that compromise results are rather poor linearity through the system, and a vulnerability to the pick-up of 'hum' and other electrical noise. Better results are usually obtained using an ultrasonic carrier wave having either pulse width or frequency modulation. In this circuit frequency modulation is used.

On the input side of the unit IC1a acts as a buffer amplifier which gives an input impedance of about 50k, and IC1b is the buffer stage in an active third order lowpass filter. This prevents high frequency signals from reacting with the carrier signal to give distortion products

AUDIO LEVEL TESTER PARTS LIST

RESISTORS: All 0.6W 1% Metal Film

R1	100k	1	(M100K)
R2	11k	1	(M11K)
R3	47k	1	(M47K)
R4,5	1k	2	(M1K)
R6	10k	1	(M10K)
R7	1k2	1	(M1K2)
RV1	10k Hor Sub-min Preset	1	(WR58N)
CAPACITORS			
C1	330nF Poly Layer	1	(WW47B)
C2	10µF 50V PC Electrolytic	1	(FF04E)
C3	100µF 10V PC Electrolytic	1	(FF10L)
SEMICONDUCTORS			
IC1	CA3140E	1	(QH29G)
IC2	LM3915N	1	(YY96E)
D1	0A91	1	(QH72P)
D2-11	Red LED	10	(WL27E)
MISCELLANEOUS			
JK1	3.5mm Jack Socket	1	(HF82D)
S1	SPDT min Toggle	1	(FH98G)
S2	SPST min Toggle	1	(FH97S)
B1	9V (PP3 size) Battery	1	(FK62S)
	Battery Clip	1	(HF28F)

SOUND TRIGGERED FLASH PARTS LIST

RESISTORS: All 0.6W 1% Metal Film

R1	470R	1	(M470R)
R2,5	4k7	2	(M4K7)
R3	1M8	1	(M1M8)
R4	2M2	1	(M2M2)
R6	1M	1	(M1M)
R7	1k	1	(M1K)
R8	390R	1	(M390R)
R9	100k	1	(M100K)
RV1	10k LOG Pot	1	(FW22Y)
RV2	22k LIN Pot	1	(FW03D)
CAPACITORS			
C1,7	100µF 10V PC Electrolytic	2	(FF10L)
C2,4,5	1µF 100V PC Electrolytic	3	(FF01B)
C3	2µ2F 100V PC Electrolytic	1	(FF02C)
C6	220µF 16V PC Electrolytic	1	(FF13P)
SEMICONDUCTORS			
IC1	NE555	1	(QH66W)
TR1,2	BC549	2	(QQ15R)
LED1	Red LED	1	(WL27E)
CSR1	C106D	1	(QH30H)
MISCELLANEOUS			
S1	SPST min Toggle	1	(FH97F)
B1	9 volt (PP3 size) Battery	1	(FK62S)
SK1	3.5mm Jack Socket	1	(HF82D)
SK2	Min. coax socket (see text)		
	Microphone and plug	1	(YB31J)

IN-CIRCUIT RESISTANCE METER PARTS LIST

RESISTORS: All 0.6W 1% Metal Film

R1	3k3	1	(M3K3)
R2	1k5	1	(M1K5)
R3,11	15k	2	(M15K)
R4	150k	1	(M150K)
R5	1M8	1	(M1M8)
R6	10M	1	(M10M)
R7	8M2	1	(M8M2)
R8	100k	1	(M100K)
R9,13	10k	2	(M10K)
R10	39k	1	(M39K)
R12	5k6	1	(M5K6)
R14	1k	1	(M1K)
RV1-5	47k Sub-min Hor Preset	5	(WR60Q)
RV6	10k Sub-min Hor Preset	1	(WR58N)
CAPACITORS			
C1	100µF 10V PC Electrolytic	1	(FF10L)
C2	100pF Ceramic	1	(WX56L)
C3	220nF Poly Layer	1	(WW45Y)
SEMICONDUCTORS			
IC1	CA3130E	1	(QH28F)
IC2	CA3140E	1	(QH29G)
TR1	BC559	1	(QQ18U)
TR2	BC549	1	(QQ15R)
TR3	BC179	1	(QB54J)
D1,2	1N4148	2	(QL80B)
LED1	LED Red	1	(WL27E)
MISCELLANEOUS			
S1	6-way 2-pole Rotary Switch	1	(FH43W)
S2	SPST Sub-min Toggle	1	(FH97F)
ME1	100µA Panel Meter	1	(RW92A)
SK1,2	2mm socket	2	(HF24X)
B1	9 volt (PP3) Battery	1	(FK62S)
	Battery clip	1	(HF28F)
	8 pin DIL IC holder	2	(BL17T)

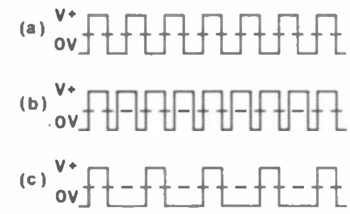
AUDIO ISOLATOR PARTS LIST

RESISTORS: All 0.6- 1% Metal Film

R1,2	100k	2	(M100K)
R3,4,5,7,11,12,13,14,18	10k	9	(M10K)
R6	4k7	1	(M4K7)
R8	1k2	1	(M1K2)
R9	470R	1	(M470R)
R10	2k2	1	(M2K2)
R16,17	47k	2	(M47K)
R18	2k7	1	(M2K7)
R19	5k6	1	(M5K6)
CAPACITORS			
C1,15	100µF 10V PC Electrolytic	2	(FF10L)
C2	1µF 100V PC Electrolytic	1	(FF01B)
C3	2n2F Poly Layer	1	(WW24B)
C4	3n3F Poly Layer	1	(WW25C)
C5	220pF Polystyrene	1	(BX30H)
C6	330pF Polystyrene	1	(BX31J)
C7,9,14	1nF Poly Layer	3	(WW22Y)
C8	680pF Polystyrene	1	(BX34M)
C10	4n7F Poly Layer	1	(WW26D)
C11	180pF Ceramic	1	(WX59P)
C12	4µ7F 63V PC Electrolytic	1	(FF03D)
C13	10µF 50V PC Electrolytic	1	(FF04E)
SEMICONDUCTORS			
IC1	1458C	1	(QH46A)
IC2	NE555	1	(QH66W)
IC3	4001BE	1	(QX01B)
IC4,5	µA741C 8 pin DIL	2	(QL22Y)
OPTO1	Single Opto-isolator	1	(WL35Q)
MISCELLANEOUS			
JK1	3.5mm Jack Socket	1	(HF82D)
	14 pin DIL IC Socket	1	(BL18U)

on the output. The carrier oscillator is a 555 astable circuit which is modulated by the normal means of coupling the audio input signal to pin 5. The carrier frequency is around 100kHz incidentally. IC2 drives the LED in the opto-isolator via current limiting resistor R8.

Unfortunately, ordinary opto-isolators are not particularly fast in operation, and the output signal across load resistor R9 is a fairly weak triangular waveform. This is amplified by TR1 though, which gives a virtual square wave output signal having quite fast rise and fall times. The F.M. demodulator is a monostable circuit which is formed by two of the 2 input NOR gates of IC3. A monostable might seem to be an unlikely form of F.M. demodulator, but it can work very well in this roll. Under quiescent conditions the output waveform of the monostable is a squarewave signal, as shown in (a) of the



Waveform

waveform diagram. If the input frequency is increased, the output pulse length remains the same, and the gap between the pulses narrows (as in (b)). With reduced input frequency the duration between output pulses increases, giving a waveform of the type shown in (c). The point here is that the average output voltage varies in sympathy with changes in the input frequency, and there is a linear relationship between the two.

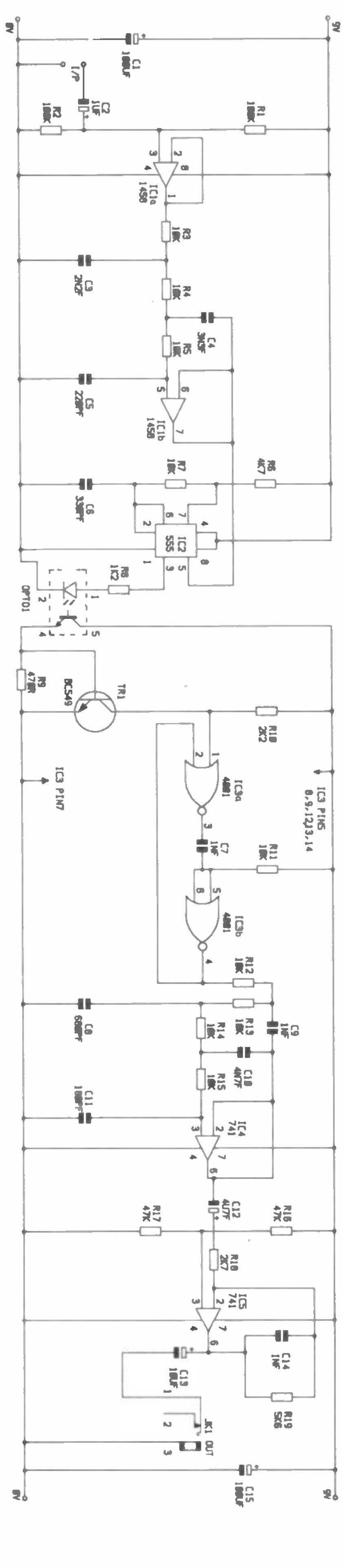
In order to recover the demodulated audio signal a lowpass filter is needed, and it must give a high degree of attenuation in order to give an output signal that contains an insignificant carrier content. In this circuit a 24dB per octave active filter is used. This is followed by a low gain amplifier based on IC5 which gives a further stage of filtering. This also boosts the output signal slightly so that there is approximately unity voltage gain through the unit.

Construction

The main point to check when constructing the unit is that there is no path of conduction through the unit. It is worthwhile checking the finished unit with a multimeter set to a high resistance range to ensure that no connection through the unit has been inadvertently left. It may be possible to tap off the supply for the input side of the circuit from the equipment which supplies the input signal, but the output side of the unit must, of course, have an entirely separate and safe power source.

As far as audio quality is concerned the unit is not up to true hi-fi standards, and it has something less than the full audio bandwidth. It provides a very acceptable level of performance though, and is more than adequate for most purposes.

Audio Isolator



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For the next issue your advertisement must be in our hands by 28th March 1987.

VARIOUS FOR SALE

AVRO MULTIMETER Model 9 Mk4. Excellent condition. Comes complete with leads, prods, crocodile clips (2 pairs), instruction manual & new battery. Very reliable, high quality meter. £50 bargain. Mr. K. Lord 82 Rossfold Road, Sundon Park, Luton, Beds. LU3 3HH.

OSCILLOSCOPE SOLARSCOPE CD1014-3 £25: 10W amp 12V £12: Multirecorder Cutec MR402 4-track home studio tapes speed 9.5cm/s £210: Icom IC2E £105: Foster microphone XLR £20: Cardioid microphone high/low imp. XLR £20. Tel. 0484 548392 or 25589.

MAPLIN MODEM fully tested, as new, £45. Pair JPW hi-fi speakers with stands, £75. Various hobbyist's bits & pieces, send for list. Toms, 212 Teignmouth Road, Torquay TQ1 4RX. (0803) 35177.

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KIKUSUI MODEL 538A single beam oscilloscope, as new. £200. Tel. (0484) 540133. Evenings only.

GOULD ALPHA 4 bench model digital multimeter, input impedance 22 MΩ, 0.2% acc., 3.5 digits, LCD, £45. Epson FX80 printer £160, Shinwa CP-80 printer £110. Oric MCP40 printer/plotter £40. Contact Mel Saunders, 7 Drumcliff Road, Thurnby Lodge, Leicester, LE5 2LH.

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SPECTRUM SYNTHESISER fully & carefully built, fitted into stylish black vinyl covered cabinet. Component cost over £200. Will sell for £130. Tel. Neil Brook (0772) 774650 (Preston, Lancs.)

MAPLIN MATINEE ORGAN October 1984, nearest £200, buyer collects. Tel. Ramsey (0487) 813353 (Huntingdon).

MAPLIN 3800 SYNTHESISER untidy but in good working order. £150. Abandoned MES53/54/55 organ project, including all PCB's (many assembled), 61-note keyboards with contacts. Component value £600+. Offers? Tel. (0249) 650926.

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SWAP MY LEARNER KIT OSCILLOSCOPE ideal for beginner (built & working) for disk drive 1541 or 1542 for Commodore plus/4. J.A. Brown, 71 Allington Close, Ilminster Road, Taunton, Somerset TA1 2NA.

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ZX81 TALKBACK Speech Synthesiser untested but believed to be working, £15. ZX81 motherboard PCB with two edge connectors, £6. O. Morris, Mochrum Park Cottage, Kirkcowan, Wigtownshire, Scotland DG8 0BY.

CLUBS

B.A.E.C. British Amateur Electronics Club is looking for more members & fresh ideas. For more details about what the club can offer send SAE to Cyril Bogod, 'Dickens', 26 Forest Road, Penarth, South Glamorgan CF6 2DP.

AMSAT-UK is the Amateur Satellite Organisation of the United Kingdom. If you wish to know more about amateur radio satellites send SAE to AMSAT-UK, London, E12 5EQ. Reply sent by return. You may also send for five back issues of 'Oscar News' for £3.00 post free from the same address.

WANTED

CIRCUIT DIAGRAMS or photocopies wanted for Peavy, Carlsbro, HH, Marshall etc. amps; also combo's, PA, mixers, etc. Sensible prices paid. Write details & prices to Mr. C. Johnson, 46 Cannell Green, Norwich NR3 1TT.

WANTED FULL CONSTRUCTIONAL DETAILS circuit diagrams & component suppliers for satellite TV receivers, dishes, LNA, LNB polarotors, motors/driver control etc. Write or contact P. Roberts, 77 The Cravens, Smallfield, Horley, Surrey RH6 9QT. Tel. 034284 3353 (evenings).

WANTED INPUT CHANNELS for Powertran 'Destiny' mixer desk. Ring J. Pearson 01-261-4288 (daytime).

WANTED 'ELECTRONICS' THE MAPLIN MAGAZINE issues 1 to 8 & 10 to 16. Contact J.D. Bramwell, 19 Pegwell Drive, Salford, M7 9ZW.

WANTED AUDIO/VIDEO in-out adaptor for Philips video VCR 2022. Contact S. Trebicki, 85 Bardley Crescent, Tarbock, Liverpool L35 1RJ. Tel. (051) 480 5423.

WANTED MAPLIN RTTY UNIT TU1000 or similar assembled or not. Also suitable receiver. Please Tel. Bishops Lydeard (0823) 432909, Taunton area.

AMENDMENTS TO 1987 CATALOGUE

SLOPING FRONT CASE XY60Q (Page 78). Please note that this case does not have ventilation holes as described in the 1987 catalogue.

0.1in. PC EDGCONN 2 X 20-WAY (Page 129). In the order code list, this should be stock code BK97F and not BK87F.

STYLUS CLEANER FLUID FV38R (Page 283). This is now supplied in a larger, new style bottle with an integral brush, but no instructions.

4K7 ENCLOSED PRESET UH15R (Page 293). In the description following the stock code for this item in the catalogue this is referred to as being horizontal mounting, whereas it is in fact vertical mounting.

74HC4351 8-WAY ANALOGUE SWITCH UF14Q (Page 329). This is a 20 pin device, and not 18 pin.

ICL7673 BATTERY BACKUP IC UH36P (Page 370). In the diagram for the high current system for the ICL7673, please note that the input is not 'Mains Supply' but should be 'Main supply' - *do not connect 240V AC to this chip.*

ICL7660 VOLTAGE CONVERTER YY75S (Page 370). Last line of description should read 'a supply voltage of +5V the output voltage will be −4.3V.' (not 15V).

FOOT SWITCH FH92A (Page 410). The description of the terminals and their operation for this switch are no longer correct. The description should be: SPDT switch. The common terminal is the centre of three solder tags. Rated 2A at 250V AC Body size: 36 x 12 x 15mm. Bush and knob length: 28mm.

AUDIO OSCILLATOR MA204 YM66W (Page 429). Third sentence states external frequencies can be connected. Although prototypes had this feature, production models will not. Frequency counter will function from internal source only. Stock of this item & YM68Y, Function Generator MG205, will not be with us until mid-May 1987.

15V MINIATURE TRANSFORMERS WB15R & LY03D (Page 457). Please note that the descriptions of these two items heve been transposed. WB15R is the 6VA version and LY03D is the 10VA type. This also applies to the physical dimensions given.

UHF MODULATORS UM1233, UM1286, FT30H & BK66W (Page 464). Types UM1233 and UM1286 have a wider and more linear bandwidth to cater for the chroma sub-carrier from a source video generator, they do not generate the chroma subcarriers internally. Same applies to the 6MHz sound carrier for the UM1286. The terminal designation letters A - D in the lower table apply to all units where the unit is turned label upwards and terminal wires are at left-hand side - UM1111 & UM1233 will have phono socket pointing away at top.

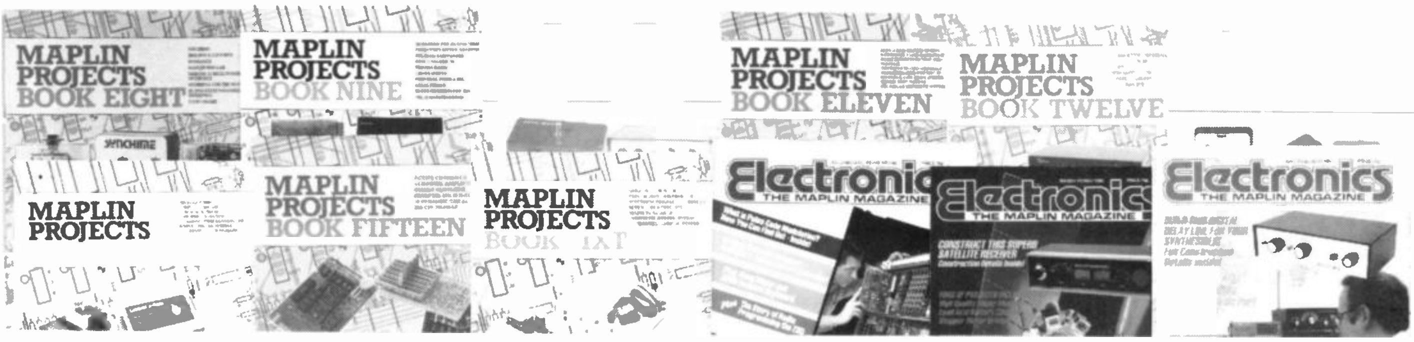
CORRIGENDA

Vol. 5 No. 20
Satellite Decoder: All that is required to connect the Decoder to the BBC User Port or Amstrad 8-bit port (LM14Q) is the IDC cable FD17T.

PRIZE DRAW WINNER

On Thursday 22nd January, after a postponement of a week due to the Siberian weather conditions in Southend-on-Sea, Maplin were able to present a Fiesta car to the winner of their recent 1987 catalogue launch prize draw.
The lucky winner was Mr. Martin Buzzard of Byfleet in Surrey. He is a 28 year old development engineer working for British Airways, his current project being the development of automatic landing techniques on 747 Jumbo jets. Martin considers himself fortunate to have a job which provides the challenge he enjoys. Martin, who used to go gliding, now prefers sailing, and other hobbies include home computing and amateur electronics. His first contact with Maplin came about 18 months ago when he spotted Maplin catalogues on the shelf in his local W.H. Smith. Since then he has become a regular subscriber of what is now his favourite magazine 'Electronics,' and he regularly visits the Maplin Hammersmith shop for components for both his hobby and design work.
Never having won anything before, Martin is now looking forward to the next Maplin prize draw in the hope that he can repeat his luck.
A hundred runners-up have won digital alarm clock radios. A full list will be published in the next issue. Runners-up have already been contacted and their prizes despatched to them.

DID YOU MISS THESE ISSUES?



Project Book 1 Universal Timer. Programmable mains controller. **Combo-Amplifier.** 120W MOSFET power amp. **Temperature Gauge.** 10°C - 100°C, LED readout. **Pass The Bomb!** Pass-The-Parcel with a difference. **Six easy-to-build Projects on Veroboard.** Car batt. monitor; Colour snap game; CMOS Logic Probe; Peak Level meter; Games timer; Multi-colour pendant.
Order As XA01B (Maplin Project Book No. 1)
Price 85p *NV*.

Project Book 2 Digital Multi-Train Controller. Controls up to 14 model trains. **Home Security System.** Six independant channels. **Digital MPG Meter.** With large LED display, a must for more economical motoring.
Order As XA02C (Maplin Project Book No. 2)
Price 85p *NV*.

Project Book 3 ZX81 Keyboard. 43 keys, plugs directly into ZX81 with no soldering. **Stereo 25W MOSFET Amp.** 25W r.m.s per channel; Disc, Tape, Tuner & Aux. **Radar Intruder detector.** 20 metres range, may be used with our security system. **Remote Control for Train Controller.** Remote control by infra-red, radio or wire.
Order As XA03D (Maplin Project Book No. 3)
Price 85p *NV*.

Project Book 4 Telephone Exchange. Up to 32 extensions on 2-wire lines. **Remote Control for Amplifier.** Volume, balance and tone controlled via infra-red link. **Frequency Counter.** 8 digit DFM, 10Hz - 600MHz range. **Ultrasonic Intruder Detector.** Areas up to 400 square feet can be covered.
Order As XA04E (Maplin Project Book No. 4)
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Project Book 5 Modem. 300 baud transmission speed over normal telephone lines. **Inverter.** 240V AC 60W from 12V car battery. **ZX81 Sound Generator.** 3 tone generators fully controlled from BASIC. **Central Heating Controller.** Optimised performance with this advanced system. **External Horn Timer.** Exterior intruder alarm. **Panic Button.** Add on to our Home Security System. **Model Train Projects.** Add on to our Multi-Train Controller. **Interfacing Micro processors.** How to use parallel I/O ports, with circuits.
Order As XA05F (Maplin Project Book No. 5)
Price 85p *NV*.

Project Book 6 VIC20 & ZX81 Talkbacks. Speech synthesis projects. **Scratch Filter.** Tunable active circuit 'reclaims' scratched records. **Bridging Module.** Converts two 75W MOSFET amps to one 400W full bridge amplifier. **Moisture Meter.** Finds damp in walls and floors. **ZX81 TV Sound and Normal/Inverse Video.** TV sound and inverse video direct. **Four Simple Veroboard Projects.** Portable Stereo Amp; Sine Generator; Headphone Enhancer and Stylus Organ.
Order As XA06G (Maplin Project Book No. 6)
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Project Book 7 CMOS Crystal Calibrator. For amateur radio receiver calibration. **DX'er's Audio Processor.** Improved sound from Comm-unications Receivers. **Enlarger Timer.** An accurate timer for the darkroom. **Sweep Oscillator.** Displays AF frequency response on an oscilloscope screen. **VIC20 and ZX81 Interfaces.** RS232 compatable.
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Project Book 8 Spectrum Modem/RS232 Interface. 2400 baud self contained operating system. **Synchime.** Simulates bells, gongs and other chiming sounds. **Dragon 32 RS232/Modem Interface.** Plugs into ROM expansion port. **Codelock.** Programmable electronic lock. **CMOS Logic Probe.** Digital display shows logic states. **Minilab Power Supply.** Versatile unit for the test bench. **Dragon 32 I/O Ports.** Two 8-bit ports. **Doorbell for The Deaf.** Flashing lamp attracts attention.
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