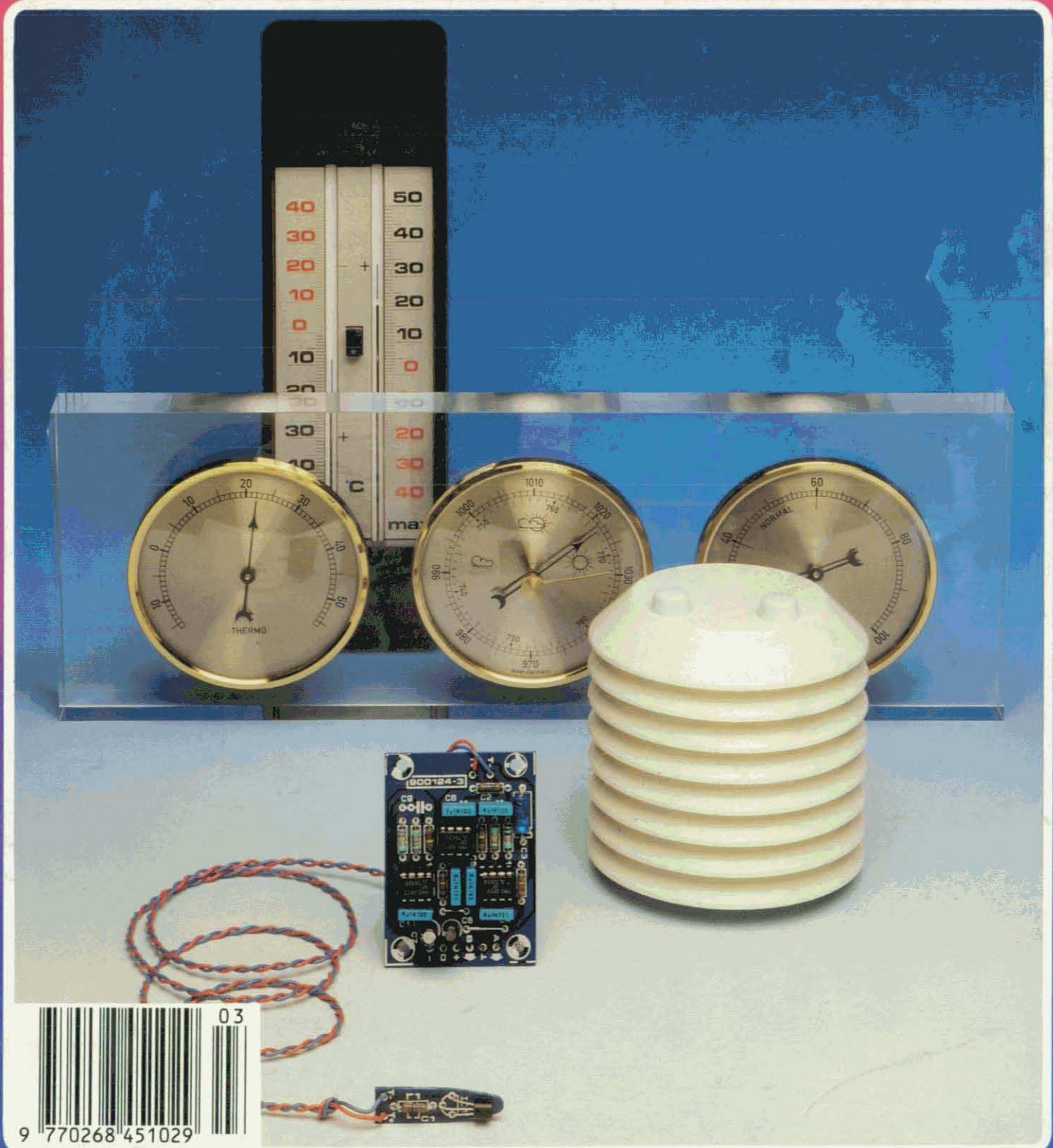


RS

# Elektor Electronics

- 6.0 MHz TV sound demodulator
- Electronic exposure timer
- Semiconductor tester
- Radar detector
- 2 metre converter
- Weather station (1)



03

**In our next issue:**

- Microphone amplifier
- P-U converter
- MIDI programme changer
- Dimmer for halogen lights
- PC-controlled semiconductor tester – Part 2
- Video D-A and A-D
- 8-bit I/O interface for Atari ST
- Computer-controlled weather station – Part 2

**Front cover**

This month we start a short series of articles describing applications of the multifunction measurement card for PCs published in our January and February 1991 issues. The articles should appeal to many since they describe interfaces for turning an IBM PC or compatible into an independent weather station for the amateur meteorologist. The complete station will be able to measure temperature, relative humidity, air pressure, wind direction and wind speed.

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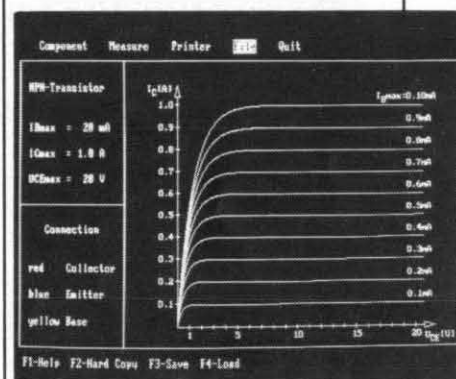
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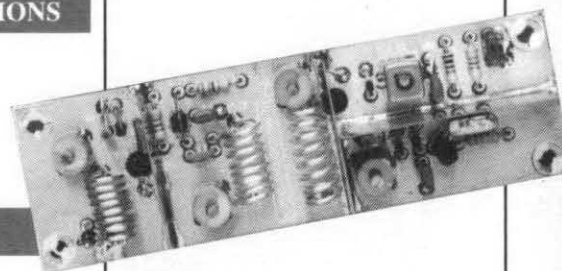
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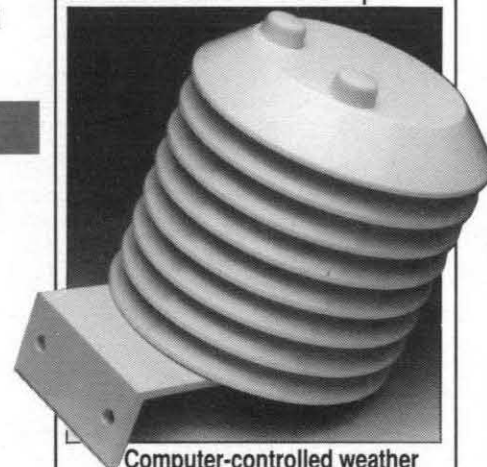
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# COMPUTER-CONTROLLED WEATHER STATION

## PART 1: INDOOR/OUTDOOR THERMOMETER

This is the first in a short series of articles on applications of the multifunction measurement card for PCs, described in the previous two issues of this magazine. The applications we have in mind should have a wide appeal, since they form the building blocks of a versatile weather station with advanced features for the amateur meteorologist.

**J. Ruffell**

**A**LTHOUGH we know that a state-of-the-art weather station is likely to score high on the list of popular electronic projects, it has taken us a while to come up with one mainly for want of a suitable central control unit. Fortunately, that has become available recently in the form of a PC insertion card offering a high resolution voltmeter and a frequency/pulse meter. This card, the multifunction measurement card for PCs, was described in two instalments in the previous two issues of this magazine (Ref. 1).

Provided that it is connected to the right types of interface and associated sensor, the measurement card forms the ideal starting point for a host of applications that require accurate processing and recording of analogue values. The PC used allows us to store measured values, such as temperature, in memory or on disk for analysis at a later stage. Few PC users will need to be informed that the results of such an analysis are perfect as input data for a graphics presentation package.

The interfaces we have in mind for the measurement card turn an IBM PC or compatible into an autonomous weather station, with sensors for temperature, relative humidity, air pressure, wind direction and wind speed. The first module, a dual indoor/outdoor thermometer, is described here.

### Dedicated or in the background

The multifunction measurement card and the associated control programs allow the PC-controlled weather station to function in one of two ways. In the first mode, a measurement is performed when the PC is switched on just to do that. During the measurement, the PC collects the measured

values produced by all sensors, and converts the data such that they may be stored on disk. Thus, a complete meteorological reading may be performed without going out of doors — you may remain seated in front of your PC and comfortably look at the measured results presented graphically on the monitor.

In the second mode of operation, the PC collects the meteorological data with the aid of a background (memory-resident) program, which allows a foreground task, such as word processing, to be carried out without the operator noticing that the PC is performing a second task. The background program automatically scans all sensors, and reads the measured values. Provision is made for the user to determine (within limits) the sampling interval. All readings and the times they were taken are collected in a file and subsequently stored on a floppy disk or a hard disk for use by a statistics or graphics/statistics program later. The software routines supplied with the main control program for the weather station allow

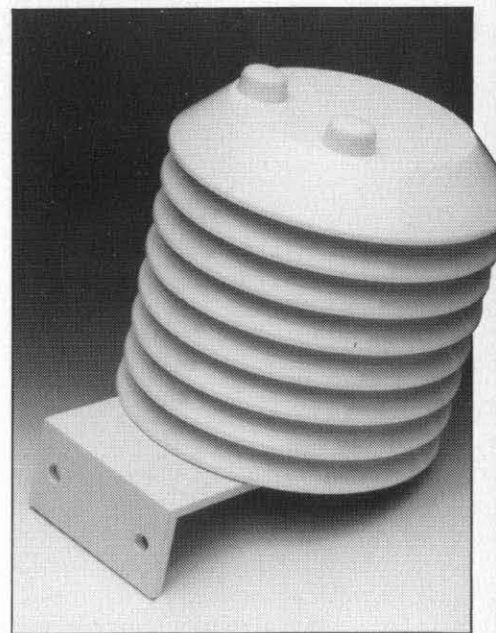
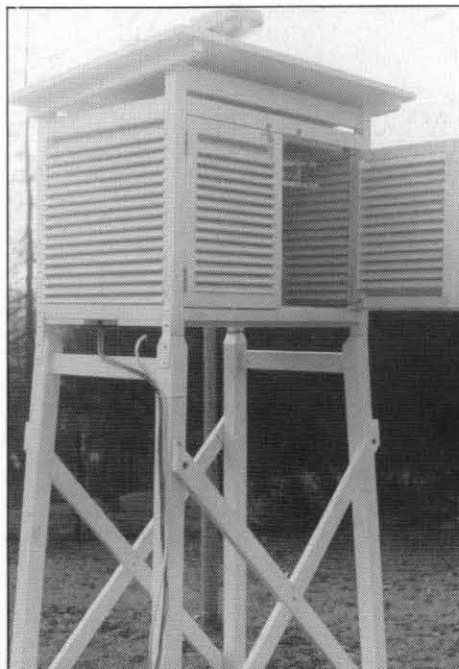


Fig. 1. This ready-made ABS enclosure contains the electronic thermometer that measures the outside temperature.

the trend of values measured over 24 hours to be presented in the form of a graph, while the current values are also shown graphically on the screen.

In this first article we describe the sensors used for measuring the temperature indoors and outside. For this purpose, most meteorologists use mercury thermometers with a mechanical minimum/maximum temperature indication. By contrast, the electronic version presented here uses a single sensor and software to record the minimum and maximum temperatures. If desired, these two parameters may be shown continuously on the PC screen.

### Temperature measurement

Temperature measurement can be tricky if the position of the sensor is not taken into account. It is not difficult to have two identical thermometers indicate different temperatures by placing them in positions that are only marginally different. Meteorologists are aware of this and are forced, for obvious reasons, to comply with certain conventions as regards their daily measurements. For instance, temperature is measured at a height of 1.5 m above a grass lawn. To prevent direct sunlight causing additional heating, the thermometer cabin is painted white, and has a door facing north. To prevent precipitation affecting the temperature readings, the cabin usually has a sloping side facing south.

Inside a meteorology cabin you will typically find a number of mercury thermometers that indicate the maximum, minimum and current temperature. In most cases, a mechanical recorder is used to produce a temperature graph over a period of 24 hours.

Since a fully equipped cabin is probably unaffordable for most amateur meteorologists, a less expensive, but reliable, alternative is described here. The photograph in Fig. 1 above shows the white, plastic enclosure used for the prototype of the thermometer.

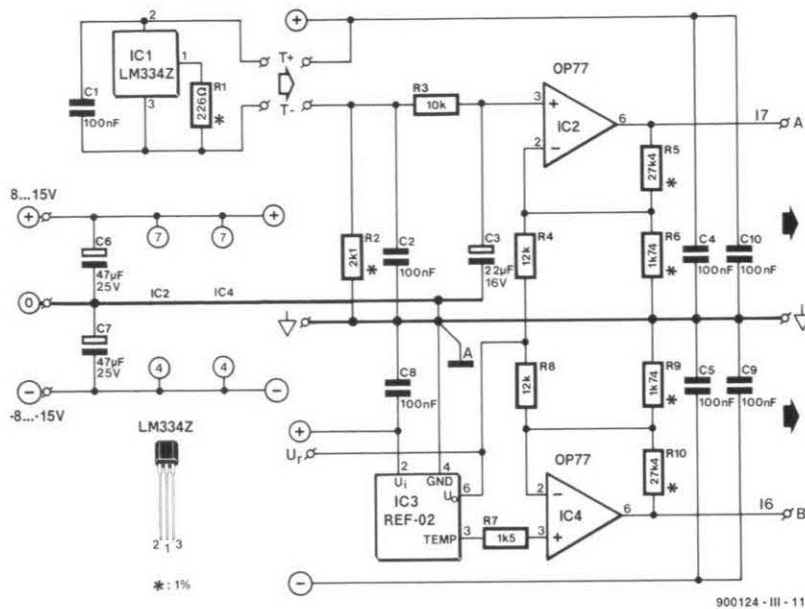


Fig. 2. Circuit diagram of the double electronic thermometer. The circuit is connected to the voltmeter input of the multifunction measurement card for PCs.

The construction of the enclosure prevents precipitation and direct sunlight reaching the temperature sensor, which is inserted through a hole at the underside, and fitted centrally in the enclosure. The ventilation

slots in the enclosure enable allow a free air flow around the sensor. Since the enclosure shown can be bought ready-made, it fairly easy to make a number of identical thermometer boxes.

If are you not so fortunate as to have a garden with a lawn, we recommend that you fit the thermometer enclosure to the north-side wall or facade of your house. Since the north facing wall is heated less by sunlight than the south facing wall, this position is the best compromise.

## The circuit

With the description of the electronics most of you will feel that you are returning to familiar ground. Figure 2 shows the circuit diagram of the interface for the two temperature sensors. Remember, this interface is connected to the multifunction measurement card for PCs.

The dual temperature sensor measures the inside (indoor) and the outside (outdoor) temperatures simultaneously. The inside temperature is measured with an REF-02, the outside temperature with an LM334Z.

The REF-02 (IC3) has two functions in the circuit. First, it provides a reference voltage of 5 V. This voltage, which is available on pin 6 of the stabilizer, is used for opamps IC2 and IC4. Pin 3 (TEMP), of the REF-02 supplies a temperature-dependent direct voltage. Since the REF-02 is fitted on a PCB that remains indoors, the TEMP output may be used for the indoor thermometer. The voltage at the TEMP output is 0.574 V at 0 °C, and rises at a rate of exactly 2.1 mV per Kelvin. Unfortunately, the TEMP voltage can not be applied direct to the ADC on the measurement card.

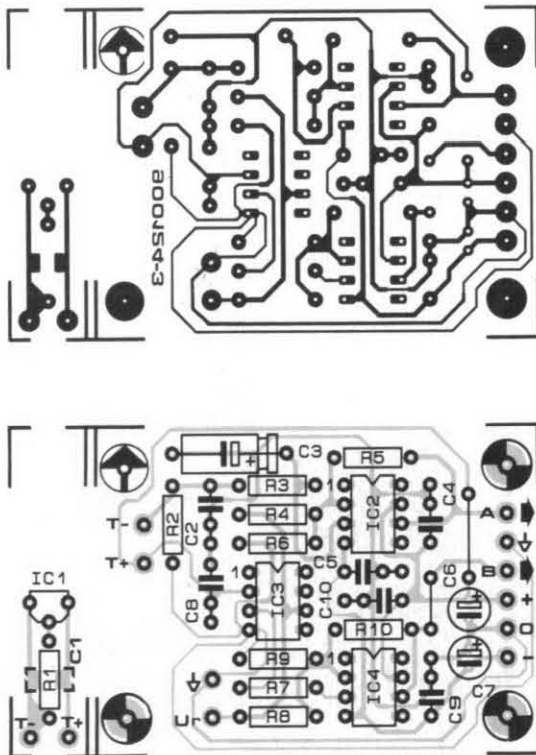


Fig. 3. Track layouts and component mounting plans of the two printed circuit boards needed for the indoor/outdoor thermometers.

## COMPONENTS LIST

### Resistors:

1	226Ω 1%	R1
1	2kΩ 1%	R2
1	10kΩ	R3
2	12kΩ	R4;R8
2	27kΩ 1%	R5;R10
2	1kΩ 74 1%	R6;R9
1	1kΩ 5	R7

(1% resistors from E96 series)

### Capacitors:

1	100nF SMA	C1
6	100nF	C2;C4;C5;C8; C9;C10
1	22μF 16V axial	C3
2	47μF 25V radial	C6;C7

### Semiconductors:

1	LM334Z	IC1
2	OP77	IC2;IC4
1	REF-02	IC3

### Miscellaneous:

1	ABS enclosure; size approx. 100×50×25 mm (e.g. Bopla EG410)
1	printed circuit board 900124-3

Note: The sensor enclosure shown in the photograph in Fig. 1 was obtained from Mierij Meteo • Tuinstraat 1-3 • 3732 VJ De Bilt • Holland. Telephone: +31 30 200064.

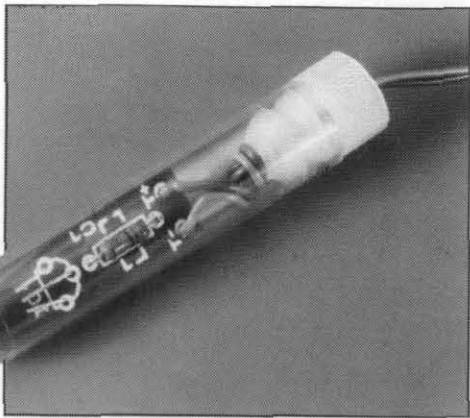


Fig. 4. The PCB with the LM334Z on it must be cut to size to fit into the plastic tube.

This problem is solved by a simple level converter in the form of an opamp, IC4. The converter is designed such that the output voltage of IC4 has a range of +2.5 V to -2.5 V for the desired temperature range, while the output voltage is 0.5 V at a temperature of 0 °C. The gradient of the output voltage is set to 40 mV/°C, so that an effective temperature range of -50 °C to +75 °C is achieved (although we know that the projects carried in this magazine are built and used around the globe, this seems a reasonably large temperature range...).

The electronic temperature measurement has a guaranteed resolution of 0.1 °C, which equals the resolution of mercury thermometers used by professional meteorologists.

The outside temperature is measured with the aid of an LM334Z, a temperature-dependent current source. As usual with this type of measurement 'in the field', the sensor is a current source rather than a voltage source. The current drive eliminates the effects of length, diameter and temperature of the cable between the sensor and the input amplifier. If voltage drive were applied, these parameters would cause a voltage drop that requires a complex type of compensation.

The sensor output current gradient is set to 1  $\mu$ A/K. Since the current flows through a 2.1 k $\Omega$  resistor, R2, a voltage gradient of 2.1 mV/K is created, which equals that of the indoor temperature sensor, IC3. Opamp IC2, like IC4, converts the temperature-dependent voltage into a value within the range between -2.5 V and +2.5 V, required for the ADC on the measurement card.

One thing that you will probably like about the interface circuit is the total absence of adjustment points or complex compensation circuits. This is by virtue of the control software, which provides routines that take care of the tracking and individual calibration of the two temperature sensors.

## Construction

The two printed-circuit boards shown in Fig. 3 (one for the interface and one for the outdoor sensor) must be separated before they are populated. Start the construction with the wire links on the interface board. Next, fit all the components — a job that is

unlikely to present any difficulty.

The outdoor sensor PCB is cut and filed until it can be fitted into a small plastic tube of the type used for storing SMA components (see Fig. 4). The PCB area that has no components on it is first filed to a size to fit the tube. In view of the size of the plastic tube, the output wires are best soldered direct to the respective copper pads on the PCB.

After inserting the completed PCB into the tube, the wires are passed through small holes in the cap. Next, the cap is hermetically sealed with a few drops of epoxy resin or potting compound. The fitting of the tube at a suitable position in the centre of the thermometer enclosure is straightforward.

## The PC connection

The outputs of the complete interface circuit are connected to analogue inputs I6 and I7 of the multifunction measurement card, while ground is connected to the analogue ground (on connector K3) of the measurement card. Note the following components at the analogue multiplexer input (refer to the circuit diagram of the measurement card):

- Resistor R6: 10 k $\Omega$
- Resistor R7: not fitted
- Resistor R8: 10 k $\Omega$
- Resistor R9: not fitted
- Capacitor C33: 100 nF
- Capacitor C34: 100 nF

These values ensure the correct measurement ranges.

The interface is powered by a simple symmetrical supply with an output voltage between  $\pm 8$  V and  $\pm 15$  V. Since the current consumption of the circuit is quite low (a few milliamperes only), a pair of fixed voltage regulators, such as the 7910 and 7810, may be used with the usual decoupling capacitors.

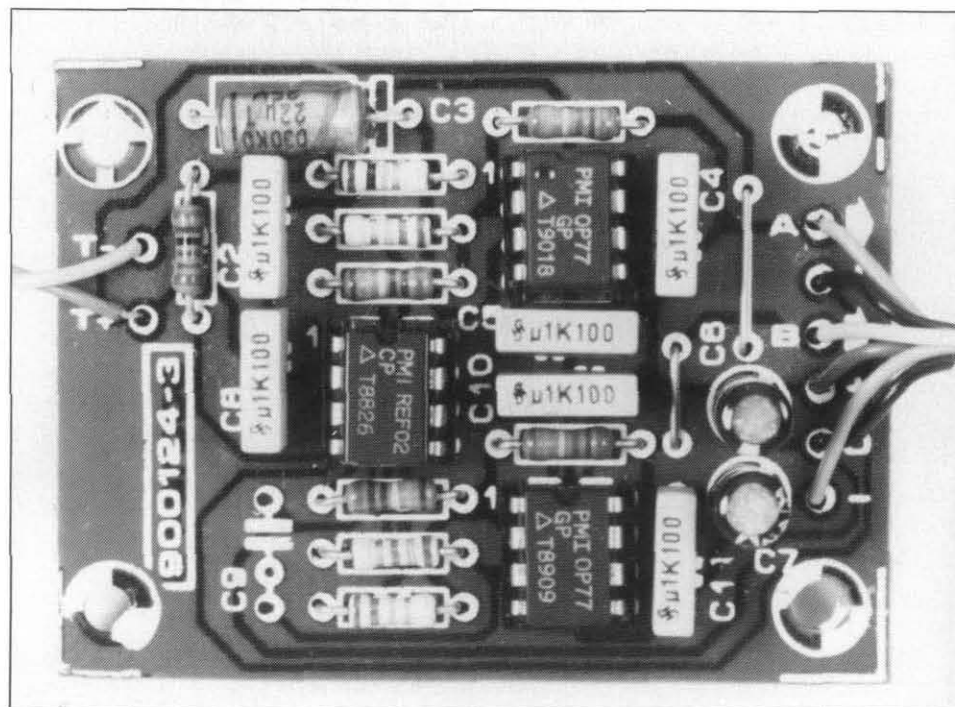


Fig. 5. Completed and ready for use: the indoor/outdoor thermometer is the first module in a computer-controlled weather station.

## SOFTWARE SERVICE

The control software mentioned in this article is available on a 5¼-inch 360 KByte MSDOS formatted floppy disk which may be ordered through our Readers Service. The order code of the disk is ESS 1551.

## Control software

As with the multifunction measurement card, the hardware is not complete without appropriate software. The control program written for the thermometer is supplied on a 5¼-inch floppy disk, and runs on any PC XT or AT fitted with a Hercules, EGA or VGA card (unfortunately, the program does not support CGA cards). The disk contains three programs: TADJUST.EXE for calibrating the sensors, TLOGGER.EXE for data logging as a background program, and TEMP.EXE, for the graphics presentation of the measured values.

The first thing to do is run TADJUST.EXE. This program requires two temperature measurements. The calibration of the outdoor thermometer is simple: immerse the sensor in melting ice, leave it there for a couple of minutes, and enter the value 0 °C in the relevant window on the screen. Next, place the sensor in free air. In the relevant window on the screen, enter the temperature read from a mercury thermometer fitted at the same position as the sensor.

Since the indoor temperature is measured with an IC fitted on the interface board, this sensor can not be calibrated with the aid of melting ice. Thus, a comparative calibration is required against a good quality mercury thermometer. As with the outdoor thermometer, two temperatures are re-

T901231.LOG

```

F1 Load file
F2 Switch plot
F9 Hardcopy
F10 Quit

```

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\*\*\* Elektor Electronics \*\*\*

\*\*\* Copyright (C) -&gt; 1991 \*\*\*

\*\*\* ESS: 155 (1, 2, 3, 4) \*\*\*

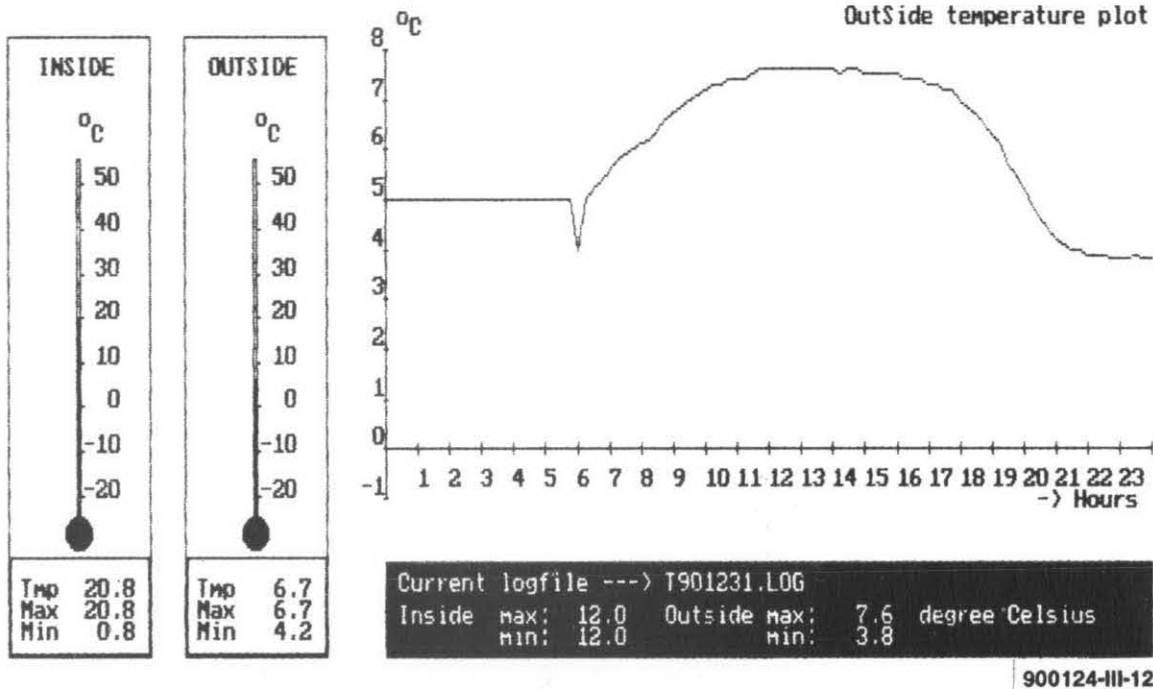


Fig. 6. Screenshot produced by the thermometer program, TEMP.EXE, which can run on any PC XT or AT fitted with a Hercules, EGA or VGA video card.

quired, which must be entered in the respective windows on the screen. The higher the temperature difference, the better. Since in most modern homes the daytime indoor temperature will typically be about 5 °C higher than the nighttime temperature, this difference may be used to calibrate the ther-

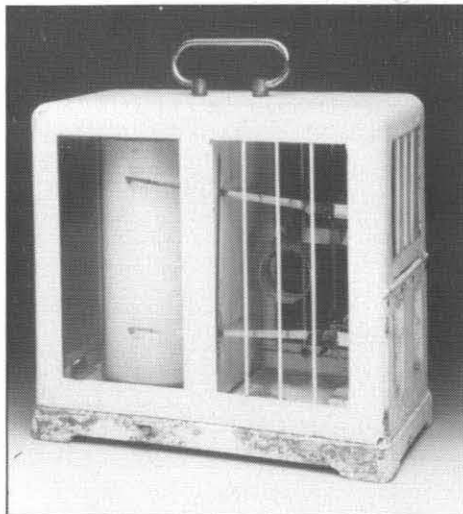


Fig. 7. Definitely a collector's item, this mechanical temperature recorder puts modern electronics in an interesting perspective.

mometer. A better, though slightly cumbersome, way of creating a larger temperature difference is to take the interface circuit out of doors for a short while.

This completes the calibration. The parameters used are automatically stored in a file called TADJUST.CFG.

Constructors who wish to use two remote sensors may build these on two separate PCBs. These sensors can share the 5-V reference voltage at terminal Ur, produced by a single REF-02.

The program TLOGGER.EXE is a background utility to collect measured data produced by the sensors. The program is made memory-resident by typing command

```
TLOGGER /I
```

(install), and removed from memory (uninstalled) by typing command

```
TLOGGER /U
```

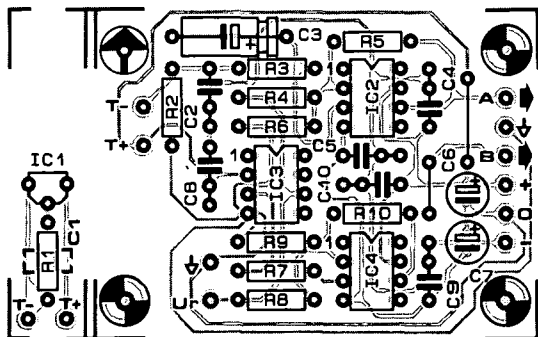
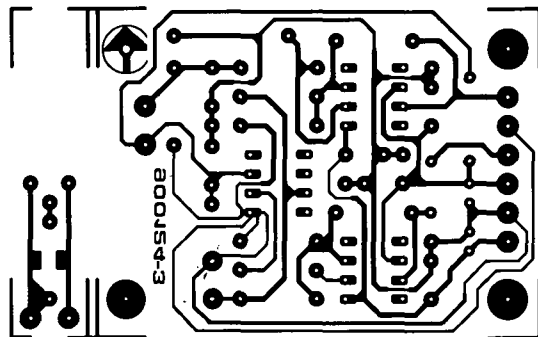
The interval between the instants at which data is to be collected on hard disk or floppy disk is set in the configuration file, TLOGGER.CFG. The default is 60 minutes. The last update of the log file is always made at mid-

night. Since the program creates one log file every 24 hours, the file of the previous day is closed after midnight. From then, the measured results are available for further processing. After it is closed, every log file is automatically stored under a name that indicates the measurement period, i.e. Tyymmdd.LOG — until, of course, the disk is full. You may want to use your own programs to handle the collected data, and feed them into a statistics calculation or analysis program at this stage to produce a nice looking presentation. Initially, however, you may want to use TEMP.EXE on the distribution disk for this purpose. The program shows a graph with the temperatures measured from midnight onwards, as well as the current indoor and outdoor temperature. To ensure optimum resolution under all circumstances, the vertical axis of the temperature graph is autoranging. The horizontal axis shows the 24 hour marks. □

#### Reference:

1. "Multifunction measurement card for PCs". *Elektor Electronics* January and February 1991.

Next time: a relative humidity sensor.



## COMPONENTS LIST

### Resistors:

1	226Ω 1%	R1
1	2kΩ1 1%	R2
1	10kΩ	R3
2	12kΩ	R4;R8
2	27kΩ4 1%	R5;R10
2	1kΩ74 1%	R6;R9
1	1kΩ5	R7

(1% resistors from E96 series)

### Capacitors:

1	100nF SMA	C1
6	100nF	C2;C4;C5;C8; C9;C10
1	22μF 16V axial	C3
2	47μF 25V radial	C6;C7

### Semiconductors:

1	LM334Z	IC1
2	OP77	IC2;IC4
1	REF-02	IC3

### Miscellaneous:

1	ABS enclosure; size approx. 100x50x25 mm (e.g. Bopla EG410)	
1	printed circuit board	900124-3

*Note:* The sensor enclosure shown in the photograph in Fig. 1 was obtained from Mierij Meteo • Tuinstraat 1-3 • 3732 VJ De Bilt • Holland. Telephone: +31 30 200064.

Fig. 3. Track layouts and component mounting plans of the two printed circuit boards needed for the indoor/outdoor thermometers.

# THE COMPLETE PREAMPLIFIER (2)

by T. Giffard

Following the circuit description in our January 1991 issue, we will now focus our attention on the practical construction of the preamplifier. The busboard is shown in Fig. 5 and 6 and the motherboard in Fig. 7 and 8.

The busboard contains all the components shown in Fig. 2 and the SOURCE SELECT and RECORD SELECT switches. These switches are fitted with extension spindles to enable them to be controlled from the front panel.

The motherboard contains the components shown in Fig. 3 with the exception of the controls, which are fitted on the front panel. By virtue of its double-sided and through-plated design, this board will be fairly easy to populate.

Most of the work lies in preparing the enclosure and connecting the controls to the motherboard.

## Choice of components

The quality of any preamplifier depends to a large degree on the opamps used and the type of capacitors in the signal paths.

In the present design, there is only one capacitor in the signal path: at the output. The board has space for two large parallel-connected types ( $C_{24}$ - $C_{25}$  and  $C_{56}$ - $C_{57}$ ). These should preferably be MKP types, but at these values they are fairly expensive. Second choice is MKT types.

There are also some capacitors at the output of the dynamic pick-up section, but their values are fairly small so that MKP types here are not too dear.

Finally, the tone control circuit also contains a couple of capacitors which is virtually unavoidable. Since this circuit in any case degrades the quality to some degree, the quality of the capacitors used in it is hardly of any consequence.

There is a wide choice of suitable opamps. The quality of the preamplifier is, however, not necessarily in direct proportion to the price of the opamps chosen. It is rather a matter of choosing the opamps on their merits and to individual requirements. We shall look at each of them in turn.

**IC<sub>1</sub>.** In this position a low-noise type with small offset voltage is preferred. The Signetics 5532 is a good and economical choice. A slightly faster version is the 5535, while the SM2132 is even faster. National Semiconductor's LM833 is, as far as its specification is concerned, almost identical to the 5532. More expensive, but fast, is Analog Devices' AD712 (which has the added advantage of FET inputs). Then there is the OP270 (a double OP27) or the OP249, which has a high slew rate and FET inputs. In the Burr-Brown family there are the OPA2107 and OPA2604, both with FET



Fig. 4. General view of the preamplifier.

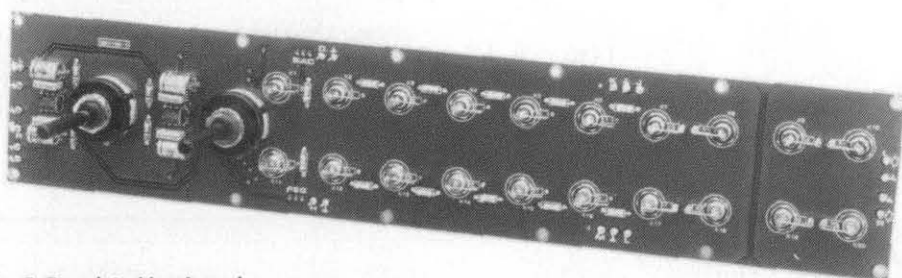


Fig. 5. Populated busboard.

## TECHNICAL DATA

Sensitivity	
dynamic PU	2.4 mV r.m.s.
line inputs	150 mV r.m.s.
Input impedance	47 k $\Omega$
Output voltage	
nominal	1 V r.m.s.
maximum	9.5 V r.m.s.
Output impedance	<100 $\Omega$
Bandwidth	
dynamic PU	20 Hz-20 kHz $\pm$ 3 dB
line inputs	5 Hz-1 MHz $\pm$ 0.5 dB
(load = 10 k $\Omega$ )	
Signal/noise ratio	
dynamic PU	>80 dB (linear)
line inputs	>100 dB (linear)
(inputs shorted)	
Channel separation	>100 dB (1 kHz)
	>70 dB (20 kHz)
( $Z_{source} = <600 \Omega$ )	
Cross-talk	>100 dB (1 kHz)
	>80 dB (20 kHz)
Harmonic distortion	<0.003%
(line in, $U_o = 1 V$ ) (20 Hz-20 kHz)	
Intermod. distortion	<0.005%
(line in, $U_o = 1 V$ ) (250 Hz/4 kHz, 4:1)	

## PARTS LIST

### Resistors:

$R_1, R_3, R_5, R_7, R_9, R_{11}, R_{19}, R_{21}, R_{23}, R_{25}$   
 $R_{27}, R_{29}$  = see text (Part 1)  
 $R_2, R_4, R_6, R_8, R_{10}, R_{12}, R_{20}, R_{22}, R_{24}$ ,  
 $R_{26}, R_{28}, R_{30}$  = 47 k $\Omega$   
 $R_{13}, R_{14}, R_{31}, R_{32}$  = 100  $\Omega$   
 $R_{15}, R_{16}, R_{33}, R_{34}$  = 47  $\Omega$   
 $R_{17}, R_{18}, R_{35}, R_{36}$  = 1 M $\Omega$

### Capacitors:

$C_1, C_3, C_5, C_7$  = 47 nF, ceramic  
 $C_2, C_4, C_6, C_8$  = 47  $\mu$ F, 25 V

### Semiconductors:

IC<sub>1</sub> = NE5532  
 IC<sub>2</sub> = AD172 (NE5532 - see text)

### Miscellaneous:

$S_1, S_2$  = 2-pole, 6-position rotary switch for PCB mounting  
 $K_1-K_{20}$  = 3.5 mm audio chassis socket  
 PCB Type 890169-1



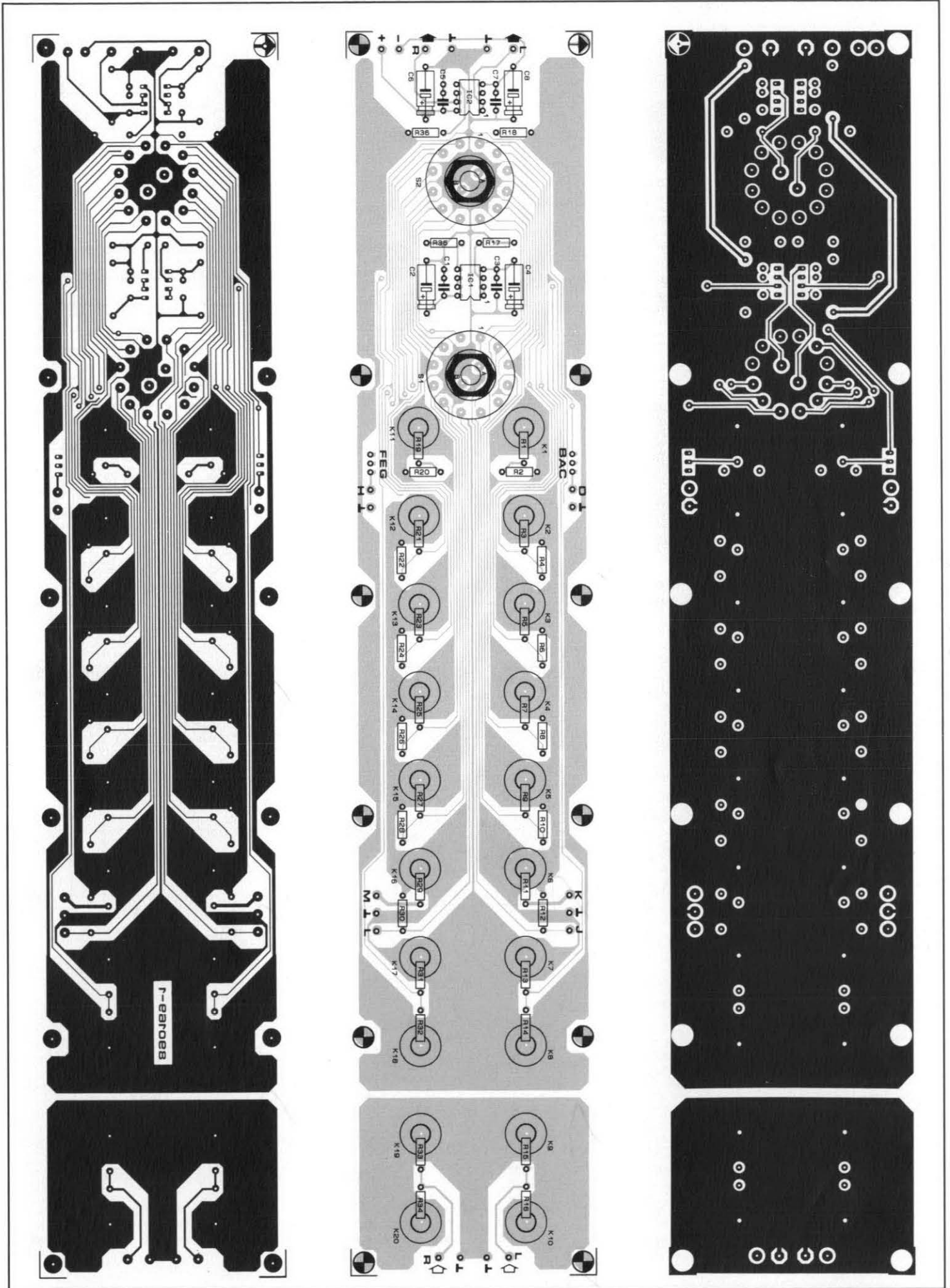


Fig. 6. Printed-circuit busboard. Note that these drawings are reproduced here at 71% of true size.



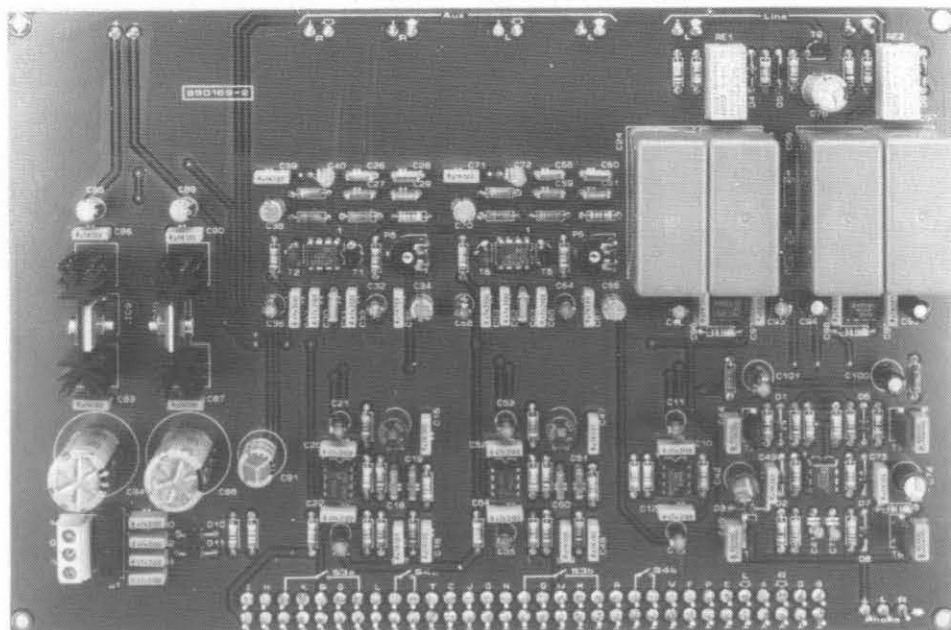


Fig. 8. Populated motherboard.

## PARTS LIST

### Resistors:

$R_{40}, R_{41}, R_{43}, R_{44}, R_{63}, R_{64}, R_{68}, R_{69}, R_{88}, R_{89} = 6k8$   
 $R_{42} = 3k3$   
 $R_{45}, R_{60}, R_{61}, R_{70}, R_{85}, R_{86} = 12k$   
 $R_{46}, R_{47}, R_{51}, R_{71}, R_{72}, R_{76} = 1M$   
 $R_{48}, R_{49}, R_{73}, R_{74} = 2k2$   
 $R_{50}, R_{775} = 18k$   
 $R_{52}, R_{77} = 1k, 1\%$   
 $R_{53}, R_{78} = 5k62, 1\%$   
 $R_{54}, R_{79} = 10k$   
 $R_{55}, R_{80} = 47\Omega$   
 $R_{56}, R_{81} = 88k7, 1\%$   
 $R_{57}, R_{82} = 7k5, 1\%$   
 $R_{58}, R_{83} = 154\Omega, 1\%$   
 $R_{59}, R_{84} = 47k5, 1\%$   
 $R_{62}, R_{87} = 1k$   
 $R_{65}, R_{66}, R_{90}, R_{91} = 27\Omega$   
 $R_{67}, R_{92}, R_{94}, R_{99}, R_{100} = 100\Omega$   
 $R_{93} = 47k$   
 $R_{95} = 68\Omega, 1/2W$   
 $R_{96} = 2k7$   
 $R_{97}, R_{98} = 4\Omega 7$   
 $P_1 = 10k$  log. stereo potentiometer  
 $P_2 = 10k$  balance control  
 $P_3 = 22k$  (or 25k) potentiometer  
 $P_4 = 10k$  linear potentiometer  
 $P_5, P_6 = 10k$  preset potentiometer

### Capacitors:

$C_{10}, C_{12}, C_{20}, C_{22}, C_{33}, C_{37}, C_{52}, C_{54}, C_{65}, C_{69},$   
 $C_{79}, C_{80}, C_{81}, C_{82}, C_{96} - C_{99} = 47nF$  ceramic  
 $C_{11}, C_{13}, C_{21}, C_{23}, C_{32}, C_{36}, C_{53}, C_{55}, C_{64}, C_{68},$   
 $C_{92} - C_{95} = 47\mu F, 25V,$  radial  
 $C_{14}, C_{46} = 10\mu F, 40V,$  bipolar, radial  
 $C_{15}, C_{16}, C_{17}, C_{35}, C_{39}, C_{43}, C_{47}, C_{48}, C_{49}, C_{67},$   
 $C_{71}, C_{75}, C_{83}, C_{86}, C_{87}, C_{90} = 100nF$   
 $C_{18}, C_{50} = 1n8$   
 $C_{19}, C_{51} = 1n2$   
 $C_{24}, C_{25}, C_{56}, C_{57} = 10\mu F,$  MKP or MKT  
 $C_{26}, C_{27}, C_{58}, C_{59} = 18nF, 1\%,$  MKT  
 $C_{28}, C_{60} = 5n6, 1\%,$  MKT

$C_{29}, C_{61} = 3n9, 1\%,$  MKT  
 $C_{30}, C_{62} = 47nF, 1\%,$  MKT  
 $C_{31}, C_{63} = 120nF, 1\%,$  MKT  
 $C_{34}, C_{38}, C_{66}, C_{70}, C_{85}, C_{89} = 10\mu F, 25V,$   
 radial  
 $C_{40}, C_{72} = 47pF,$  polystyrene  
 $C_{41}, C_{73} = 100pF,$  polystyrene  
 $C_{42}, C_{74} = 100\mu F, 10V,$  radial  
 $C_{44}, C_{45}, C_{76}, C_{77} = 150nF$   
 $C_{78}, C_{91} = 220\mu F, 25V,$  radial  
 $C_{84}, C_{88} = 2200\mu F, 40V,$  radial  
 $C_{100}, C_{101} = 100\mu F, 25V,$  radial  
 $C_{102}, C_{103} = 150pF,$  polystyrene

### Semiconductors:

$D_1 - D_4, D_6 - D_9 = 1N4148$   
 $D_5, D_{10}, D_{11} = 1N4001$   
 $B_1 = B80C1500$   
 $T_1, T_5 = BC550C$   
 $T_2, T_6 = BC560C$   
 $T_3, T_7 = BD139$   
 $T_4, T_8 = BD140$   
 $T_9 = BC517$   
 $IC_3, IC_4, IC_5 = OP27$   
 $IC_6, IC_7 = LT1028CN8$   
 $IC_8 = NE5532$   
 $IC_9 = 7815$   
 $IC_{10} = 7915$   
 $IC_{11}, IC_{12} = NE5534$

### Miscellaneous:

$S_3, S_4 =$  DPST miniature toggle switch  
 $S_5, S_6 =$  DPCO miniature toggle switch  
 $S_7 =$  SPST miniature toggle switch  
 $Re_1, Re_2 = 12V$  relay, 1 CO contact  
 1 off 6 mm stereo audio socket  
 2 off heat sink for  $IC_9$  and  $IC_{10}$   
 1 off 3-way PCB-type terminal block  
 1 off DPST mains press button switch  
 1 off fuse holder with 315 mA slow fuse  
 1 off strain relief sleeve  
 1 off mains transf.  $2 \times 15V, 1A$   
 1 off PCB Type 890169-2  
 1 off front panel foil Type 890169-F

inputs. An inexpensive but good choice is the TL072, which has FET inputs but a rather-higher noise figure.

**IC2.** The same considerations as for IC1 apply, but in this position it is even more important to have a type with a low offset voltage, because all deviations between input and output are amplified. In view of the switching clicks and level changes that occur when a different input channel is selected, opamps with FET inputs are preferred. Both conditions are met by the AD712, OP249, OPA2107 and OPA2604. The least expensive choice is the TL072 (but remember its noise figure).

**IC3.** In this, the mono count, position a low-noise opamp is essential: the OP27, 5534A and SSM2134 are suitable. The last two types are not unity-gain stable, however, which makes it necessary to fit a 22 pF capacitor between pins 5 and 8 at the underside of the motherboard. FET inputs are not necessary. Again, a TL072 may be used where economy is a must.

**IC4 and IC5.** The same considerations as for IC3 apply: remember the 22 pF capacitors if a 5534A or SSM2134 is used.

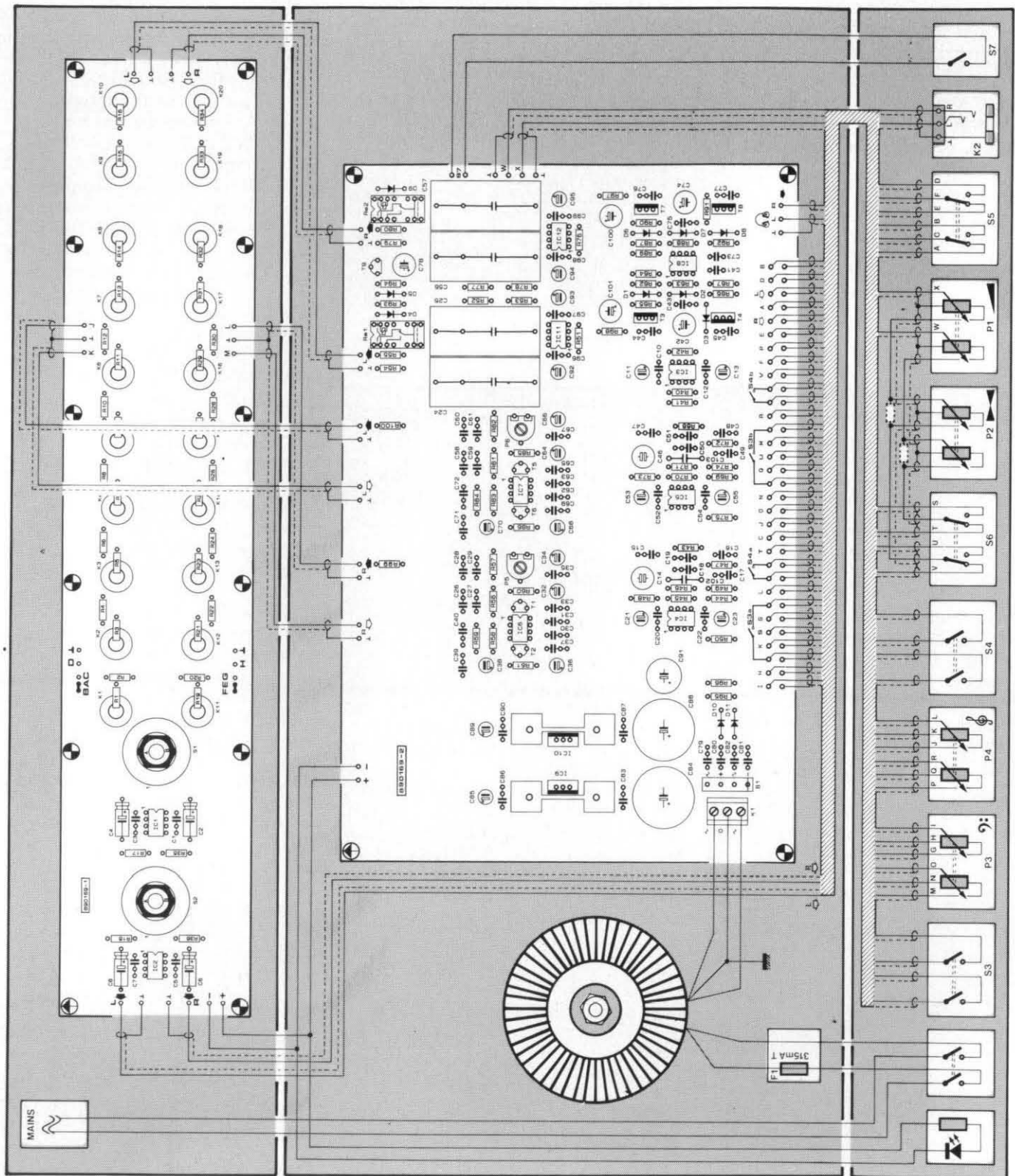
**IC6 and IC7.** Because very low noise in the dynamic pick-up circuit is imperative, a Linear Technology Type LT1028 would be ideally suitable in these positions, were it not for a tendency to become unstable (for reasons we have not been able to ascertain) and, therefore, the same manufacturers' Type LT1115 is preferred. This type has virtually the same specification as the 1028, but does not become unstable. A less expensive choice is the OP27, while the 5534A and SSM2134 would also be suitable. These last two types require, apart from the 22 pF capacitor mentioned earlier, a change of value to 100 k $\Omega$  for presets P5 and P6.

**IC8.** In this, the headphone amplifier, position, very low noise is a prime requirement, and this is met by the Signetics Type 5532 or 5535, an SSM2132, an LM833 or an OP27. If the preamplifier will be required to deliver regularly fairly large output voltages, i.e. larger than the nominal 1 V r.m.s., a type with FET inputs should be used in this position. The inputs of the 5532, for instance, are provided with protection diodes that may cause small d.c. voltages at the line output if the amplifier is overdriven.

**IC11 and IC12.** The prime reason for using a 5534 in this position is its facility to provide sufficient current to low impedances (<600  $\Omega$ ), but the SSM2134 is also suitable. Most opamps with FET inputs do not perform well with such low impedances. If the load on the preamplifier is never likely to be below 2 k $\Omega$ , an AD711 or TL071 may also be used.

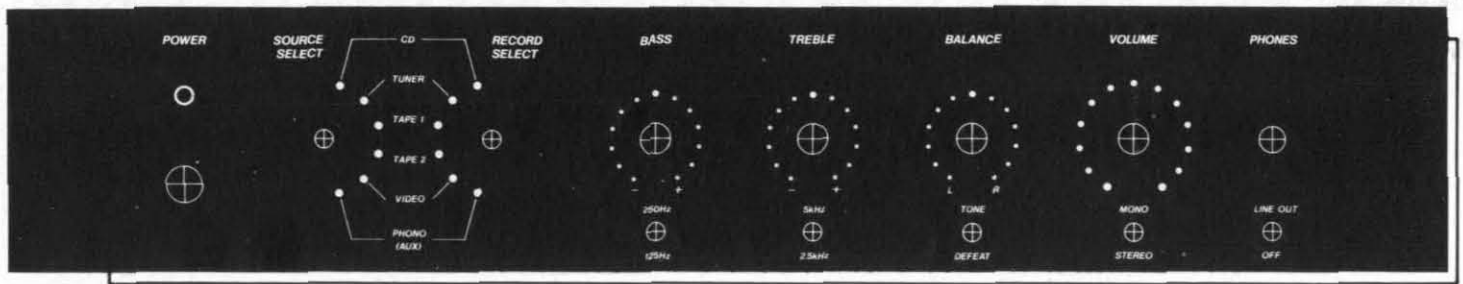
## Construction

It is better not to use IC sockets: we believe that each extra point of contact, and this applies particularly to IC sockets, degrades the quality of any audio circuit. Our preference is to solder ICs on to the board, although we admit that sockets enable the quick and easy exchanging of ICs to compare their performance.



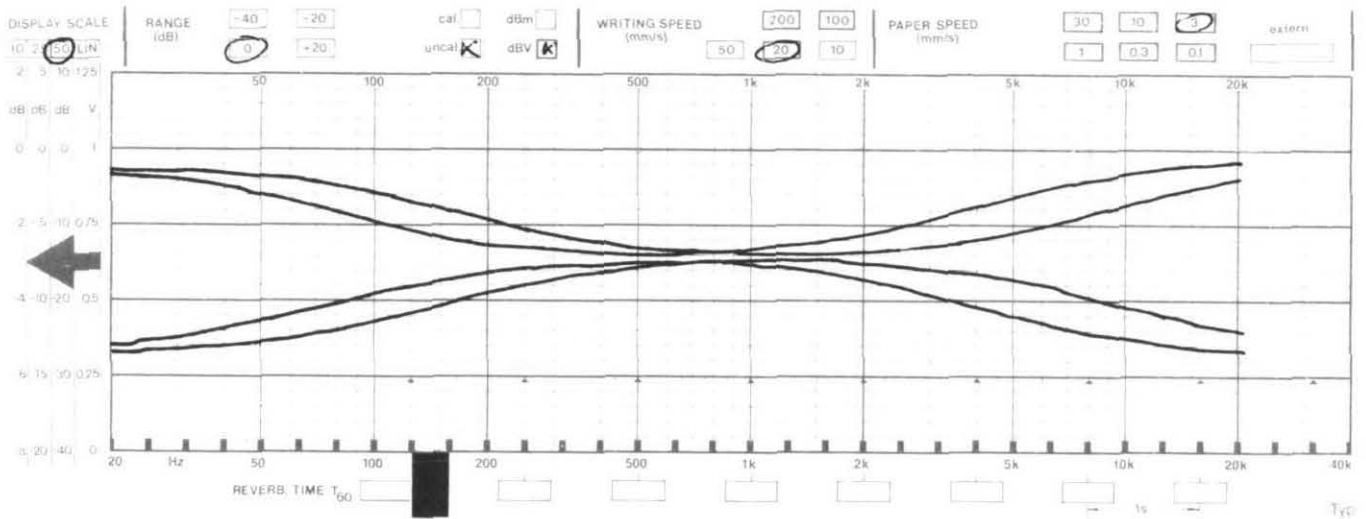
890165-11-11

Fig. 9. Wiring diagram.



890169F

Fig. 10. Front panel foil (available through our Readers' services).



890169

Fig. 11. Tone control characteristics.

Populating the boards should not give any difficulties. Fit solder pins at all input and output points: this will make the wiring later on that much easier. On the motherboard solder a wire bridge between J and K and between L and M if you do not intend to use the dynamic pick-up amplifier. Wire bridges are also required between A and B and between E and F.

Note that both voltage regulators need an individual heat sink.

Once the boards have been completed, they can be fitted in the enclosure when this has been prepared. As shown in the wiring diagram in Fig. 9, the motherboard fits into the left-hand side of the enclosure to enable the extension spindles of the rotary switches to just clear the heat sinks of the voltage regulators. At the right-hand side there is space for the mains transformers.

The layout of the front panel—see Fig. 10—determines the location of the busboard at the back of the enclosure. Depending on the dimensions of the enclosure, a mains input plug with integral fuse holder or a mains cable entry with strain relief may be used. In the last case, a fuse holder must be fitted within the enclosure, preferably near the transformer.

Photocopies of the front panel foil (shown in Fig. 10 at a scale of 3:4) and of the bus-

board (Fig. 6) may be used as templates for drilling the required holes in the front and rear panels respectively.

Once the enclosure is ready, the boards and the various controls can be fitted. If Bourns potentiometers are used, make sure that these have 6.3 mm spindles and not the usual 6 mm ones.

Finally, the inter-wiring can be carried out. Take good care to insulate all mains-voltage carrying parts. All signal wires should be screened, but their diameter should not exceed 5 mm to prevent difficulties in soldering them to the motherboard where they are very close together.

The wiring between bus- and motherboard should be carried out first, followed by that between the boards and the controls on the front panel and finally the power lines.

Although the screen of each and every signal line is connected to a separate solder pin, only those at the volume and balance controls are actually connected to the earth line: those of all other screened cables are left unconnected. The enclosure earth is connected to the mains earth and this is the only real earth connection of the preamplifier.

The output socket of the headphone amplifier must be well insulated from the enclosure to avoid earth loops



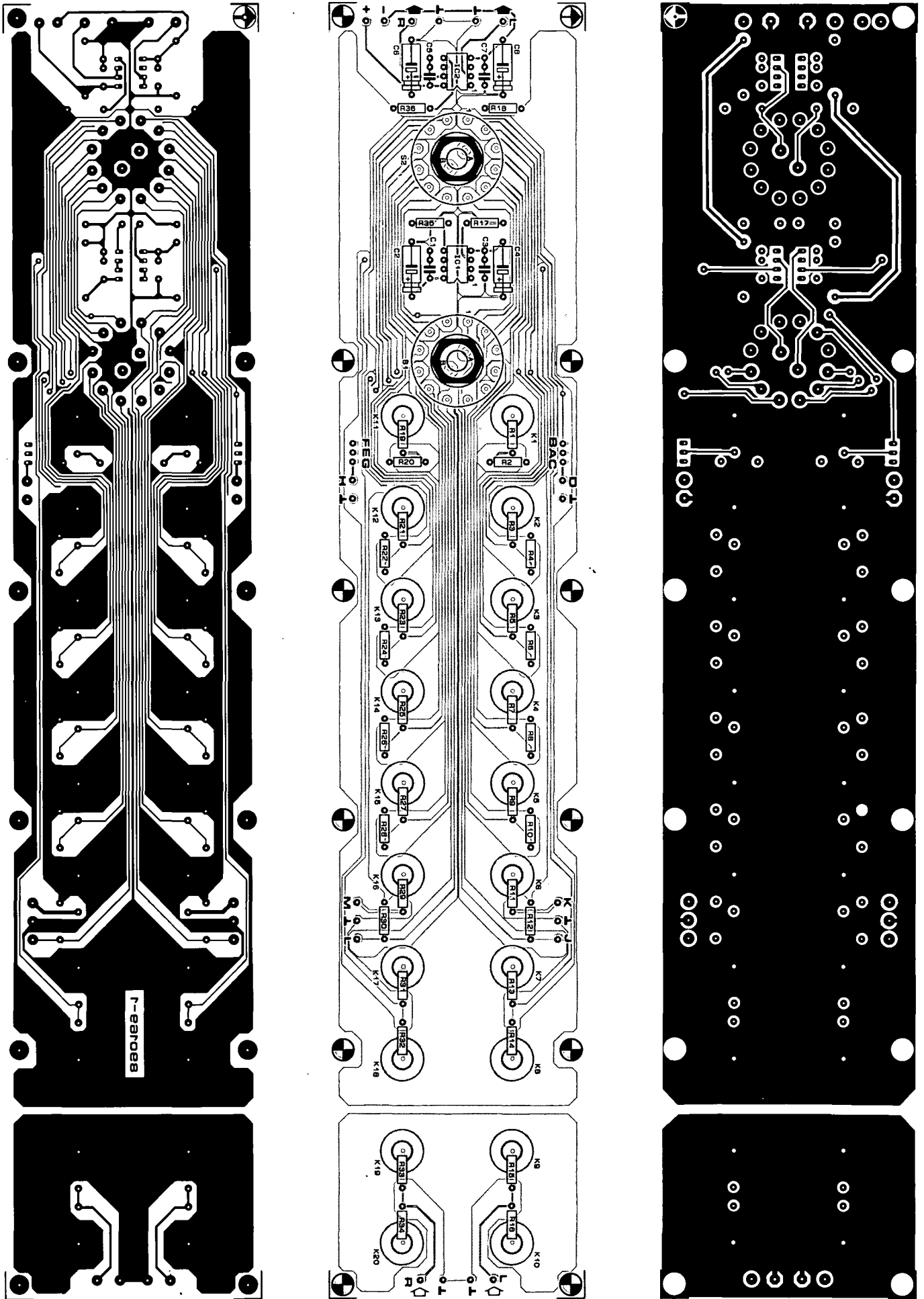
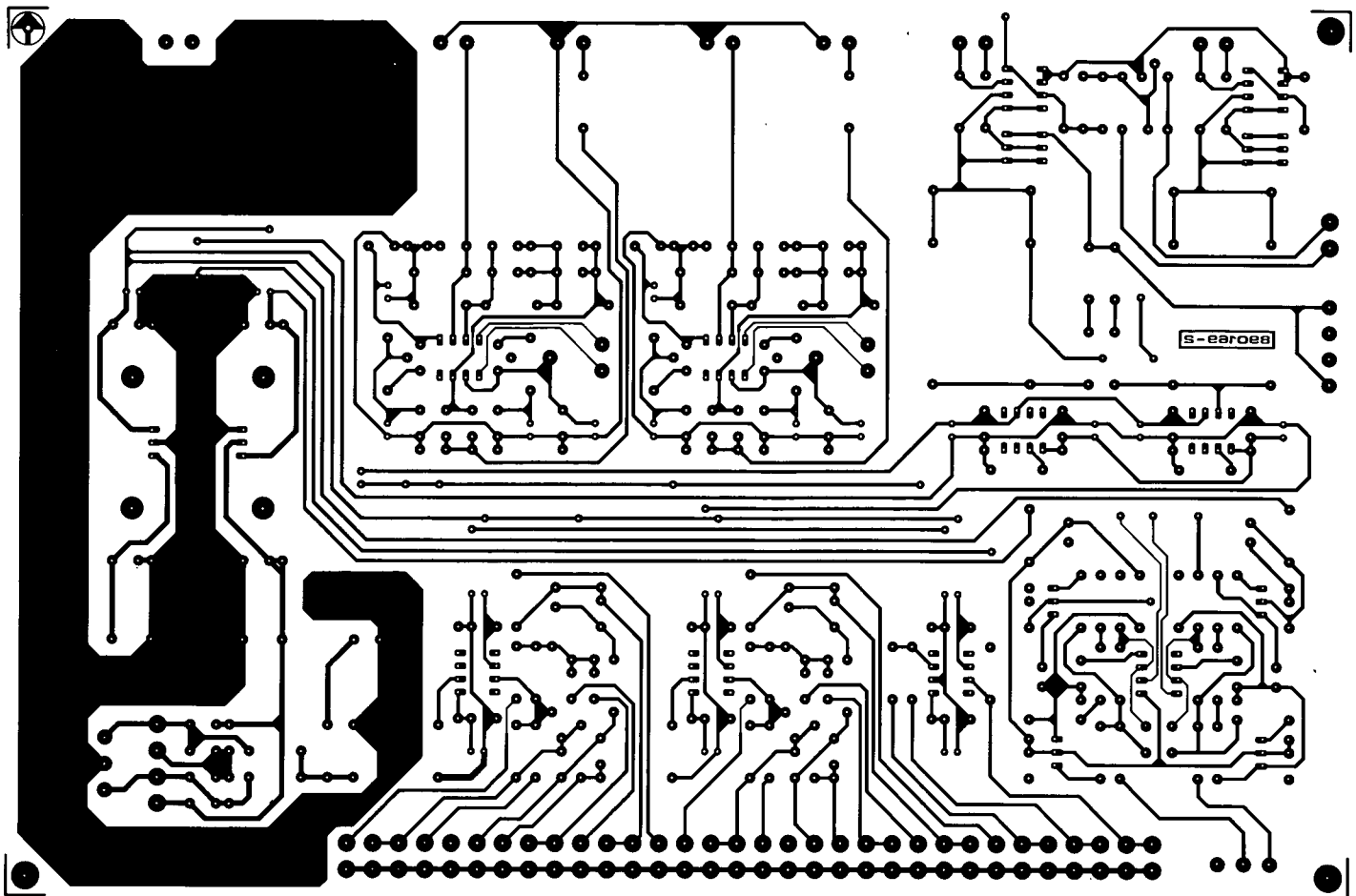



Fig. 6. Printed-circuit busboard. Note that these drawings are reproduced here at 71% of true size.



# MEASUREMENT TECHNIQUES (5)

by F.P. Zantis 

**Audio-frequency technology is of particular interest to many electronics enthusiasts since it seems to surround us in our everyday life in the shape of television and broadcast receivers, audio amplifiers, equalizers, and so on. To keep such apparatus in tip-top condition, it is important to be able to test and check it with suitable equipment.**

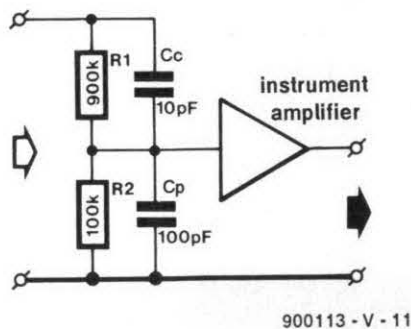
The first question that arises when audio-frequency (AF) equipment is to be checked or tested is what test gear is suitable. For example, a multimeter is only suitable if it is designed to work at frequencies between 30 Hz and 16,000 Hz. Such instruments are pretty expensive: a less expensive alternative is an audio-frequency millivoltmeter. Often, such an instrument is not readily available, but an oscilloscope is, and this is perfectly suitable for audio-frequency measurements. Even the simplest oscilloscope has an operating range extending from DC to about 10 MHz. It should be noted, however, that an oscilloscope measures peak values, while a multimeter or AF millivoltmeter measures root-mean-square (r.m.s.) values.

Apart from an oscilloscope or AF millivoltmeter, a function generator is required to provide sinusoidal and rectangular voltages in the audio frequency range.

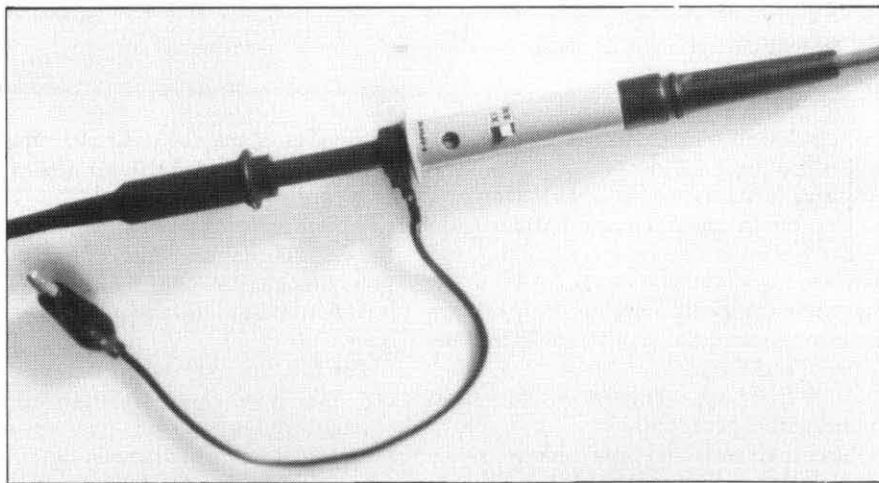
The input resistance of most AF millivoltmeters and oscilloscopes is of the order of 1 M $\Omega$ . The resistors of the input voltage dividers in all test equipment intended for AF measurements are shunted by small capacitors of 1–500 pF. The reason for these becomes clear from Fig. 32. Here, the lower resistor of the 1:10 divider is shunted by the parasitic capacitance, estimated at 100 pF, contained in the wiring and circuit. At a frequency of 16 kHz, this capacitance has a reactance of some 100 k $\Omega$ , which reduces the lower branch of the divider to 50 k $\Omega$ .

Clearly, this will cause a serious error in the measurement. To obviate this, a compensating capacitor is connected in parallel with the upper resistor of the divider. This solution has a disadvantage, however, in that the load presented by the measuring instrument to the measurand depends on the frequency, which is the reason for the limited frequency range of most instruments. The value of the input (i.e., compensating) capacitance is therefore always clearly stated on all instruments intended for operation at audio or high frequencies. The smaller it is, the better (and more expensive) is the instrument. But here again, when the cause of the error is known, its effect can be estimated fairly accurately. Also, it should be remembered that

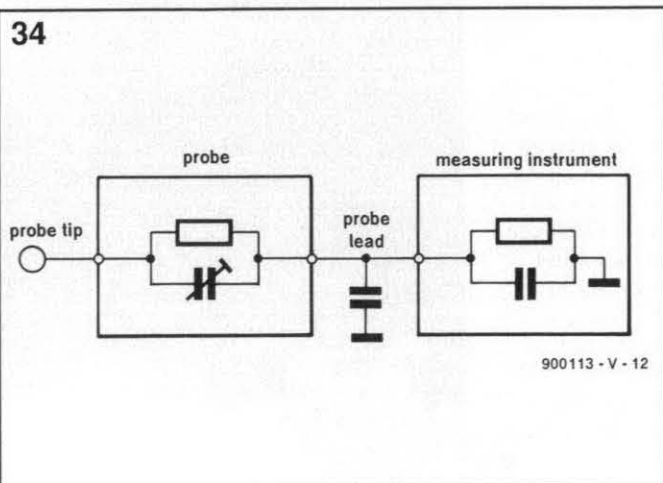
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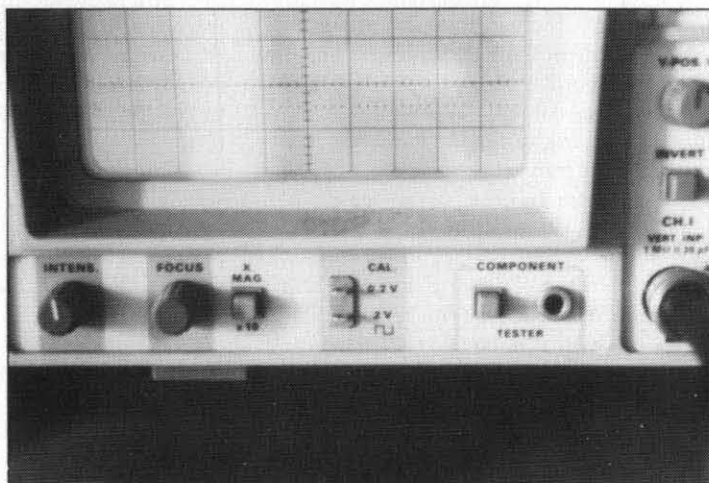
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error-free measurements are not possible.

The capacitance of the screened cable of a probe as shown in Fig. 33 also affects the measurement and it has therefore to be compensated in a similar manner. For this, a variable trimmer as shown in Fig. 34 is normally used. The probe is calibrated with the aid of a rectangular voltage. Such a signal consists of a large number of sinusoidal voltages superimposed on each other. If one or more of these sinusoidal voltages is attenuated, the rectangular signal becomes rounded. Most oscilloscopes have an integral 1 kHz rectangular-signal generator for this purpose as shown in Fig. 35 (CAL). The frequency of this signal is often not very precise, although its level is stabilized and stated in the technical specification, for instance, 0.2 V

peak-to-peak  $\pm 1\%$ . The compensating capacitor is adjusted until the waveform on the screen of the oscilloscope is truly rectangular as shown at the centre of Fig. 36.

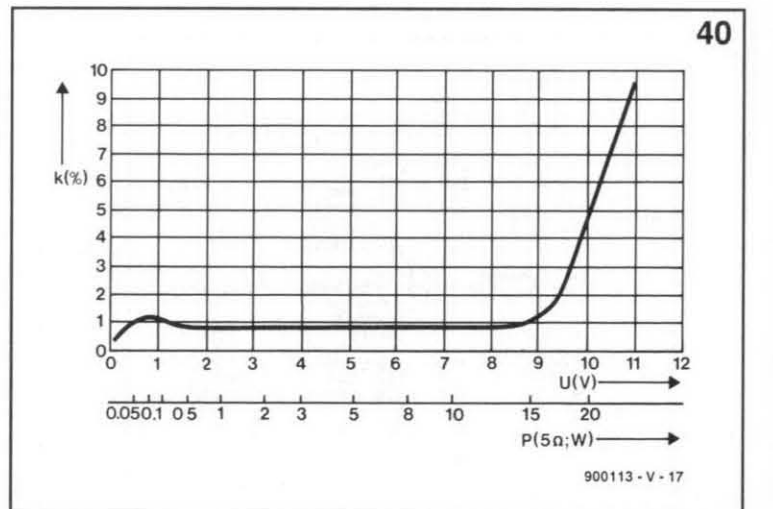
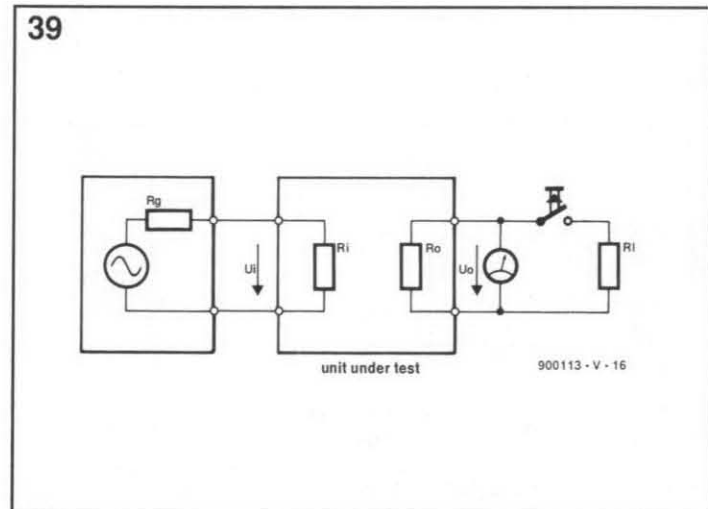
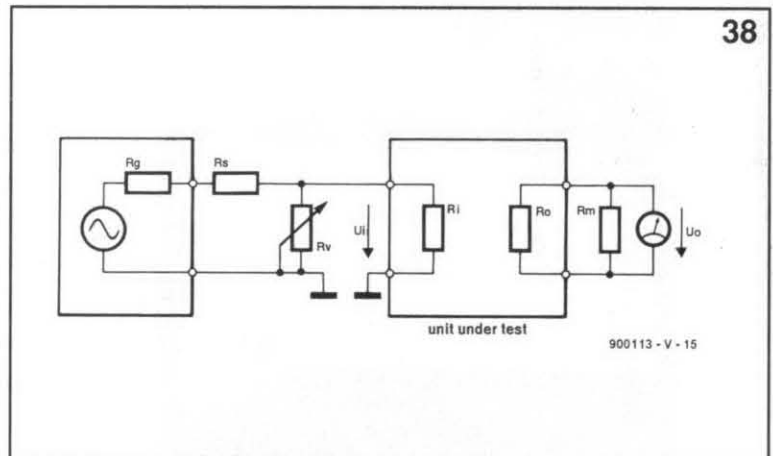
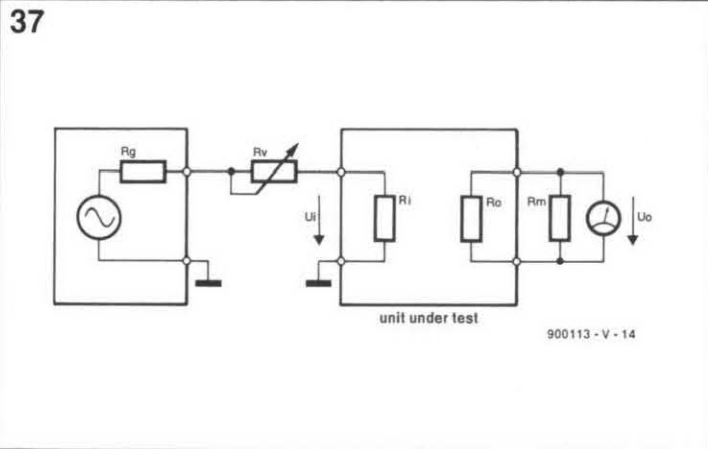
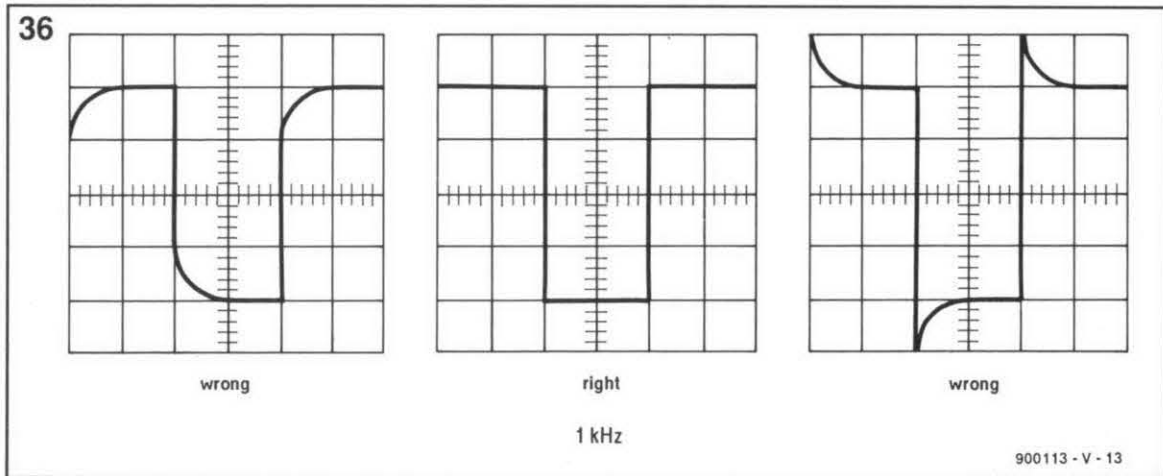
### Measuring input and output resistance

The input resistance,  $R_i$ , of an audio circuit may be measured with a set-up as shown in Fig. 37 if it is appreciably larger than the internal resistance,  $R_g$ , of the signal generator. The output frequency of the generator is 1 kHz. A variable resistor,  $R_v$ , needs to be inserted between the generator and the amplifier input. To keep the error introduced by the load presented by the measuring instrument small, the output voltage rather

than the input voltage of the amplifier is measured. If  $R_v = R_i$ , the input voltage of the amplifier is halved, and so, of course, is its output signal. To be exact,  $R_g$  should be added to  $R_v$ . If the input resistance of the amplifier is very low, the test set-up shown in Fig. 38 should be used.

The output resistance of an amplifier may be ascertained with the set-up shown in Fig. 39. The unit under test, i.e., the amplifier, is driven, but not over-driven, by a tone generator. First, the open-circuit output voltage,  $U_1$ , is measured and then the output voltage,  $U_2$ , across  $R_L$ . From the values of these voltages the output resistance,  $R_o$ , may be calculated as follows

$$R_o = R_L \{ [U_1 - U_2] / U_2 \}$$



Some older amplifiers may have a tendency to become unstable under open-circuit conditions and then generate large spurious signals that not only invalidate the measurement, but may also damage the amplifier and the measuring instrument. It is therefore advisable to monitor the waveform at the output with an oscilloscope. This will also indicate if the amplifier is overdriven, which would also invalidate the test results.

the output power is specified at a distortion of 1%. If therefore the output power needs to be measured exactly, a distortion meter must be used as shown in Fig. 41. The amplifier, terminated into its nominal load  $R_L$ , is then driven till a distortion of 1% is indicated. The output power,  $P_o$ , is then

$$P_o = U_o / R_L$$

power ratio or twenty times the common logarithm of the voltage or current ratio. Thus, if two powers  $P_1$  and  $P_2$  differ by  $n$  decibels,

$$n = 10 \log_{10} [P_1 / P_2]$$

and, if two voltages or currents differ by  $n$  decibels,

$$n = 20 \log_{10} [U_1 / U_2]$$

or

$$n = 20 \log_{10} [I_1 / I_2]$$

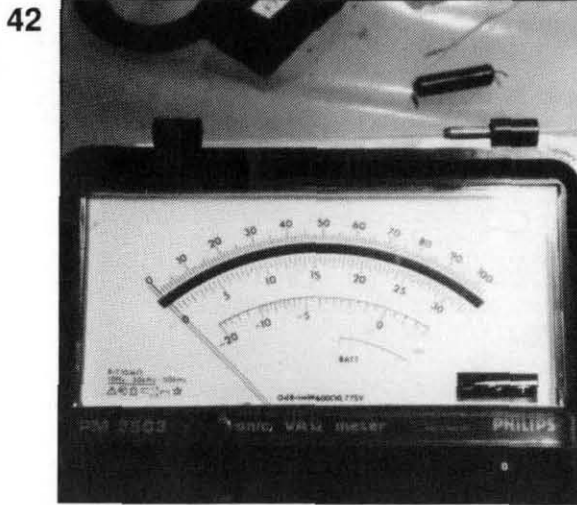
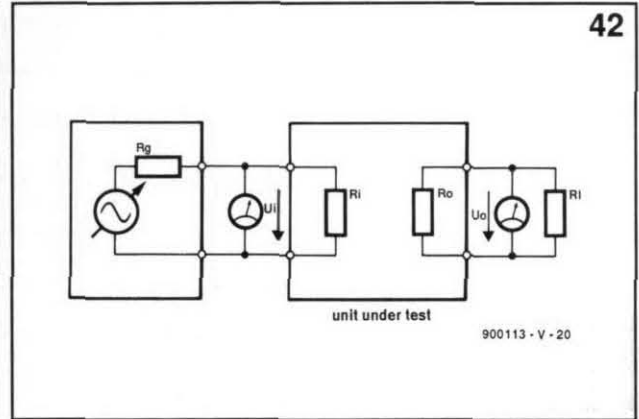
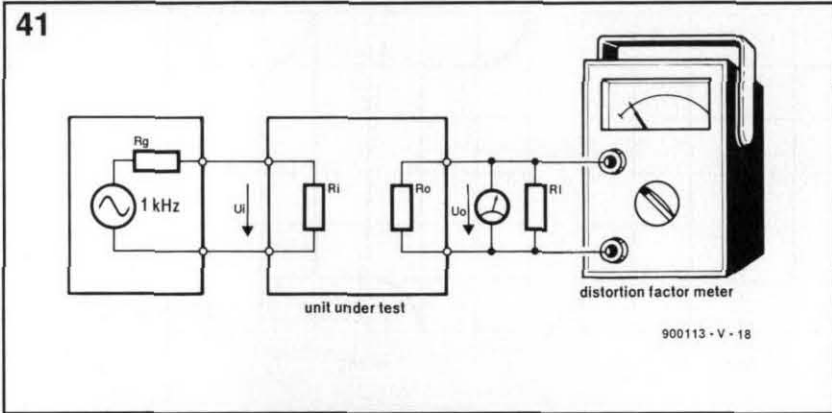
Low-frequency millivoltmeters and some good-quality multimeters have a decibel scale (see Fig. 43 – lowest scale) that enables the ratio to be read directly. If, for instance, the gain of an amplifier is to be measured,

### Measuring output power

The specification of the output power of an amplifier is of practical use only if it includes the distortion, which is an indication of the non-linearity of the amplifier. The distortion increases rapidly when the amplifier is over-driven as shown in Fig. 40. Normally,

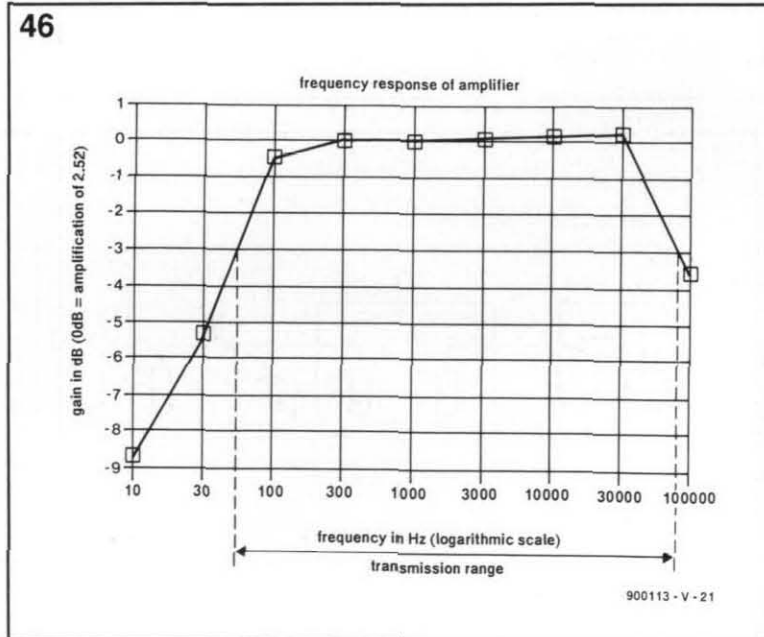
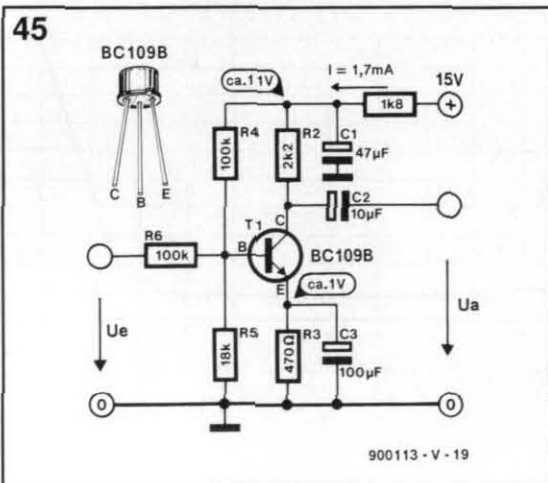
### The decibel scale

The behaviour of audio components is often better observed on a logarithmic scale, which is calibrated in bel, B, or a tenth of this, the decibel, dB. These are dimensionless units expressing the ratio of two powers, currents, voltages, or sound intensities. The decibel is ten times the common logarithm of the



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f / Hz	A / dB
10	-8.67311
30	-5.29
100	-0.46962
300	0.0506
1000	0
3000	0.101
10000	0.200839
30000	0.2008
100000	-3.52182



the amplifier is driven by a 1 kHz signal at a level at which it just is not over-driven. An AF millivoltmeter is connected across its input and the decibel scale read and noted. Then, the millivoltmeter is connected across its output and the decibel scale again read and noted. If the output is greater than the input, the difference between the two readings is the gain in dB; if the input is greater than the output, the difference is the attenuation in dB.

## Measuring frequency response

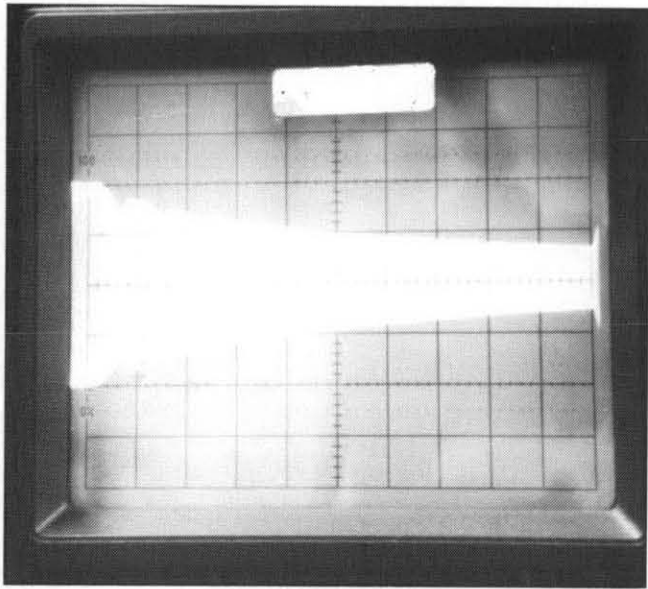
The circuit diagram of a small audio amplifier is shown in Fig. 45. Its frequency response may be determined in a manner similar to that used for measuring its gain: the test set-up is shown in Fig. 42. With a 1 kHz signal input, the level is set to give an output of 0 dB. The decibel readings are noted when the frequency is changed to, say, 10 Hz, 30 Hz, 100 Hz, 300 Hz, 3000 Hz, 10,000 Hz, and 30,000 Hz. The more frequencies are used, the more exact the test result will be. A voltmeter is used in parallel with the signal generator to make sure that the input level to the amplifier remains the same. From

the results, tabulated in Fig. 44, a frequency response curve as shown in Fig. 46 (relating to the amplifier in Fig. 45) may be drawn. The frequency range of the amplifier is that between the two -3 dB points.

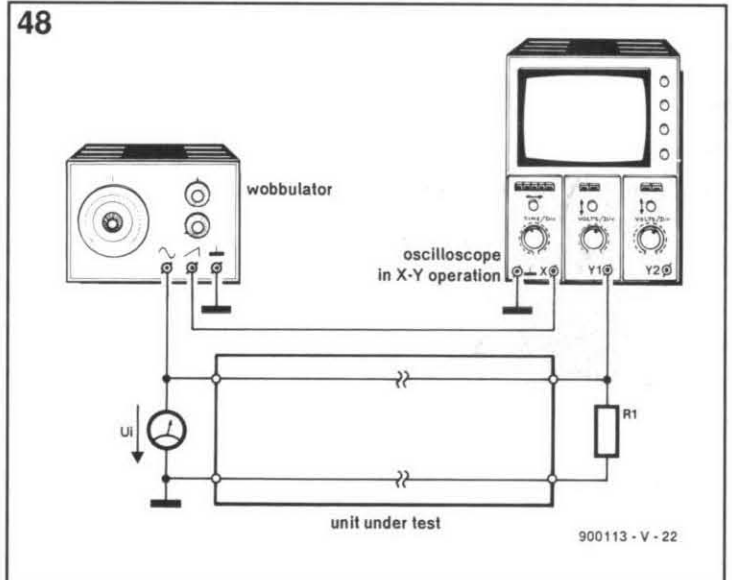
This method of determining the frequency response requires no special or expensive instruments, but it is very time-consuming. Far more convenient is the use of a wobulator, whose output is varied automatically over a predetermined range of frequencies. In the example discussed above, the frequencies would be varied between 10 Hz and 30,000 Hz. Moreover, its scanning rate may be synchronized with the horizontal deflection of the oscilloscope to give a stable trace on the screen. Some wobulators give an additional sawtooth output to facilitate the synchronization with the oscilloscope's horizontal time base. This sawtooth may also be used in X-Y operation to deflect the horizontal trace. Figure 47 shows the screen image during measurements on a cable in this manner. The test set-up for this is shown in Fig. 48: the frequency was varied from 10 Hz to 510 kHz; the horizontal scale was 50 kHz per division. The falling level of the signal at higher frequencies is quite evident.

The use of a wobulator gives an appreciable saving in test time and the oscilloscope always shows a complete signal period, provided the wobulator is adjusted properly. The peak-to-peak value of the signal is easily read from the screen.

The test becomes even more straightforward if the signal at the output of the unit under test is applied to the oscilloscope via a peak detector. The frequency response of the unit under test is then shown on the screen of the oscilloscope as a curve. Again, the screen shows the peak values of the signal, but these may be converted to r.m.s. values with the aid of a voltage divider. The test set-up is shown in Fig. 49, while Fig. 50 shows the result when a band-pass filter is measured in this.

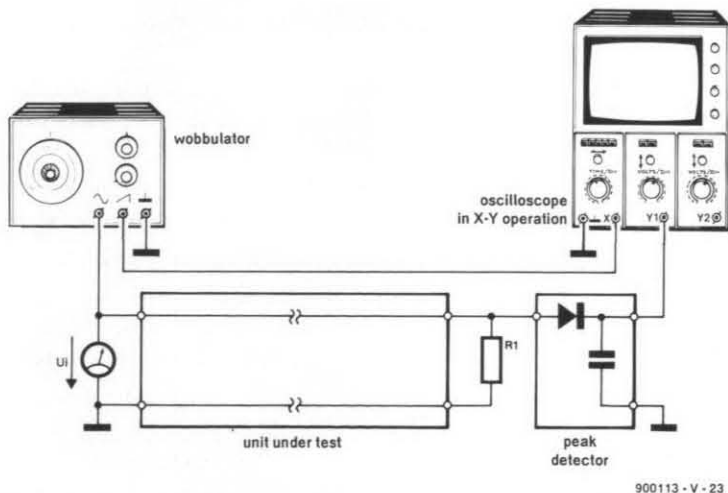


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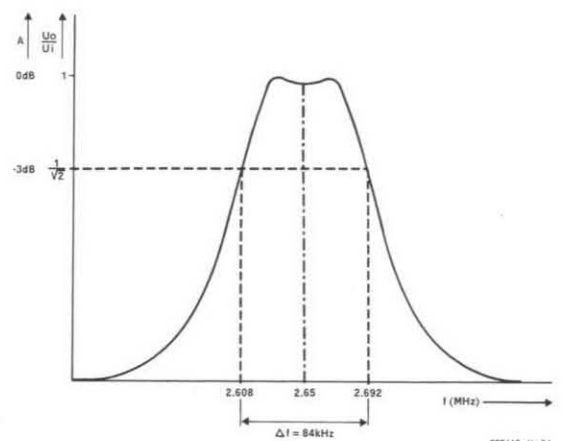


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# DESIGN IDEAS

The contents of this article are based solely on information obtained from the author and do not imply practical experience by *Elektor Electronics*.

## 8-CHANNEL AUDIO/VIDEO SWITCH (PHILIPS COMPONENTS)

J. Vinckier 

### General description

The TDA8440 from Philips Components is a versatile video/audio switch, intended to be used in colour TV receivers equipped with an auxiliary video/audio (SCART) input.

The IC provides two 3-state switches for audio channels, and one 3-state switch for the video channel and a video amplifier with selectable gain (unity gain or 2 times).

The TDA8440 can be used in conjunction with a microcontroller from the MAB8400 family, and is then controlled via

a bidirectional I<sup>2</sup>C bus. Sufficient sub-addressing is provided for the I<sup>2</sup>C bus mode. The IC can also be controlled directly by d.c. switching signals. This option is worked out in the present application note.

### Functional description

The block diagram of the TDA8440 is given in Fig. 1. The IC incorporates three 3-state switches with the following functions:

- one video switch with selectable gain (unity gain or 2 times) for switching between an internal video signal (from the TV's IC amplifier/demodulator) and an AUXILIARY input signal;
- two electronic audio switches for two sound channels (stereo or dual language), for switching between internal audio sources and signals from the AUXILIARY VIDEO/AUDIO connector.

Each switch on board the TDA8440 allows a selection to be made between two input signals and a high-impedance 'off' state. The 'off' state is necessary if more than one TDA8440 is used.

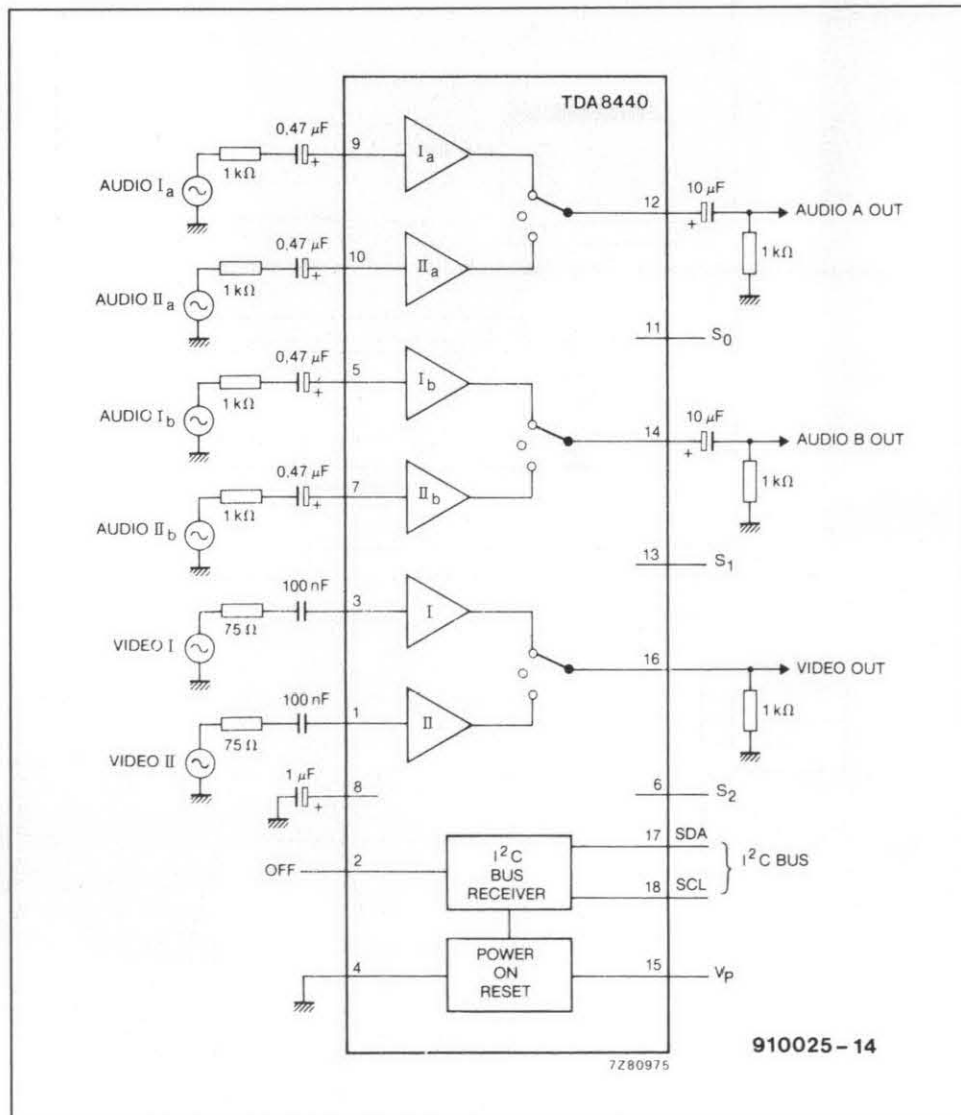


Fig. 1. Block diagram of the TDA8440 audio/video switch IC (illustration reproduced by courtesy of Philips Components).

### TDA8440 MAIN SPECIFICATIONS

- Combined analogue and digital circuitry gives maximum flexibility in channel switching
- 3-state switches for all channels
- Selectable gain for the video channel
- Sub-addressing facility for I<sup>2</sup>C bus
- I<sup>2</sup>C bus or non-I<sup>2</sup>C bus mode (controlled by d.c. voltages)
- Slave receiver in the I<sup>2</sup>C bus mode
- External OFF command
- System expansion possible up to 7 devices (for 14 signal sources)
- Static short-circuit resistant outputs

The SDA and SCL pins can be connected to the I<sup>2</sup>C bus, or to d.c. switching voltages. Inputs S0 (pin 11), S1 (pin 13) and S2 (pin 6) are used for selection of sub-addressing or switching to the non-I<sup>2</sup>C bus mode.

The non-I<sup>2</sup>C bus mode is selected by making S0, S1 and S2 permanently logic high (+12 V). In this mode, the sources (internal and external), and the gain of the video amplifier can be selected via the SDA and SCL pins, by means of the switching voltage from the AUXILIARY VIDEO/AUDIO connector. The four available functions are controlled as follows:

- sources 1 are selected if SDA = 12 V (external source);
- sources 2 are selected if SDA = 0 V (TV mode);
- video amplifier gain is 2 times if SCL = 12 V (external source);
- video amplifier gain is unity if SCL = 0 V (TV mode).

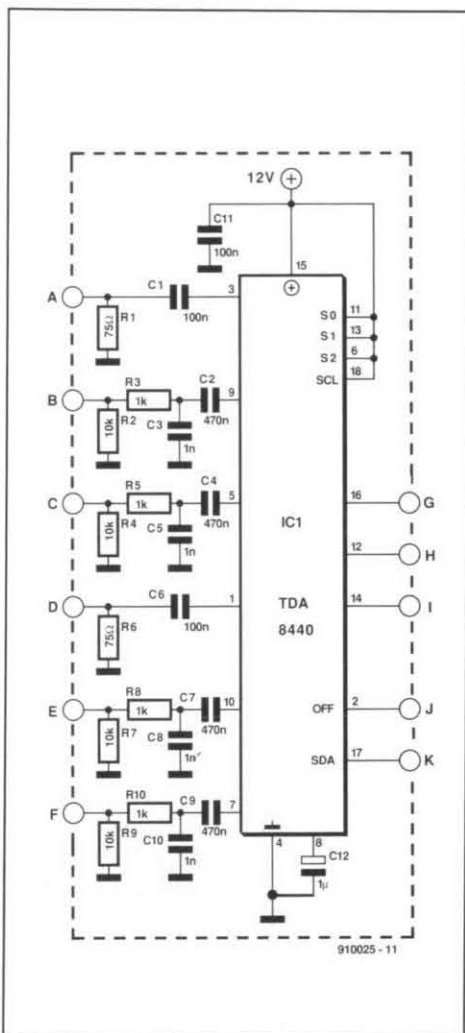


Fig. 2. Circuit diagram of the basic audio/video switching module.

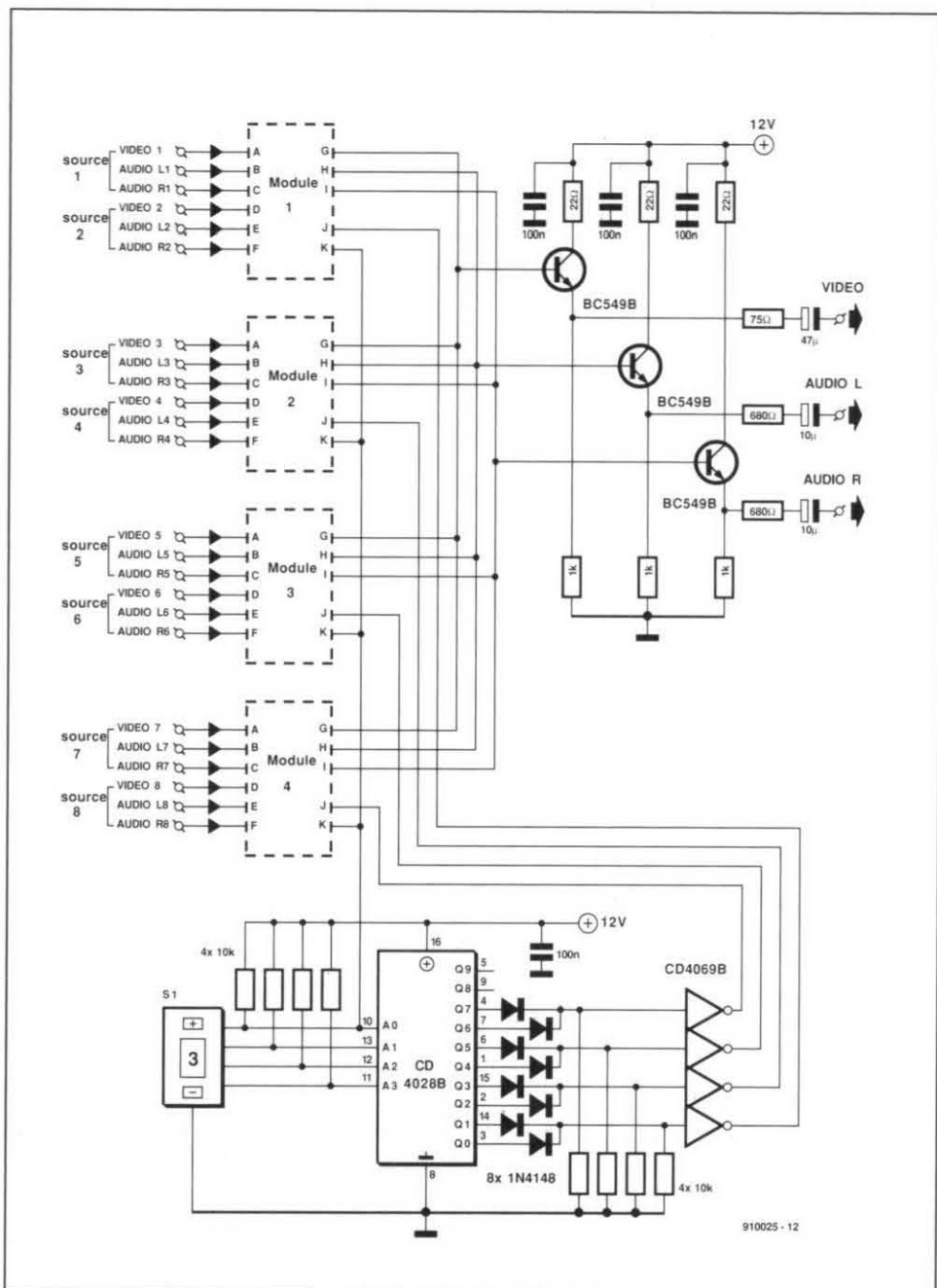


Fig. 3. Four modules as shown in Fig. 2 and a BCD thumbwheel switch interface together make a versatile eight-way electronic audio/video switch.

switch position	BCD				CD4028 decoder outputs								SDA	OFF OFF OFF OFF				Selection
	3	2	1	0	1	2	3	4	5	6	7	8		1	2	3	4	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	-
1	0	0	0	1	1	0	0	0	0	0	0	0	1	0	1	1	1	source 1
2	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	1	1	source 2
3	0	0	1	1	0	0	1	0	0	0	0	0	1	1	0	1	1	source 3
4	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	1	1	source 4
5	0	1	0	1	0	0	0	0	1	0	0	0	1	1	1	0	1	source 5
6	0	1	1	0	0	0	0	0	0	1	0	0	0	1	1	0	1	source 6
7	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	1	0	source 7
8	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	source 8

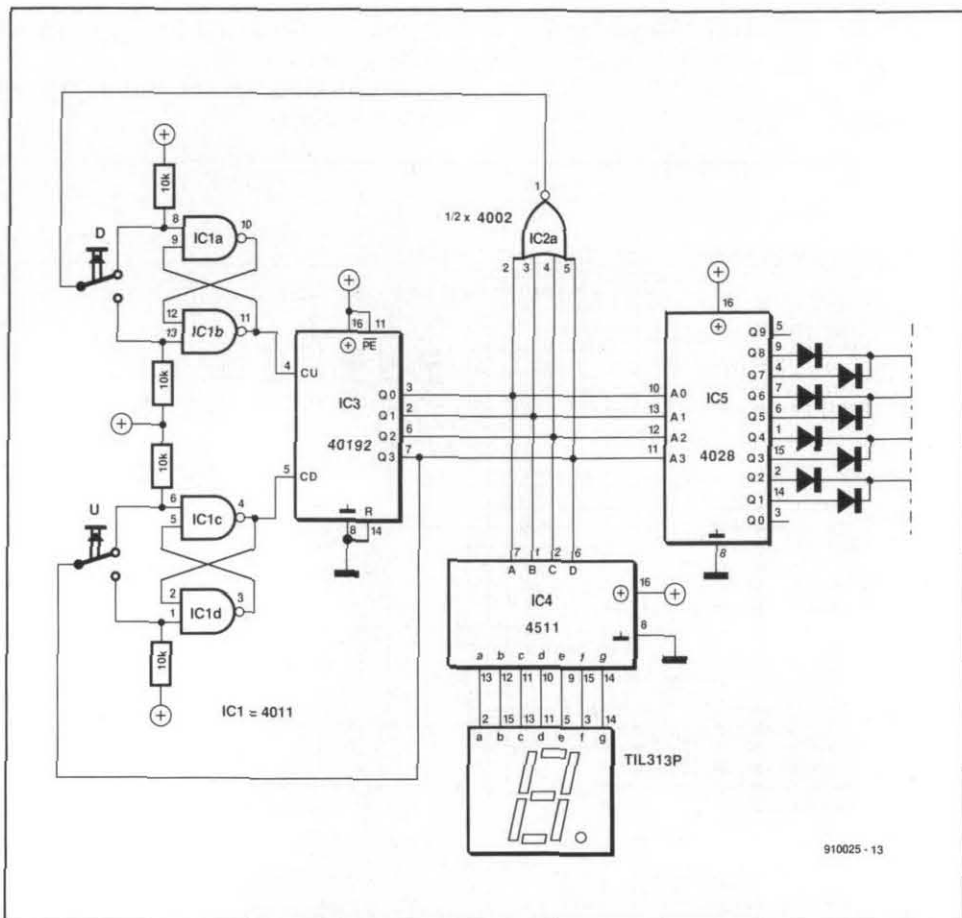


Fig. 4. A possible substitute for the BCD thumbwheel switch in the circuit of Fig. 3.

If more than one TDA8440 device is used in the non-I<sup>2</sup>C bus system, the OFF pin (pin 2) can be used to switch off the desired devices. This can be done via the 12-V switching voltage of the AUXILIARY VIDEO/AUDIO connector:

- all switches are in the high-Z (off) position if OFF = 12 V;
- all switches are in the position selected with SDA if OFF = 0 V.

### Application circuits

The circuit shown in Fig. 2 is one of four identical switching modules based on the TDA8440. The two video inputs, A and D, are terminated with 75-Ω resistors, while the two stereo audio inputs (pairs B-C and E-F) are terminated with 10-kΩ resistors. The audio signals are filtered with R-C networks to suppress noise. The amplification of the video switch is set to 2 times here by the permanently high level at the SCL input. The voltage at the SDA input determines the source selection as discussed above.

The final 8-way audio/video switcher (Fig. 3) contains four modules of the type shown in Fig. 2. A thumbwheel switch with BCD-coded outputs is used to select one of eight AV channels. The LSB (least-significant bit) of the BCD switch is connected to the SDA inputs of the four modules.

The four 'module select' lines are created with a CD4028 BCD-to-decimal decoder. The eight decoded outputs of this IC are connected in pairs. Each of the four signals so obtained is inverted by a CD4069

gate to ensure the correct control of the OFF input of the relevant AV switching module. The channel selection of the 8-way switching unit is shown in the Table below Fig. 3. All channels are switched off by setting the thumbwheel switch to 0.

The audio and video outputs of the four modules are connected in parallel and buf-

fered with the aid of emitter follower stages that provide the appropriate source impedance (75 Ω for the video output and about 600 Ω for the audio outputs). The gain of the video channel is set to two times here to compensate the 6 dB voltage attenuation introduced by the series resistor at the video output and the input resistance of the load.

Connectors for the inputs and outputs are not specified here since they depend on the practical use of the switching unit. BNC sockets, phono sockets or SCART sockets may be used as required. Likewise, the switcher can be built to handle fewer or more than eight AV channels as proposed here. A simple AV switcher for two video and two audio channels, for instance, requires only one module controlled by a much simpler selection circuit than the BCD switch plus the 4028.

One application of the AV switching unit is the connection of a video recorder, a home computer and a CD player to the SCART input of the TV set, eliminating the need of changing lots of cables any time a different source is selected.

Finally, a 'discrete' replacement for the (expensive) BCD switch is given in Fig. 4. The channel selection is effected by pressing the U (up) and D (down) keys. The number of the selected channel appears on a 7-segment LED display.

### Reference:

TDA8440 Development Data. Philips Components.

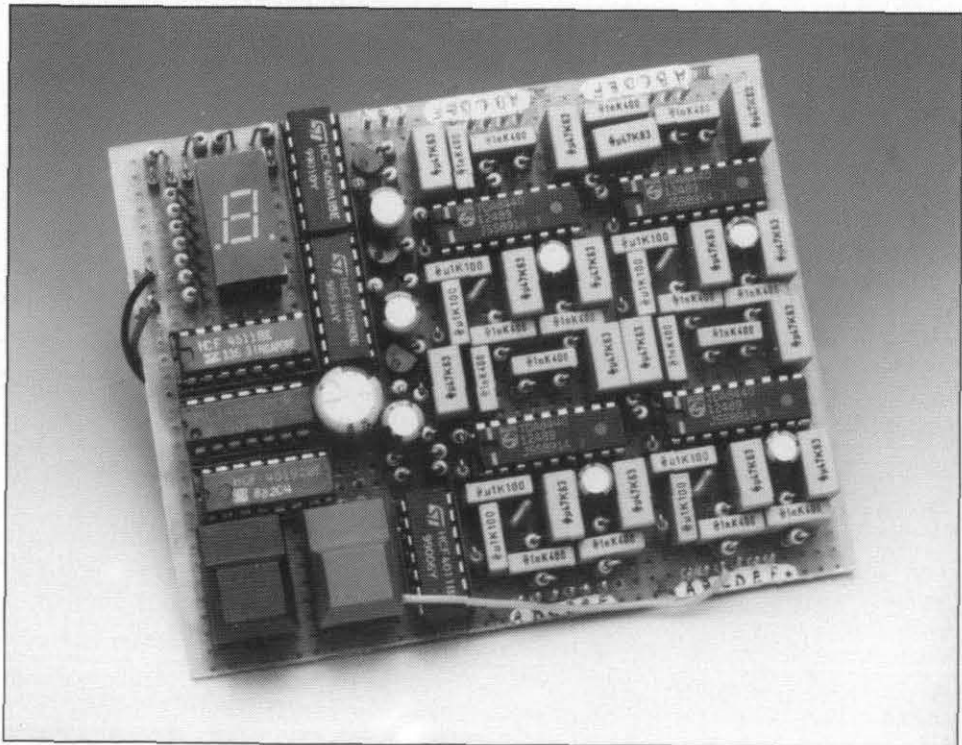


Fig. 5. Prototype of the eight-way audio/video switch built on a small piece of Vero stripboard. In this version, the unit has the up/down keys and the 7-segment LED display shown in Fig. 4 to set and visualize the selected AV channel.

# ELECTRONIC EXPOSURE TIMER

by A. Ladwig

**Many amateur photographers spend a disproportionate amount of their time in the dark-room. The exposure timer presented here can cut down that time because the exposure is controlled entirely electronically. That results not only in perfect prints every time, but also in a reduction in paper and chemicals used and that is good for the environment and for your wallet.**

The traditional way to determine the exposure time for a photographic print is to use a test strip and expose the negative for a number of different periods. The strip is then developed and a judgment taken which exposure time is the most nearly perfect one and that time is taken to print the negative(s). Clearly, this technique wastes time, paper and chemicals. With the timer\* described here, this technique becomes a thing of the past. It also ensures that the setting of the diaphragm in the enlarger does not affect the exposure meter.

The procedure with the timer is simplicity itself: the negative or slide is placed in the enlarger, the wanted size of the print is determined, the enlarger is focused, the photographic paper is placed on the easel and covered with a sheet of glass, and the start button on the timer is pressed. The electronics in the timer will ensure perfect exposure.

## Principle of operation

Two methods are commonly in use to assess the correct exposure time for prints. The spot measurement is used for determining the exposure for a certain part of the photograph. This is of particular interest if the photo has sharp contrasts, such as somebody standing in the shade against a very bright background.

The second method is the integrated measurement in which the entire photograph is used to determine the correct exposure time. This is done by diffusing the light falling on to the paper with the aid of some frosted glass and measuring the light intensity.

The two methods may be combined by concentrating the integrated measurement on the light falling on the centre of the photograph, and this is the one used in the present timer. The light is measured at twelve different points spread across the paper. The diffuser is the paper on which the print will appear. This method of measurement is made possible by placing the light-sensitive cells of the exposure meter not above the paper as is usual, but underneath it. The only proviso of the method is, therefore, that the paper is translucent, which it normally is.

\*Patent applied for (provisional Patent Number is G 89 08 446.2)



Fig. 1. The timer in use in a typical dark-room.

## The design

The twelve light-sensitive cells are contained in a man-made fibre paper easel as shown in Fig. 2. Each of the cells consists of a photo-transistor Type BPW40. The easel consists of a sheet of transparent perspex (US: lucite) into which 12 holes are drilled. The cells must not protrude through the sheet (since the paper would then not lie flat and cause the photo to be distorted). The diameter of the holes should preferably be larger at the paper side than at the underside.

Since experience shows that most photos are printed in 130x180 mm (5x7 in.) format, the prototype easel has been made in that format, too, but you may, of course, decide on other dimensions.

Tests with the prototype to verify that the principle is sound resulted in output voltages at five of the cells (P<sub>1</sub>-P<sub>5</sub>) as shown in Table 1. The tests were made with the negative in the enlarger first not illuminated for 1 second and then exposed to maximum illumination for 32 seconds. The diaphragm of the enlarger was stopped down by two *f*-numbers. The voltages were measured with a digital volt-

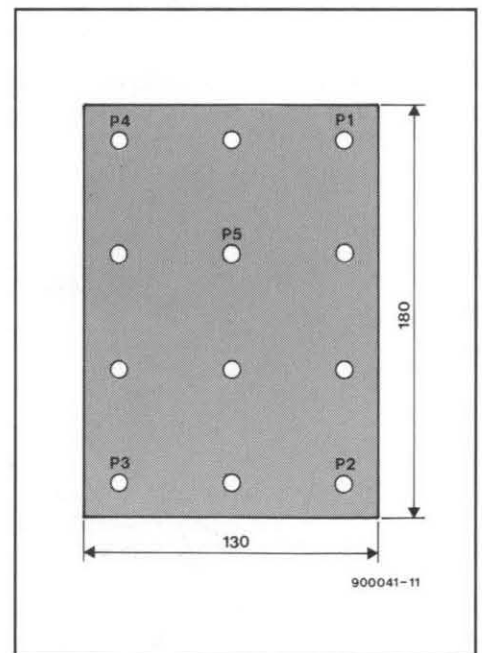


Fig. 2. Layout of the perspex (lucite) easel that houses the twelve photocells.

Table 1

	Exposure	
	Min.	Max.
P <sub>1</sub>	17 mV	490 mV
P <sub>2</sub>	18 mV	495 mV
P <sub>3</sub>	16 mV	491 mV
P <sub>4</sub>	17 mV	488 mV
P <sub>5</sub>	26 mV	750 mV

meter with  $R_i = 10 \text{ M}\Omega$ .

It is clear that the cell at the centre of the easel (P<sub>5</sub>) receives more light than those at the edges. Furthermore, the tolerances of the phototransistors proved to be small enough to be of no consequence to the operation.

The block diagram in Fig. 3 shows how the output voltages of the phototransistors are processed. First, they are summed and the total voltage,  $U_t$ , is fed to a time-voltage integrator. The output of the integrator,  $U_{int}$ , is proportional to the luminous flux radiated on to the easel. The output is then compared with a reference voltage,  $U_r$ ; when these two potentials are equal, the exposure is correct. Since the sensitivity of different printing paper varies, the integrator is provided with a control with which the integration constant can be altered. This enables the timer to be calibrated according to the photographic paper used.

At the moment  $U_{int} = U_r$ , the lamp of the enlarger is switched off and the photo is ready for chemical processing. Arrangements may be made to switch on the dark-room lighting at the same time; this is, however, not advisable when colour photographs are being processed as that should take place in the dark.

During exposure, the light in the dark-room must be switched off, since diffused light will adversely affect the exposure measurement and, consequently, the quality of the print. As stated earlier (see also Table 1), the photocells provide a maximum output of 490–750 mV at an exposure time of 1 s and a minimum potential of 16–19 mV at an exposure time of 32 s. The output voltage,  $U_{int}$ , of the integrator at which the print is exposed optimally is calculated from:

$$U_{int}(t) = -\frac{1}{RC} \int_{t_0}^{t_1} U_t dt$$

where  $t_1 - t_0 = t_{exp}$ , the exposure time. From this, it follows that

$$\begin{aligned} U_{int}(t) &= -\frac{1}{RC} (U_t t_1 - U_t t_0) \\ &= -\frac{1}{RC} U_t t_{exp} \end{aligned}$$

At the longest exposure time, the average output voltage of the photocells is 19 mV. The output of the integrator is then

$$32 \times 12 \times 19 \times 10^{-3} = 7.3 \text{ V.}$$

At the shortest exposure time used in the design stages, the average output of the photocells is 620 mV. At 1 s, the shortest period possible on the timer, the output of the integrator is

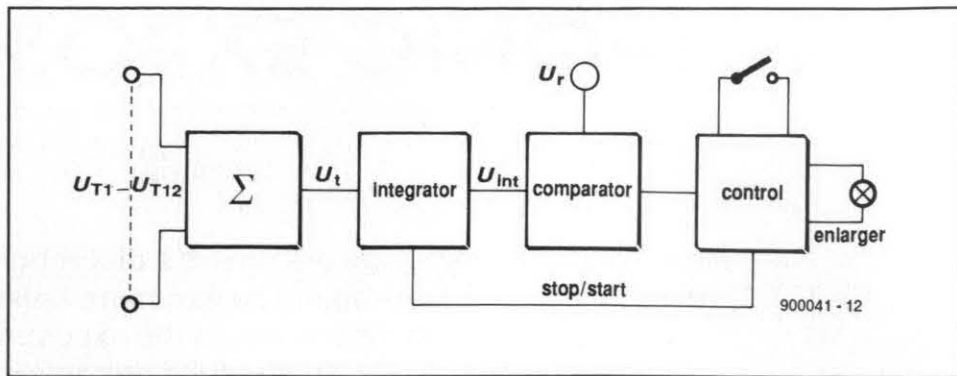


Fig. 3. Block diagram of the exposure timer.

$$12 \times 620 \times 10^{-3} = 7.44 \text{ V.}$$

From these results, it would appear that the reference voltage for the timer should be about 7.4 V. To make calibration possible, the level chosen in the prototype is 9 V.

### The circuit

The circuit diagram of the timer is given in Fig. 4. The twelve phototransistors are connected as emitter followers whose emitters are connected to the summing circuit via  $10 \text{ M}\Omega$  resistors. The phototransistors are shown in groups of four to coincide with the way they are to be fitted on three separate PCBs (see Fig. 5). This enables the constructor to experiment at an early stage with the mechanical layout of the exposure timer.

Opamp IC<sub>1</sub> sums the output voltages of phototransistors T<sub>1</sub>–T<sub>12</sub> and inverts the result. This inversion is necessary because integrator IC<sub>2</sub>, which follows IC<sub>1</sub>, also inverts its input.

Integration constant RC is obtained from R<sub>28</sub>, P<sub>1</sub>, and C<sub>6</sub>. Preset P<sub>1</sub> enables the constant to be varied so that calibration to allow for the various types of paper is possible. If the range of the preset is not sufficient for a certain type of paper, the value of C<sub>6</sub> may be altered accordingly. When the exposure time is too long, halving the value of C<sub>6</sub> results in one stop down; when it is too short, doubling the value of C<sub>6</sub> results in one stop up.

The integrator is followed by IC<sub>3</sub>, which compares the output of the integrator with a reference voltage,  $U_r$ , derived from potential divider R<sub>30</sub>–R<sub>31</sub>. As soon as the integrator voltage becomes larger than the reference voltage, the level at the output of IC<sub>3</sub> goes high and bistable (flip-flop) IC<sub>4a</sub> is reset. This causes output  $\bar{Q}$  to go high, which results in transistor T<sub>13</sub> being switched on. The integrating capacitor, C<sub>6</sub>, is then completely discharged and the timer is ready for use. At the same time, output Q of IC<sub>4a</sub> goes low, which causes transistor T<sub>14</sub> to switch off, so that relay Re<sub>1</sub> is deenergized. The timer is then switched off and the light in the dark-room comes on again (if wanted).

Since the enlarger is required to be on permanently during focusing and some other operations, switch S<sub>2</sub> has been added to bypass the electronics.

Start switch S<sub>1</sub> passes a clock pulse to

### PARTS LIST

#### Resistors:

R<sub>1</sub>, R<sub>3</sub>, R<sub>5</sub>, R<sub>7</sub>, R<sub>9</sub>, R<sub>11</sub>, R<sub>13</sub>, R<sub>15</sub>, R<sub>17</sub>, R<sub>19</sub>,  
R<sub>21</sub>, R<sub>23</sub> = 1 MΩ  
R<sub>2</sub>, R<sub>4</sub>, R<sub>6</sub>, R<sub>8</sub>, R<sub>10</sub>, R<sub>12</sub>, R<sub>14</sub>, R<sub>16</sub>, R<sub>18</sub>, R<sub>2</sub>  
R<sub>22</sub>, R<sub>24</sub>, R<sub>27</sub> = 10 MΩ  
R<sub>25</sub> = 470 kΩ  
R<sub>26</sub> = 820 kΩ  
R<sub>28</sub> = 6M8  
R<sub>29</sub> = 22 kΩ  
R<sub>30</sub>, R<sub>32</sub>, R<sub>33</sub> = 100 kΩ  
R<sub>31</sub> = 330 kΩ  
R<sub>34</sub> = 10 kΩ  
P<sub>1</sub> = 2M5

#### Capacitors:

C<sub>1</sub>–C<sub>9</sub>, C<sub>12</sub> = 100 nF  
C<sub>10</sub>, C<sub>11</sub> = 100 μF, 25 V  
C<sub>14</sub>, C<sub>15</sub> = 100 μF, 25 V, radial

#### Semiconductors:

IC<sub>1</sub>, IC<sub>2</sub> = LF356  
IC<sub>3</sub> = LM741  
IC<sub>4</sub> = 4013  
IC<sub>5</sub> = 7812  
IC<sub>6</sub> = 7912  
T<sub>1</sub>–T<sub>12</sub> = BPW40  
T<sub>13</sub> = BS170  
T<sub>14</sub> = BC547B  
D<sub>1</sub>, D<sub>2</sub> = 1N4148  
D<sub>3</sub>–D<sub>6</sub> = 1N4001

#### Miscellaneous:

K<sub>1</sub> = 5-way DIN plug, 180°  
K<sub>2</sub> = 5-way DIN socket for PCB, 180°  
S<sub>1</sub> = push-button switch, 1 make  
S<sub>2</sub> = miniature switch, 1 make  
Re<sub>1</sub> = relay, 12 V, for PCB mounting  
Tr<sub>1</sub> = mains transformer, 2×9 V, 2.8 A  
PCB Type 900041



bistable (flip-flop) IC<sub>4a</sub>, which starts the entire measuring cycle. Since the D input of the bistable is connected permanently to the positive supply line, the Q output goes high

when S<sub>1</sub> is pressed. The integrator commences operation and the enlarger is switched on. When the supply is switched on, network R<sub>33</sub>-C<sub>9</sub> ensures that the bistable receives a

clock pulse although the D input is then still low (because the time constant on that input is much longer). This ensures that after power-on the enlarger is switched off and the dark-

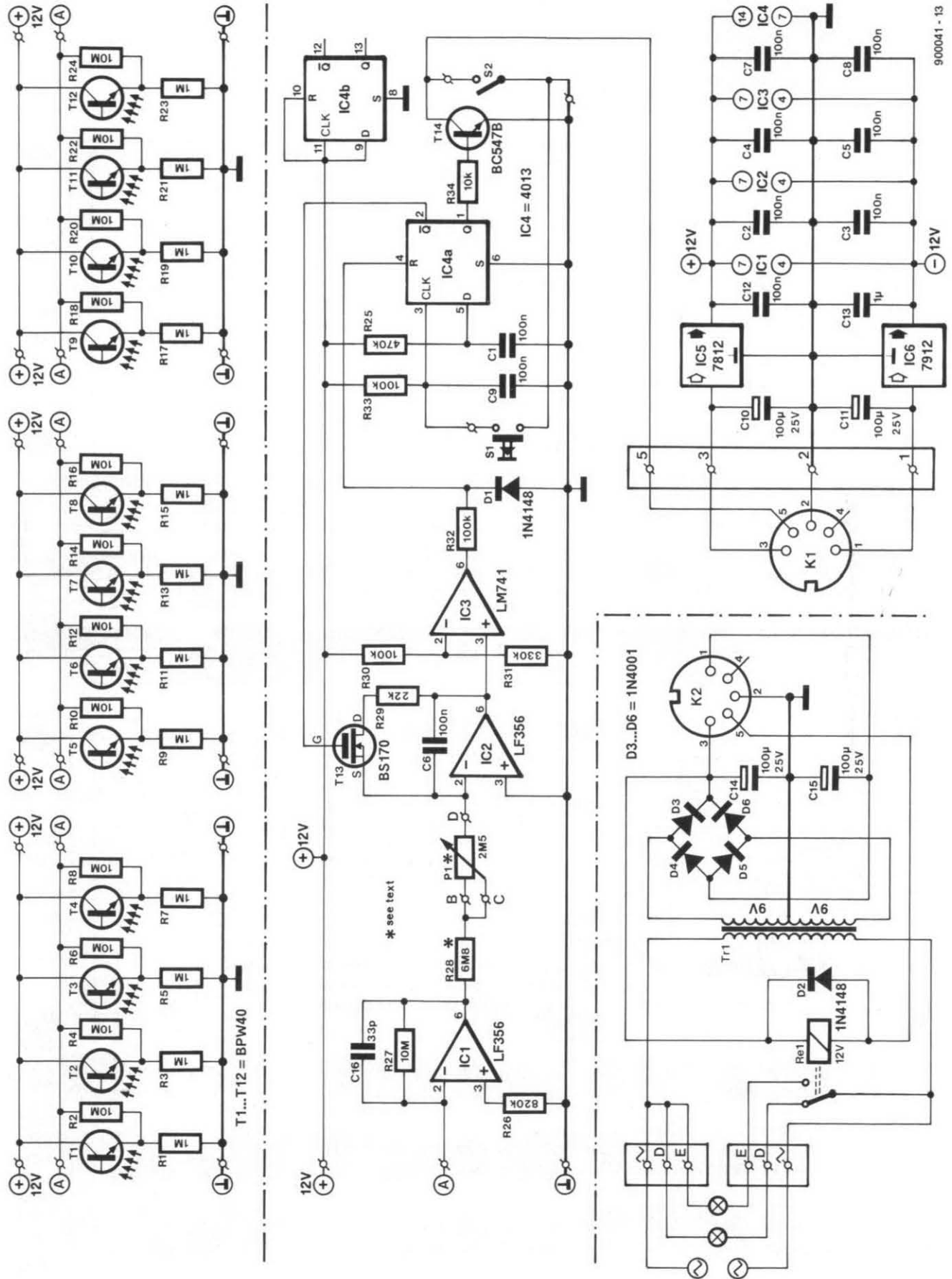


Fig. 4. Circuit diagram of the electronic exposure timer.

room lights are on.

From Fig. 4 it is seen that the circuit consists of two sections that are interconnected by a length of 4-way cable and two five-pin DIN plugs. This arrangement makes it possible for some of the components, such as the mains transformer, relay, mains entry to be fitted away from the working area, which then only needs to house the control box of the timer. An additional advantage is that mains-carrying parts are well away from the

chemicals to lessen the likelihood of any mishaps.

The power supply for the timer is fairly simple. The alternating voltage at the secondary winding of the mains transformer is rectified (full wave) by D<sub>3</sub>-D<sub>6</sub> and smoothed by C<sub>14</sub> and C<sub>15</sub>. A negative and a positive voltage are then supplied via a length of 4-way cable to the voltage regulators, IC<sub>5</sub> and IC<sub>6</sub>, in the control box. These regulators provide supply voltages of +12 V and -12 V. The

mains supply for the dark-room lights and the enlarger may be taken from the 3-way terminal blocks.

## Construction

The five printed-circuit boards for the entire timer are shown in Fig. 5. Since these are delivered as one, they need to be separated with a fret saw (US: jig saw) before being populated.

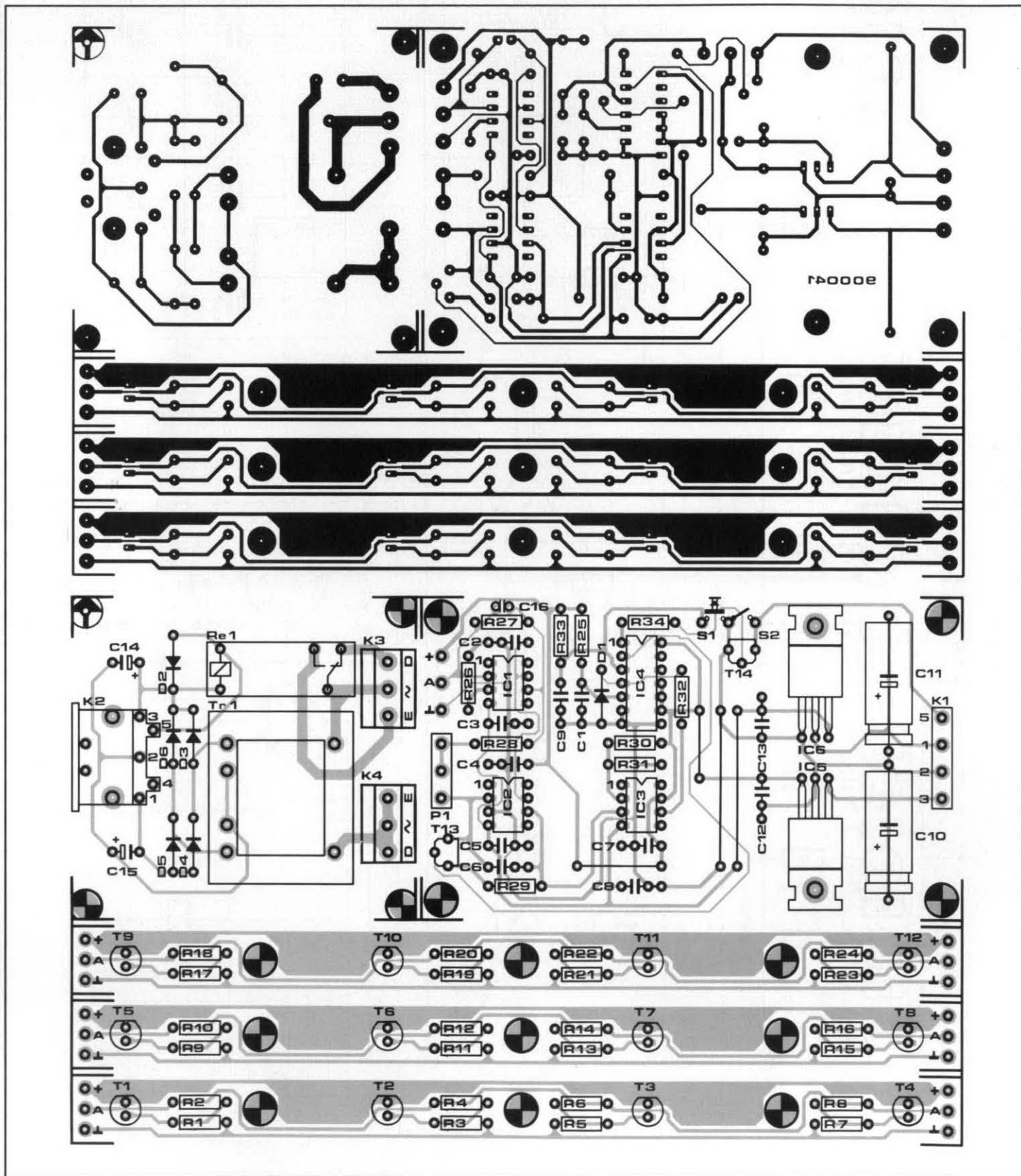


Fig. 5. The printed-circuit board for the electronic exposure timer consists of five parts.

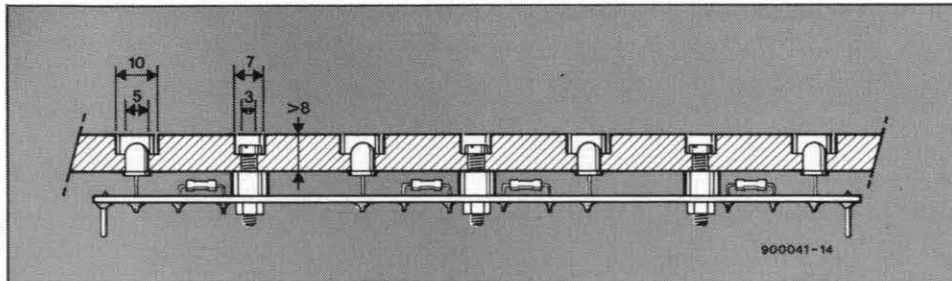


Fig. 6. Construction of the perspex (lucite) easel. It is important that the upper surface is smooth to ensure that the paper lies perfectly flat.

The three prints housing the phototransistors must be mounted on to the perspex (US: lucite) easel as shown in Fig. 6. The perspex sheet must be thick enough to take in the bodies of the phototransistors. After the three PCBs have been interconnected, they are linked to the motherboard by a length of

3-way cable.

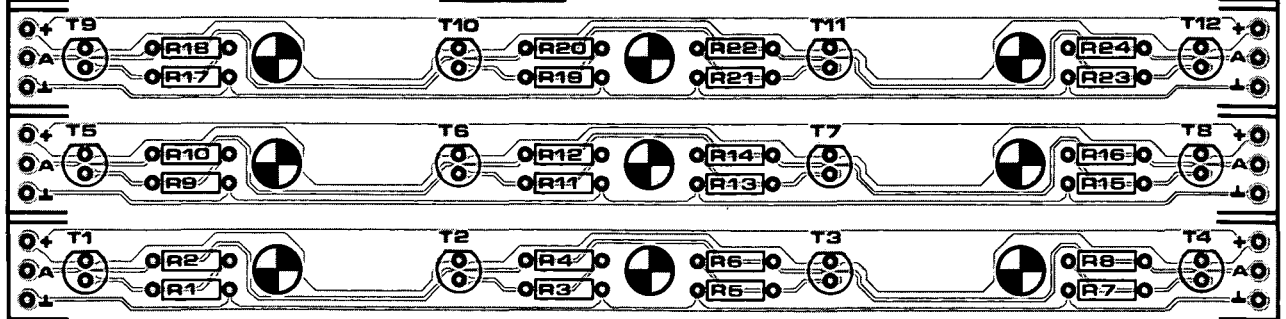
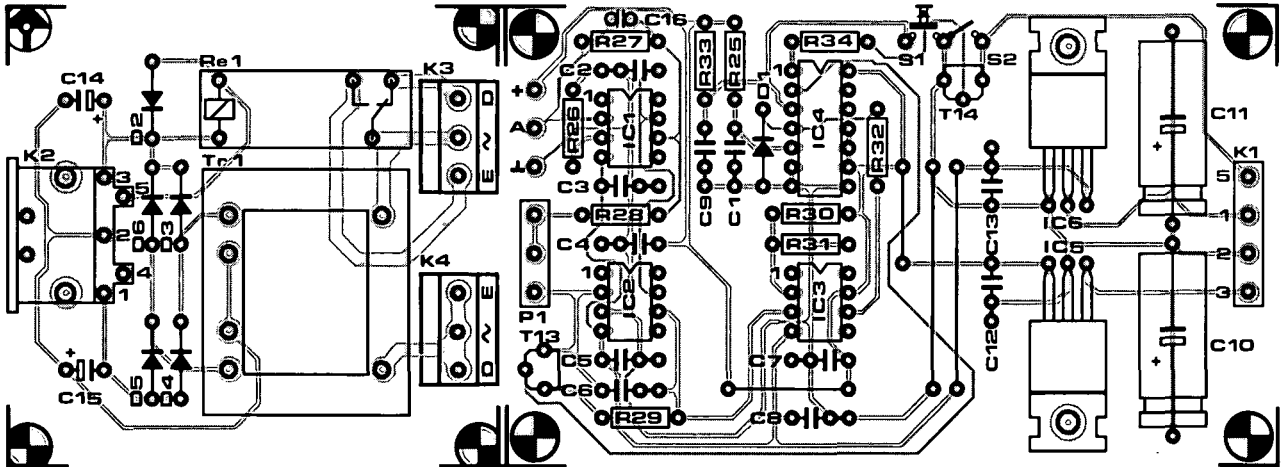
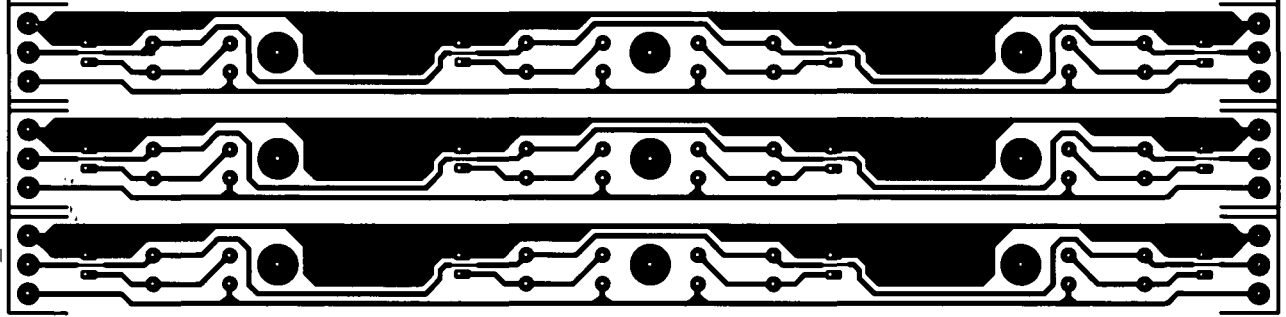
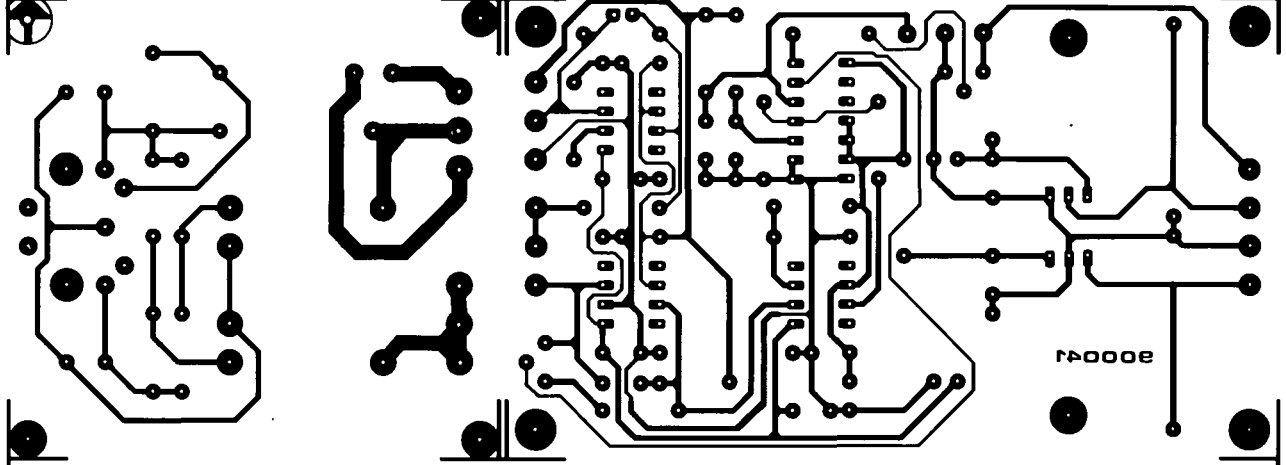
It is advisable to start by placing the required wire bridges on the motherboard and then mount the other components. The regulators do not need a heat sink and may therefore be fitted directly on to the board. Potentiometer  $P_1$  and switches  $S_1$  and  $S_2$  are

mounted on the front panel of the enclosure that contains the motherboard.

It is also possible to fit the motherboard underneath the easel. Two different types of DIN connector must then be used for connecting the board to the power supply and to the switches and potentiometer which are then housed in a small, separate box.

If at all possible, fit the power supply board in a man-made fibre enclosure with moulded mains plug. If wanted, the dark-room light(s) can be switched from this unit via a separate cable. The enclosure should be fitted with a hole through which the DIN plug for the power lines can be passed.

Once the boards have been completed and fitted in the enclosures,  $P_1$  must be adjusted with the aid of a number of test exposures. The setting so found needs to be altered only if photographic paper with a different sensitivity is used in the future. ■



# CORRECTIONS

## Wattmeter

April 1991, p. 32-35

With reference the circuit diagram, Fig. 1, the right-hand terminal of the lower section of switch S2 should be connected to the circuit ground. This point is indicated by a dot.

In the adjustment procedure given on page 35, the references to presets P4 and P5 have been transposed. Contrary to what is stated, P4 sets the VY offset, and P5 the VX offset. The functions of the presets are shown correctly in the circuit diagram, Fig. 1.

To improve the accuracy of the instrument, connect R5 direct to the circuit ground instead of junction R6-R7. Finally, all circuit board tracks carrying mains current must be strengthened with 2.5-mm<sup>2</sup> cross-sectional area solid copper wire if currents higher than about 5 A are measured.

## 80C32/8052 Single-board computer

May 1991, p. 17-23

When a CPU type 8031 or 8052AH-BASIC is used, IC1, IC2, IC3, and IC8-IC12 must be 74HCT types. Jumper B is erroneously referred to as Br2 in the text under "On-board EPROM programmer". Contrary to what is stated, this jumper must be fitted only when an EPROM is to be programmed — for all other use of the SBC, it must be removed. Also note that jumper B may only be fitted when the programming LED is out.

## Sequential control

July/August 1991, p. 61

Motor M should be a d.c. type, not an a.c. type as shown in the circuit diagram.

## Digital phase meter

June 1991, p. 32-39

In Fig. 5, the switch between input 'A' and IC1 should be identified 'S1', and that between input 'B' and IC2 'S2'. Switch S4 is an on/off type, not a push-button as shown in the diagram. Capacitors C3 and C6 are shown with the wrong polarity. The component overlay of the relevant printed-circuit board (Fig. 8) is all right.

## Universal NiCd battery charger

June 1991, p. 14-19

The parts list on page 19 should be corrected to read

C7 = 2200µF 25V

When difficult to obtain, the BYW29/100 (D5) may be replaced by the BY229, which is rated at 6 A.

The text under the heading 'Calibration'

should be replaced by:

4. Connect a multimeter between points G and H on the board, and adjust P4 until the measured voltage is 1 V lower than the voltage on the battery terminals.

## MIDI program changer

April 1991, p. 14-17

The contents of the EPROM should be modified as follows:

address	data
00BC	E5
00C7	80
00C8	CB
00C9	F5
00CA	7B
00CB	12
00CC	00
00CD	D2
00CE	C2
00CF	02
00D0	80
00D1	C2

Readers who have obtained the EPROM ready-programmed through the Readers Services may return it to obtain an update.

## Electronic exposure timer

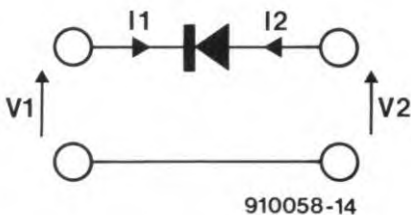
March 1991, p. 31-35

Please add to the parts list on page 32: C16 = 33 pF

## Augmented A-matrices

May 1991, p. 42-43

The drawing below was erroneously omitted in the left-hand bottom corner of page 43.



# MIDI-TO-CV INTERFACE

## Some additional notes

Although the MIDI-to-CV interface was described fully in our February 1991 issue, it was thought that some additional notes might prove useful to a number of readers.

### MIDI connections

The MIDI-IN socket, K<sub>6</sub> (next to the mains input plug) must be connected via a suitable MIDI cable to the MIDI output of your MIDI keyboard, synthesizer, or other equipment. The MIDI input signal appears unchanged at the MIDI OUT socket (MIDI through function). The name of that socket may seem somewhat confusing ('through' function at 'out'), but that is because the interface is principally intended to output the data in changed format (e.g., filtered). Other equipment may be connected to the MIDI OUT socket, but this must be controlled by the same data as the present interface.

### Connection to CV/gate

The connection to a monophonic synthesizer is via the two 6.3 mm connectors marked "CV OUT" and "GATE OUT". The 1 V/octave tone control voltage is available at the CV socket. The 0 V reference point (i.e., the MIDI code for 0 V control voltage) is normally 36, which is equivalent to low C on a standard five-octave keyboard.

The 0-5 V gate voltage is available at the gate socket. Depending on the type of synthesizer, this is a positive gate signal, i.e., +5 V when a key is depressed and 0 V when the key is released, or a negative gate signal, i.e., 0 V when a key is depressed and +5 V when the key is released. Consult your

synthesizer handbook to ascertain which of these signals you need.

The gate LED lights when a correct gate signal is applied. This diode can also be used to check whether the interface is functioning correctly, even when this is not (yet) connected to a synthesizer.

### Setting the MIDI channels

The MIDI channels are set with the aid of the 4-pole DIP switches, SW<sub>1</sub>-SW<sub>4</sub>, on the interface board. The settings and associated channels are shown in Fig. 3. The settings should be carried out before the equipment is switched on (if they are made while the equipment is switched on, the channel will not change).

### Faultfinding check list

If the interface does not work (correctly) check the following.

- Is the power supply correct? The LED should light briefly on power on and then go out again. Are the power lines reversed?
- Are the connections to the MIDI transmitter and synthesizer in order? These include the earth connections!
- Has the correct MIDI channel been set on the interface? Does the gate LED light when the controlling MIDI equipment sends data on the set MIDI channel? Does the MIDI sender transmit on the correct channel? For security's sake, check the MIDI cable and whether the MIDI sender operates correctly.
- Do the sent tones lie in the correct range,

i.e., normally between 36 and 97 or five octaves from low C.

- Does the gate LED light correctly, but the connected equipment does not function? This is almost certainly a failure of the cable connecting the interface to the synthesizer.
- If the scale of the interface does not correspond exactly with that of the synthesizer, shown by the increasing detuning away from the reference point, a correction can be made with potentiometer P<sub>1</sub>.



# 6.0 MHz TV SOUND DEMODULATOR

Although local low-power repeaters make it possible to receive British TV programmes in some areas on the European Continent, the sound channel is missing when a locally purchased TV set is used. The reason is the difference in the sound subcarrier frequency, which is 6.0 MHz in the UK (PAL system I) and 5.5 MHz (PAL system B) in most Continental countries. Aimed at the many expatriates among our readers, the simple circuit proposed here is used to upgrade existing PAL System-B TV sets with a 6.0 MHz sound channel.

A. Franzen

MANY of the British communities clustered around NATO and related military bases on the European Continent enjoy their own local radio and TV services, the best known of which are provided by the SSVC and the BFBS (British Forces Broadcasting Services). The radio programmes are transmitted in the VHF FM band, the TV programmes in the UHF band. To enable the expatriates to use a TV set and an antenna brought over from the UK, the TV signals are transmitted to the PAL-I system with the FM sound subcarrier at 6.0 MHz, and with vertical polarisation.

## A classic FM demodulator

The circuit shown in Fig. 1 is based on an old faithful, the now nearly twenty-years-old TBA120 quadrature FM demodulator from Siemens. Here, the T-suffix version of the IC is used since this is designed for use with ceramic filters and discriminators. The internal diagram of the TBA120T is given in Fig. 2.

The demodulator is capable of operating both at 5.5 MHz and 6.0 MHz by virtue of two ceramic filters, FL1 and FL2, and two ceramic discriminators, CD1 and CD2. The filters and discriminators used are ceramic types manufactured by Murata.

Since a simple parallel connection of the discriminators, CD1 and CD2, is not permissible because of the risk of mutual loading and detuning, the 6.0 MHz discriminator is connected to the quadrature outputs of the

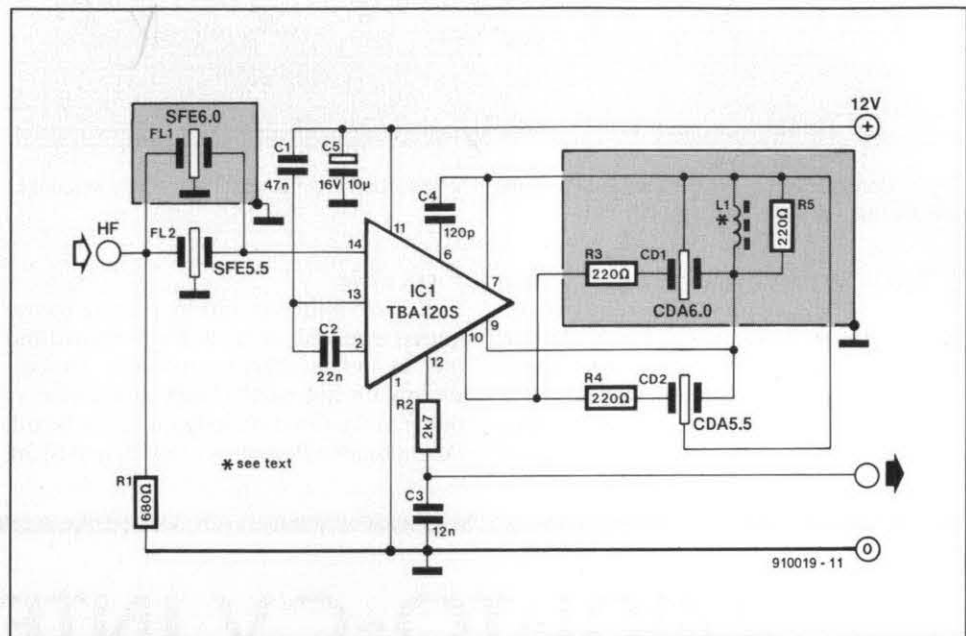


Fig. 1. Circuit diagram of the sound demodulator: a standard application of the TBA120T.

TBA120T via an inductor, which functions as a decoupling device. The inductor, L1, consists of 46 turns of 0.2 mm diameter enamelled copper wire on a T50-6 ferrite ring core from Amidon or MicroMetals. Note that the 6.0 MHz input filter and the 6.0 MHz discriminator parts are screened to prevent interference. Network R2-C3 at the AF output of the TBA120T forms a simple de-emphasis. Since the AF signal is superimposed on a direct voltage, you may need a coupling capacitor to connect it to the input of the AF amplifier in the TV set.

Initially, the circuit is best built with the 5.5 MHz discriminator only. Check that it

works, and measure the direct voltage at the AF output of the TBA120T, pin 12. This should be at roughly half the supply voltage. Next, add the 6.0 MHz discriminator parts. If necessary, increase or reduce the number of turns on L1 to ensure that the previously noted voltage is still measured while a 5.5 MHz subcarrier is received. Next, tune to a PAL-I transmission to check that the sound channel at 6.0 MHz is received properly.

Finally, a word of warning: the chassis of many TV sets is connected direct to the mains. Be sure to use a mains isolating transformer while installing and testing the sound demodulator. ■

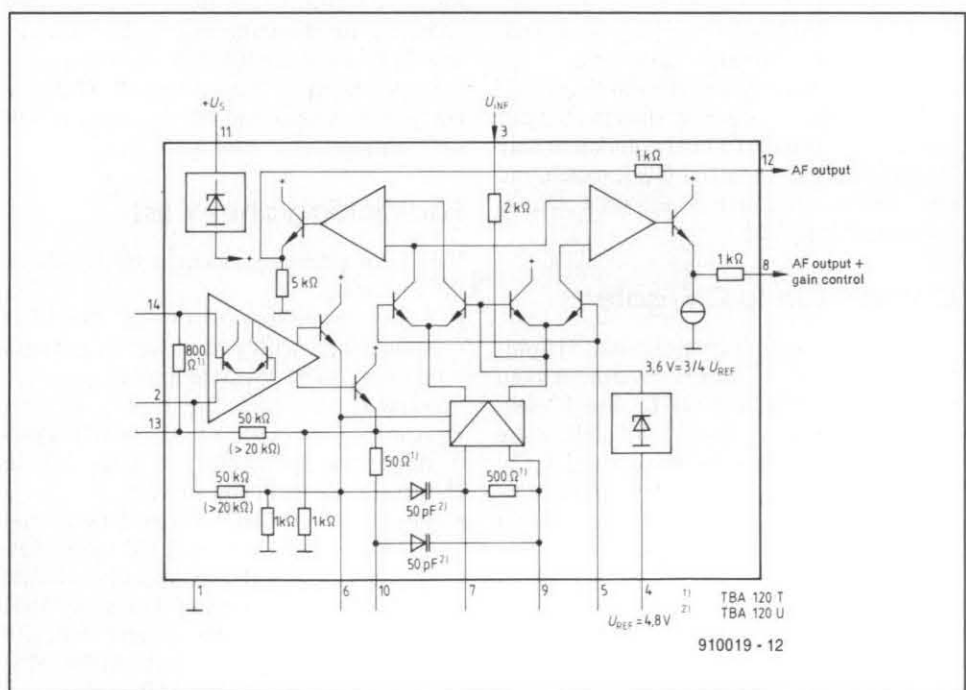


Fig. 2. Internal schematic of the demodulator IC Type TBA120T (illustration courtesy Siemens Components).

# INTERMEDIATE PROJECT

A series of projects for the not-so-experienced constructor. Although each article will describe in detail the operation, use, construction and, where relevant, the underlying theory of the project, constructors will, none the less, require an elementary knowledge of electronic engineering. Each project in the series will be based on inexpensive and commonly available parts.

## 2-METRE BAND CONVERTER

This month we tackle a high-frequency project by venturing out into the exciting world of VHF radio amateur communication. Build this converter if you have a general coverage SW receiver and would like to listen to licensed radio amateurs working in the popular 2-metre VHF band (144–146 MHz).

J. Bareford

**M**OST multimode SW receivers have a frequency range of about 150 kHz to 30 MHz, and are capable of receiving CW, SSB, AM and FM signals. The 10-metre radio amateur band between 28 MHz and about 29.6 MHz is located just above the CB band (27 MHz) towards the top of the receiver's frequency range (the actual frequency assignment of the 10-m band may differ de-

pending on the country you live in). The present 2-metre converter allows you to listen to radio amateurs working with SSB (single-sideband) and CW (morse) in the lower part of the 2-m band, as well as to 'local' FM (frequency modulation) traffic and repeater stations in the frequency range between 145.0 and 146.0 MHz. The 2-metre band is very popular among radio amateurs

because of the ready availability of transceivers, the small antenna size, and the low power required to cover considerable distances, even when going 'mobile'. All in all, if you are a beginning electronics enthusiast, listening to local radio amateurs might well prove useful to learn a lot about electronics, as most radio amateurs are keen and helpful experimenters. In and around large cities you can expect a lot of traffic in the 2-m band, with dominant repeater activity in the upper section of the band between 145.600 MHz and 145.875 MHz. At the low side of the band, just above 144 MHz, there is long-distance (DX) traffic in CW and SSB. Here, it pays to have a directional aerial to pick up signals from distances up to 300 km and more under favourable propagation conditions.

### The basics

What we want to do is convert the frequency range from 144 MHz to 146 MHz down to 28 MHz to 30 MHz (see Fig. 1). Once this has been achieved, a general coverage receiver tuned to the 10-m band can be used to receive all signals of all types of modulation used (CW, SSB, FM and possibly AM).

The frequency conversion of the 2-MHz wide band is effected with the aid of a local oscillator operating at 116 MHz, as shown in the block diagram in Fig. 2. The arithmetic behind this conversion is simple: the output frequency of the converter equals the difference between the input frequency and the local oscillator frequency. Thus, for the low end of the band:





144 MHz – 116 MHz = 28 MHz

while for the high end of the band:

146 MHz – 116 MHz = 30 MHz

Note that in principle the required output frequency may also be obtained with a local oscillator operating at 172 MHz. A frequency of 116 MHz is used here, however, since this can be generated with a standard quartz crystal.

As shown in Fig. 2, the antenna signal is amplified before it is applied to a band-pass filter. Next, it is mixed ('heterodyned') with the 116 MHz local oscillator signal. The mixer consists of a transistor, T2. The output signal of the mixer is the intermediate frequency, 28 MHz – 30 MHz, obtained from subtractive mixing. A band-pass filter formed by L6 couples the output signal of the converter to the input of the general coverage receiver.

The band-pass filter ahead of the mixer is needed to suppress signals at the so-called image frequency. In the present converter, these signals occur between 86 MHz and 88 MHz, since these two frequencies result in intermediate frequencies of 30 MHz and 28 MHz respectively when mixed with 116 MHz. Since part of the image frequency band falls in the VHF broadcast band, a filter is a must to prevent signals in the 2-m band being blocked out by a local radio station!

## Practical circuit

The circuit diagram in Fig. 3 shows a number of dashed lines, which indicate RF screening plates that serve to keep interference between the sub-sections of the circuit to a minimum. As shown, these screening plates are connected to ground.

The antenna signal is coupled to the converter via a low-impedance tap on inductor L1. Tuned circuit C1-L1 forms a bandfilter tuned to the 2-m band. At the same time, the L-C tuned circuit provides the necessary impedance conversion between the low impedance of the aerial cable (50–75 Ω) and the high impedance (several mega-ohms) of the gate-1 (G1) terminal of dual-gate MOSFET T1. This conversion is usually called impedance transforming or matching.

To reduce the risk of oscillation, the output signal of the amplifier based on T1 is connected capacitively to a low-impedance tap on inductor L3. The bandpass filter needed to suppress the image band is formed by L3, C5, L4 and C6. As you can see from the circuit diagram, the coupling between amplifier T1 and mixer T2 is inductive (no, we have not forgotten a coupling capacitor between L3 and L4). Both L3 and L4 are tuned to about 145 MHz by trimmer capacitors.

The mixer is formed by a second dual-gate MOSFET, T2. Conventionally, the RF signal is applied to gate 1, and the local oscillator signal to gate 2. The difference frequency is filtered out at the drain of T2 by transformer L6. The output winding of L6

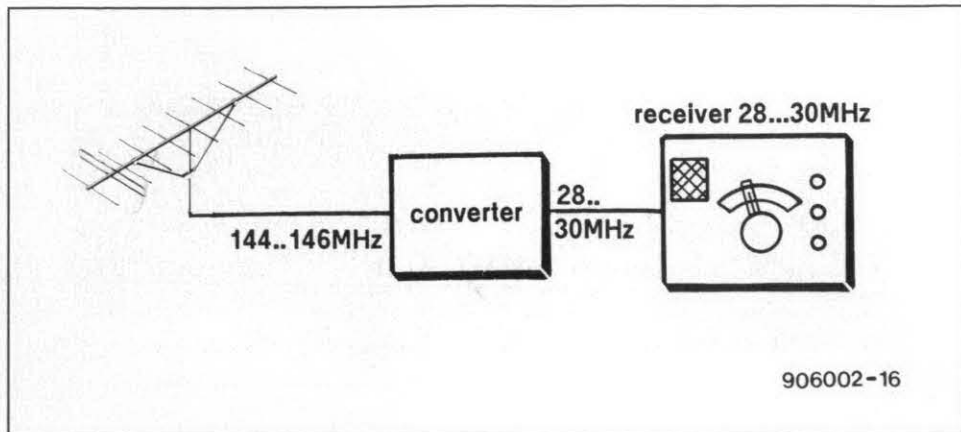


Fig. 1. The converter described here sits between a 2-metre antenna and the input of a multimode SW receiver tuned to the 10-m band

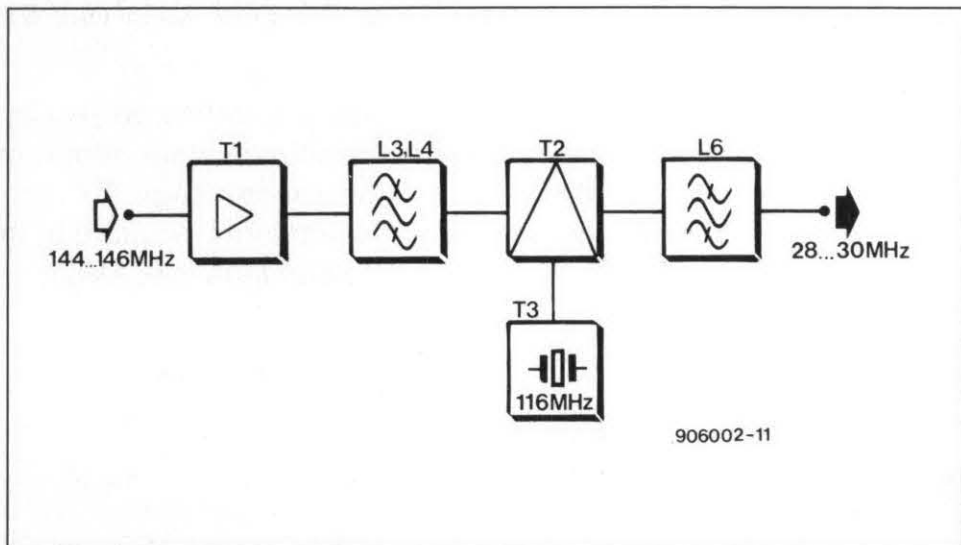


Fig. 2. Block diagram of the 2-metre converter.

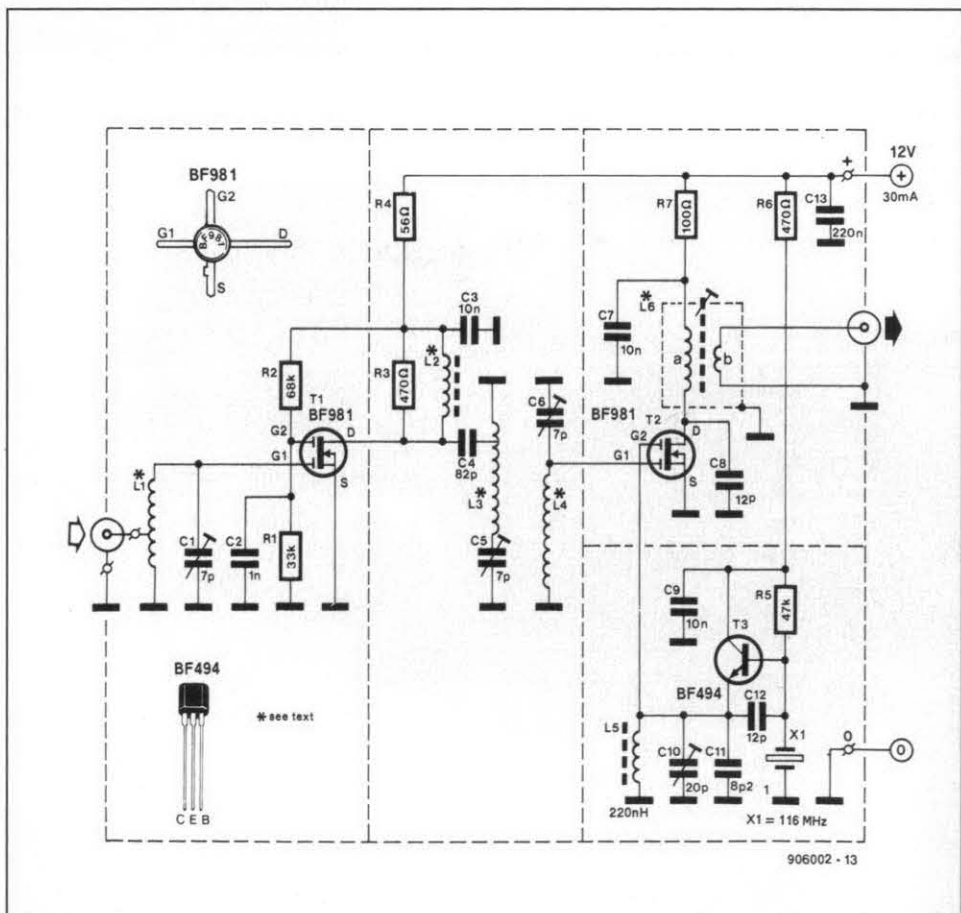


Fig. 3. Circuit diagram of the 2-metre converter. Note that only three transistors are used.

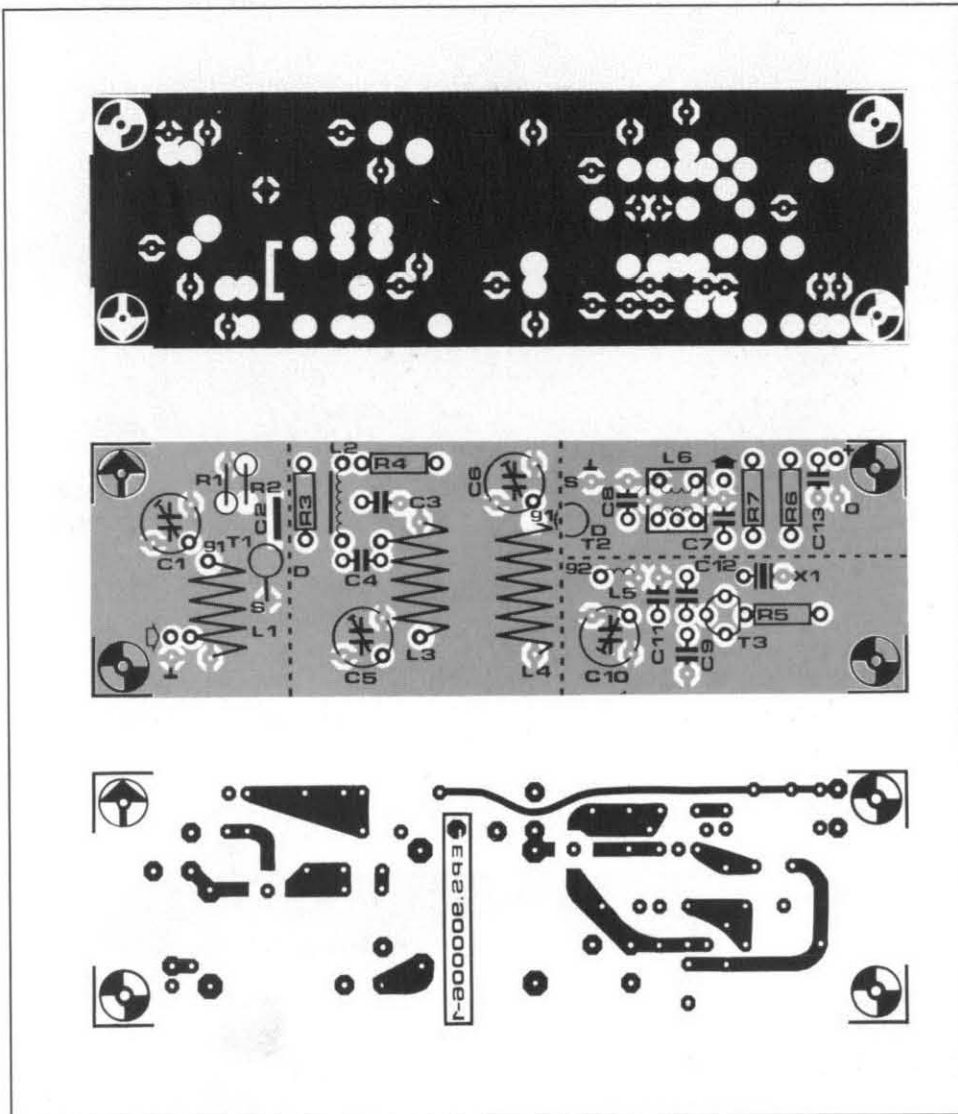


Fig. 4. Track layouts (mirror images) and component overlay of the double-sided printed circuit board for the converter.

has a relatively low impedance to enable the input of the SW receiver to be matched correctly. The output of the converter is connected to the input of the SW receiver via a

short length of 50- $\Omega$  coax cable fitted with suitable RF plugs.

The local oscillator based on T3 is quartz-controlled with a 116-MHz crystal, X1, oper-

## COMPONENTS LIST

### Resistors:

1	33k $\Omega$	R1
1	68k $\Omega$	R2
2	470 $\Omega$	R3;R6
1	56 $\Omega$	R4
1	47k $\Omega$	R5
1	100 $\Omega$	R7

### Capacitors:

3	7pF trimmer	C1;C5;C6
1	1nF coffin capacitor	C2
3	10nF ceramic	C3;C7;C9
1	82pF	C4
1	12pF	C8
1	20pF trimmer	C10
1	8pF2	C11
1	12pF	C12
1	220nF ceramic	C13

### Inductors:

1	0 $\mu$ H22 axial choke	L5
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The other inductors are home made; see text. Required materials:

- 1-mm dia. silver-plated wire
- 0.2-mm dia. enamelled copper wire

1	7K1S inductor assembly (Neosid)	
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### Semiconductors:

2	BF981	T1;T2
1	BF494	T3

### Miscellaneous:

1	quartz crystal 116MHz 5th overtone	X1
1	tin-plated metal sheet	
1	printed circuit board	900006-1

ating at fifth overtone, i.e., the fundamental frequency of X1 is 23.2 MHz. Circuit L5-C10 is tuned to 116 MHz and serves to suppress any spurious output signals produced by the oscillator.

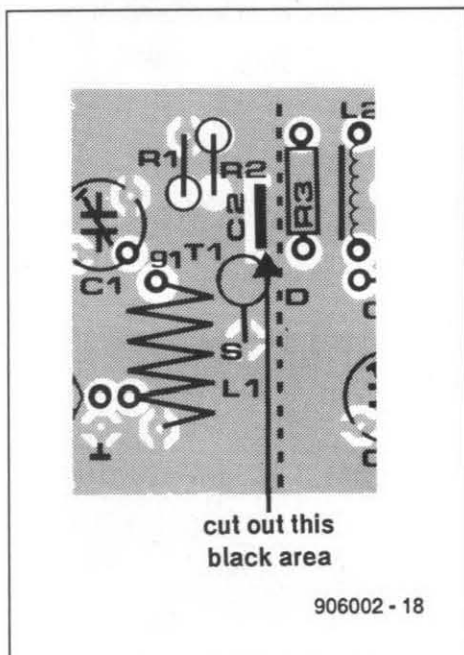


Fig. 5. Cut a small slot in the PCB to enable the coffin-type capacitor to be seated.

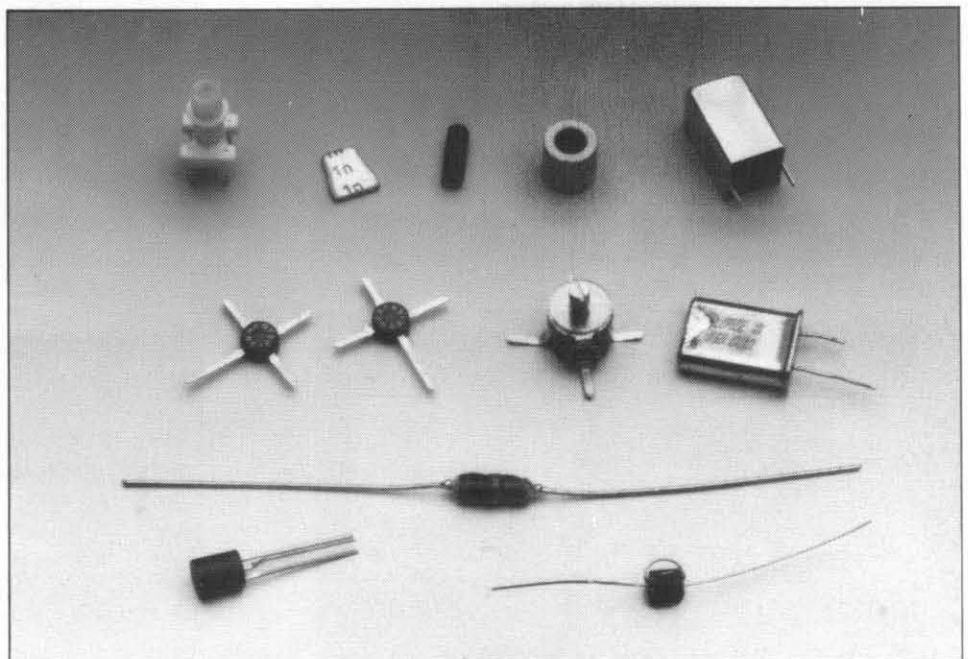


Fig. 6. The RF parts used in this project. The coffin-type leadless ceramic capacitor, C2, is the second device on the left in the top row.

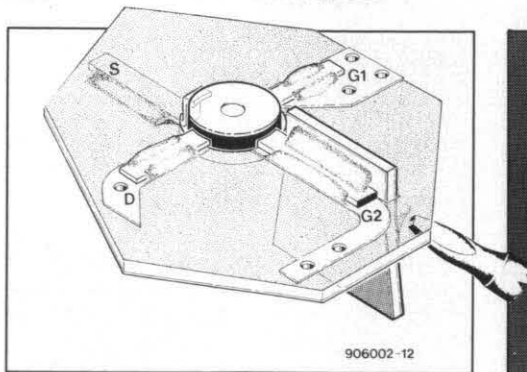


Fig. 7. Illustrating the mounting of dual-gate MOSFET T1 and capacitor C2.

### Building the converter

The circuit is best built on the double-sided printed-circuit board shown in Fig. 4. This board is available ready-made and helps you to go round the pitfalls of RF circuit construction. Before you fit any component on the board, cut the slot for capacitor C2 as shown in Fig. 5. C2 is a so-called coffin-type leadless ceramic capacitor (quite a mouthful for a basically simple and small component). The slot is carefully cut and filed until the 'shoulders' of the capacitor rest on the component side of the PCB. One side of the capa-

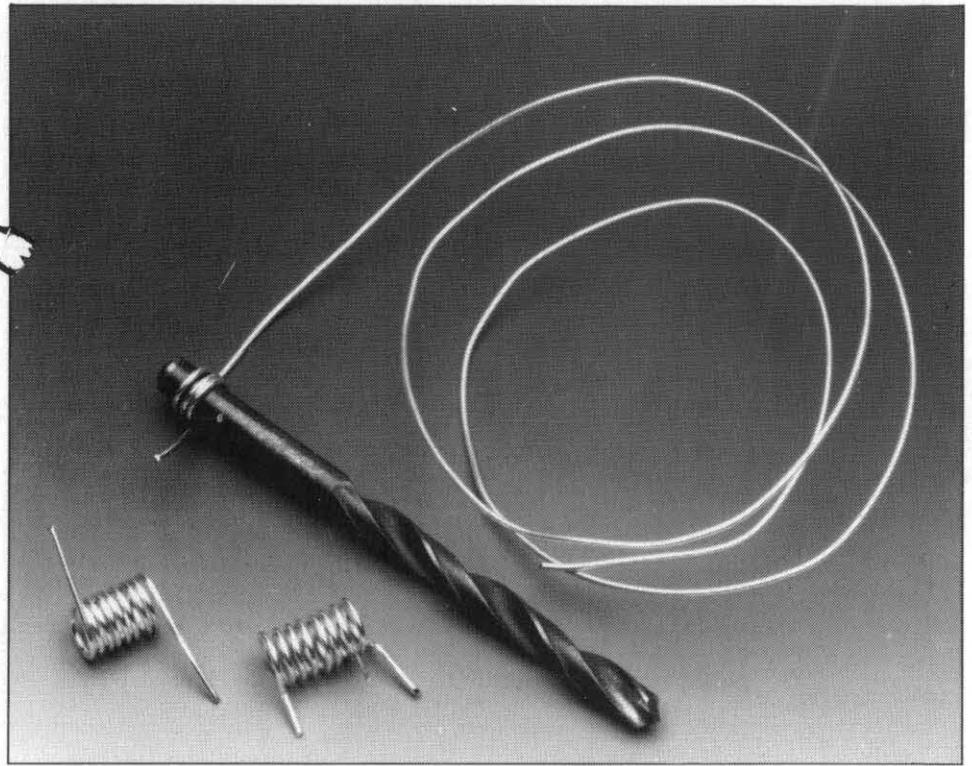


Fig. 8. A 6-mm dia. drill bit is used to wind to the three 145-MHz inductors in the converter.

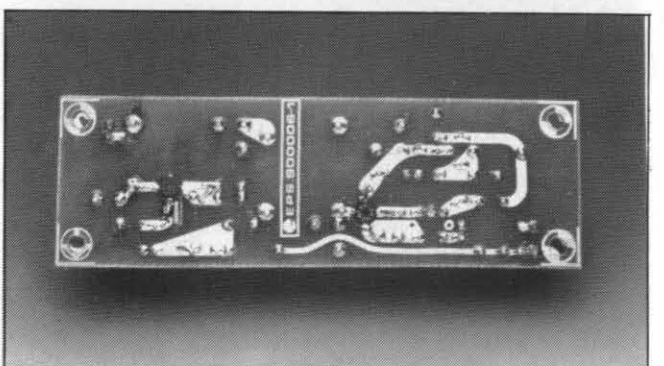
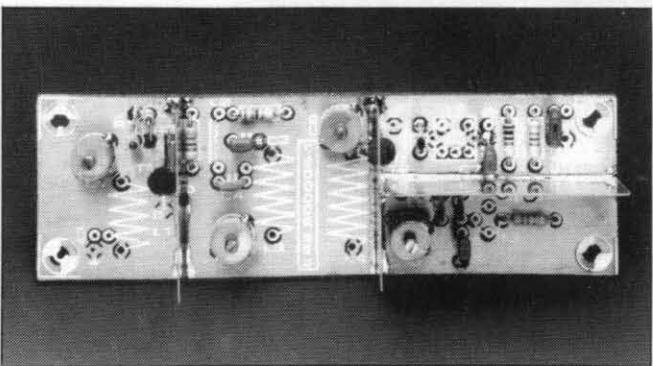
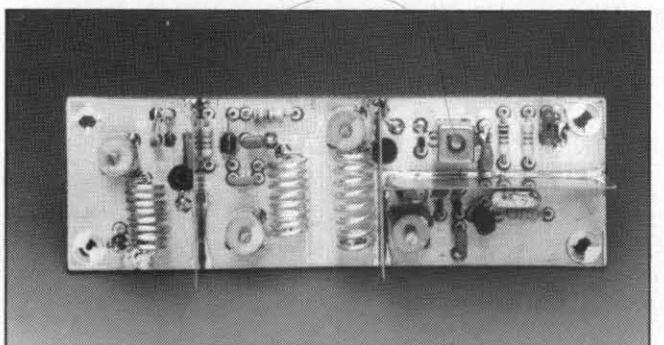
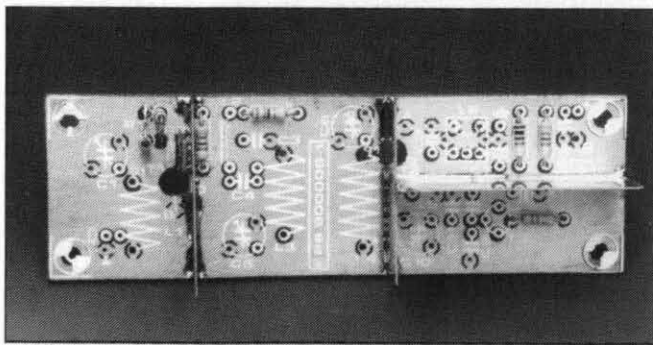
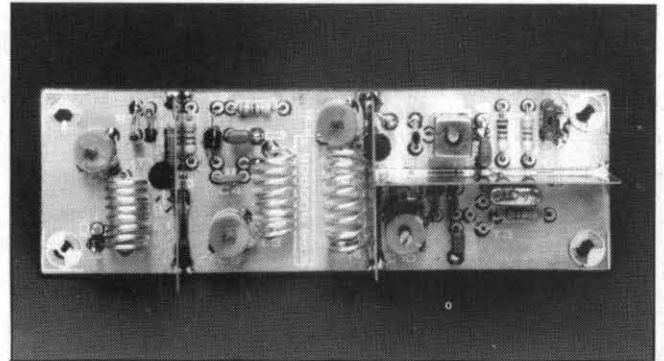
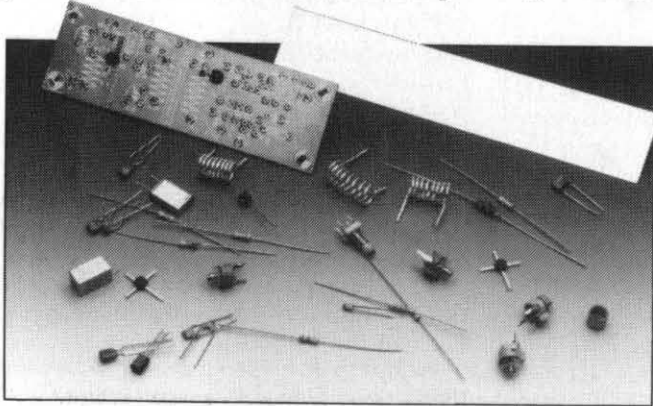


Fig. 9. These photographs illustrate the construction of the 2-m converter. Note the screening plates on the PCB.

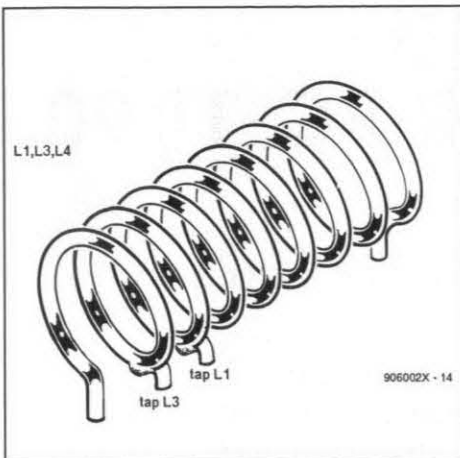


Fig. 10. Construction of the 145-MHz inductors in the circuit.

citor is soldered to the same track as the G2 terminal of T1 (at the track side of the board; see Fig. 7), and the other side to ground formed by the copper surface at the component side of the board. Be careful not to break or overheat the coffin capacitor, as it is a relatively brittle component.

Next, cut the screening plates to size, noting their length from the dashed lines on the PCB overlay. The height of the screens is about 15 mm. Position the screens vertically on to the board, and solder them over the full length with a medium-power iron. Do not go for the easy way out by fixing the screens at a few positions only — to be effective, they must be soldered over the full length.

The next step in the construction is the fitting of the resistors. Note that two of these, R1 and R2, are mounted vertically, and that one terminal of R1 must be soldered at both sides of the PCB to effect a through-contact.

Proceed with the capacitors. With the exception of C4 and C12, all capacitors have one terminal soldered at both sides of the PCB. Miniature ceramic capacitors must be used where appropriate. In all cases, the capacitors must be fitted as close as possible to the PCB.

Except for L5, the inductors in this project are home-made. Start with L1, L3 and L4, which consist of eight turns of 1-mm dia. silver-plated wire. A drill bit is used to give these inductors an internal diameter of 6 mm (see Fig. 8). The taps on L1 and L3 are made as shown in Fig. 10.

Inductor L2 is the simplest to make, since it consists of four turns of 0.2 mm dia. enamelled copper wire through a ferrite bead. The construction is illustrated in Fig. 11.

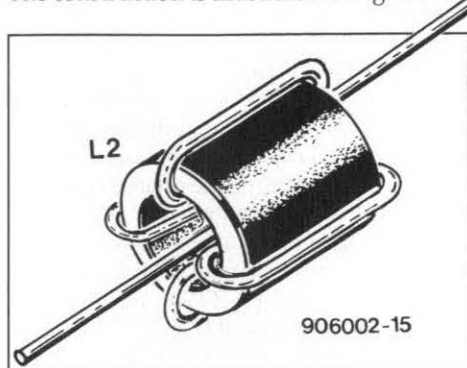


Fig. 11. Construction of choke L2.

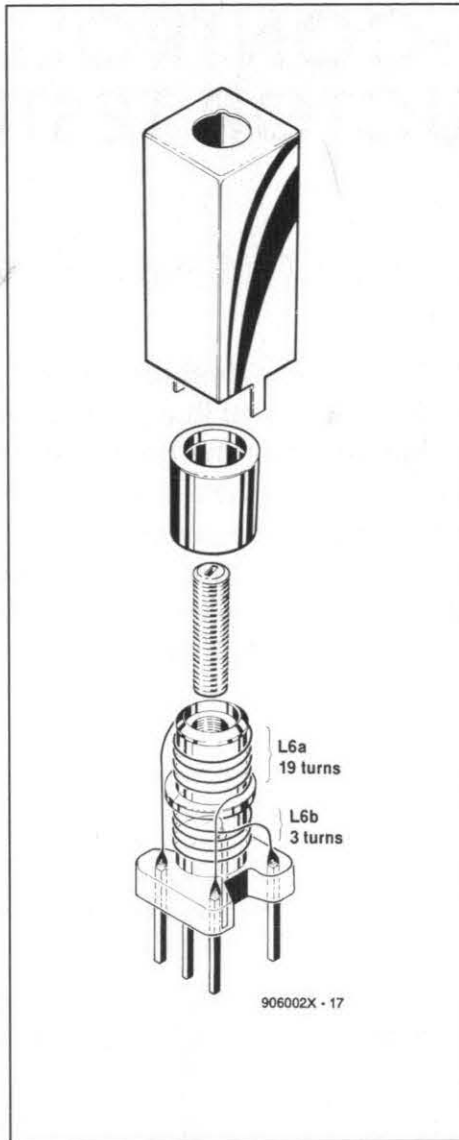


Fig. 12. Construction and assembly of the IF output transformer, L6.

The construction of the IF output transformer, L6, is slightly more complex as it requires an inductor assembly Type 7K15 from Neosid. Constructional details are however apparent from the drawing in Fig. 12. Although it is shown in the drawing, the small rim that divides the former into two equal lengths must be cut off carefully with the aid of a sharp hobby knife. Inspect the windings and check the continuity at the base pins of the inductor. Next, carefully fit the cup core and the screening can before you fit the inductor on to the PCB and subsequently solder the five base pins and the two pins at the sides of the screening can.

One terminal of the quartz crystal must be soldered to ground, while the device must be fitted as close as possible to the PCB surface. Unless you have a solder bit small enough to insert between the crystal body and the PCB, you will have to bend one terminal close to the crystal body, and solder it flat on to the ground plane of the PCB.

The last parts fitted on to the PCB are the semiconductors. Transistor T3 is fitted first in the normal manner. The MOSFETs, T1 and T2, require special attention. The PCB has 5-mm holes to accept these 4-pin transistors, whose terminals are soldered direct to the

copper tracks. The drawing in Fig. 7 illustrates the way in which T1 is fitted. Note that the source terminal is bent down before the transistor is inserted in the PCB hole. Next, the terminal is pushed flat on the ground plane at the component side of the board. Also note that the type number of T1 is legible from the component side of the board. The other FET, T2, is simpler to fit as all four terminals are soldered at the track side of the PCB. Note however that the device is turned such that its type number is legible from the track side of the PCB. The photographs in Fig. 9 further illustrate the construction of the converter.

## Adjustment

To begin with, the tuned circuit in the local oscillator must be set to 116 MHz to force the crystal to operate at its fifth overtone. To perform this adjustment without the help of specialist test gear, place a simple portable FM radio near the converter board, and tune the radio to 94.6 MHz. In most cases, this will mean that the local oscillator in the FM radio operates at  $94.6 + 10.7 = 105.3$  MHz. If necessary, check this with a second receiver. The image frequency of the FM radio is  $105.3 + 10.7 = 116$  MHz. Provided its image rejection is bad enough, the radio will happily receive a sufficiently strong signal at 116 MHz. Solder a short length of thin, solid wire to the drain of T2, and wind this around the whip antenna of the FM radio. Switch the converter on, and adjust trimmer C10 until the FM receiver is silenced by the 116 MHz signal. Peak C10 for minimum noise (if necessary make the coupling at the antenna a little looser). Next, remove the wire from the drain of T2.

Connect a 50-cm long wire to the input of the converter, and the SW receiver to the output. Tune the receiver to 29.0 MHz, and check that its output noise in SSB mode increases when the converter is switched on. Next, peak L6, then C6, C5 and C1 for maximum noise. If you are lucky, the wire at the converter input will be sufficient to pick up local 2-m signals, and you may start to listen to radio amateurs by tuning the SW receiver between 28 MHz and 30 MHz. For serious DXing however you will soon find that a directional antenna is a must. ■

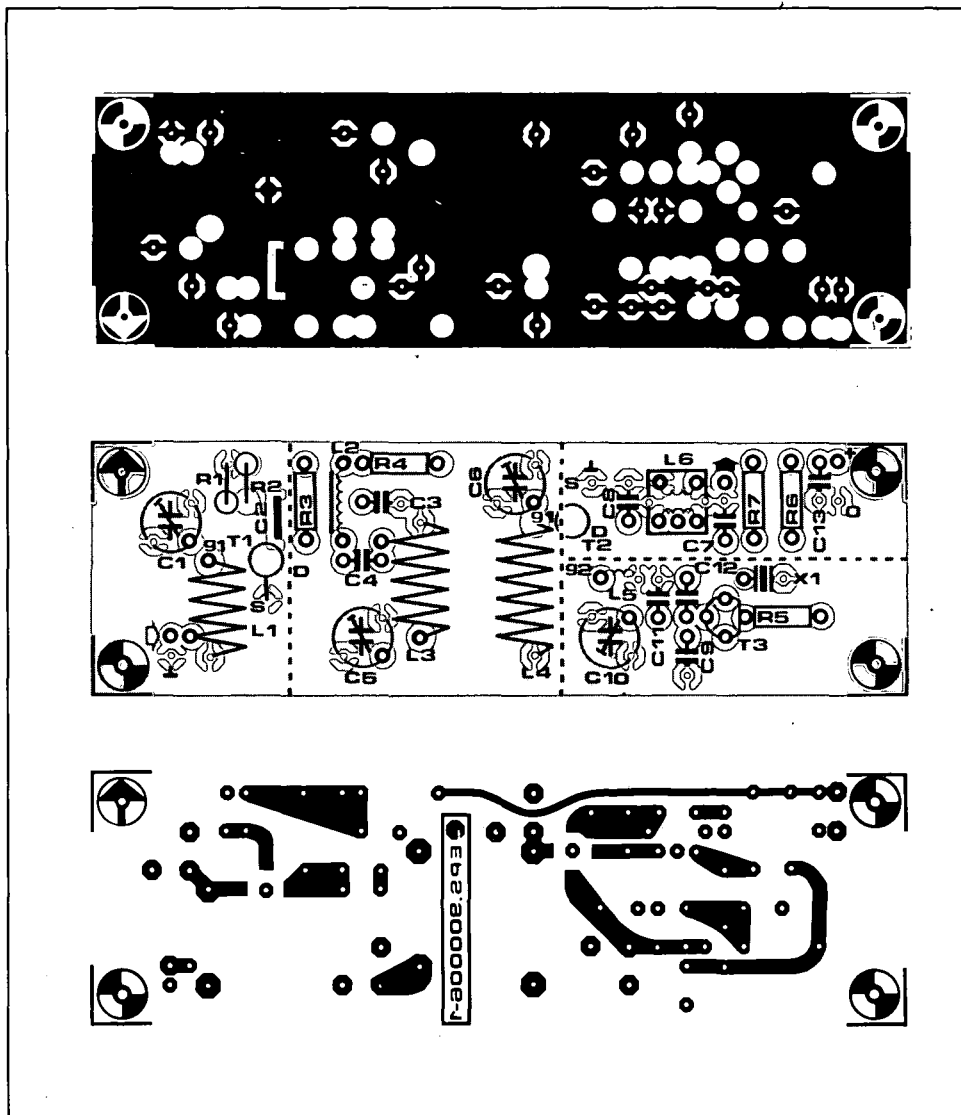


Fig. 4. Track layouts (mirror images) and component overlay of the double-sided printed circuit board for the converter.

has a relatively low impedance to enable the input of the SW receiver to be matched correctly. The output of the converter is connected to the input of the SW receiver via a

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The local oscillator based on T3 is quartz-controlled with a 116-MHz crystal, X1, oper-

COMPONENTS LIST		
<b>Resistors:</b>		
1	33k $\Omega$	R1
1	68k $\Omega$	R2
2	470 $\Omega$	R3;R6
1	56 $\Omega$	R4
1	47k $\Omega$	R5
1	100 $\Omega$	R7
<b>Capacitors:</b>		
3	7pF trimmer	C1;C5;C6
1	1nF coffin capacitor	C2
3	10nF ceramic	C3;C7;C9
1	82pF	C4
1	12pF	C8
1	20pF trimmer	C10
1	8pF2	C11
1	12pF	C12
1	220nF ceramic	C13
<b>Inductors:</b>		
1	0 $\mu$ H22 axial choke	L5
The other inductors are home made; see text. Required materials:		
1-mm dia. silver-plated wire		
0.2-mm dia. enamelled copper wire		
1	7K1S inductor assembly (Neosid)	
<b>Semiconductors:</b>		
2	BF981	T1;T2
1	BF494	T3
<b>Miscellaneous:</b>		
1	quartz crystal 116MHz 5th overtone tin-plated metal sheet	X1
1	printed circuit board	900006-1

ating at fifth overtone, i.e., the fundamental frequency of X1 is 23.2 MHz. Circuit L5-C10 is tuned to 116 MHz and serves to suppress any spurious output signals produced by the oscillator.

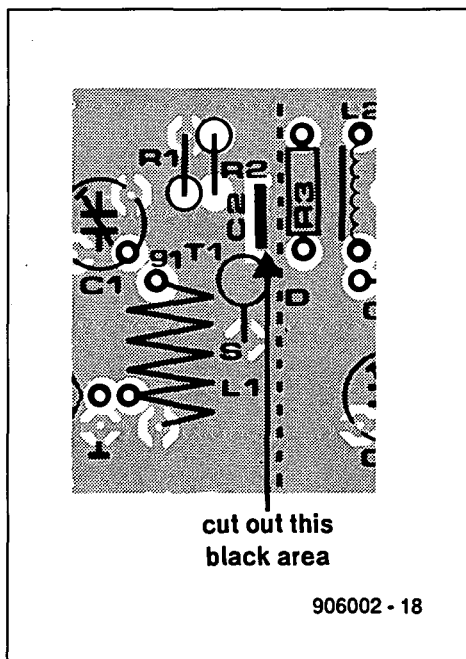


Fig. 5. Cut a small slot in the PCB to enable the coffin-type capacitor to be seated.

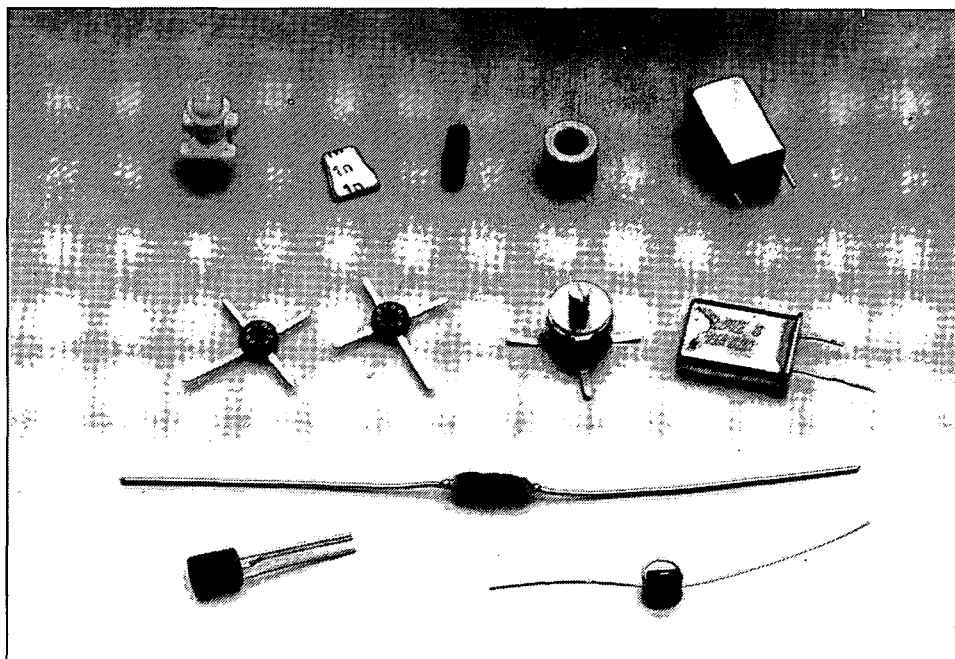


Fig. 6. The RF parts used in this project. The coffin-type leadless ceramic capacitor, C2, is the second device on the left in the top row.

# PC-CONTROLLED SEMICONDUCTOR TESTER PC-TT 90

## PART 1: INTRODUCTION AND BASIC FEATURES

**This versatile, PC-controlled, test instrument, designed and marketed as a kit by ELV, puts you in a position to view, on your PC monitor, the curves that describe the main electrical characteristics of transistors, LEDs, zener diodes, triacs and thyristors. These curves, like no other test on these devices, provide a definitive good/faulty indication and in addition can help you decide whether or not a discrete semiconductor is suitable for a particular application.**

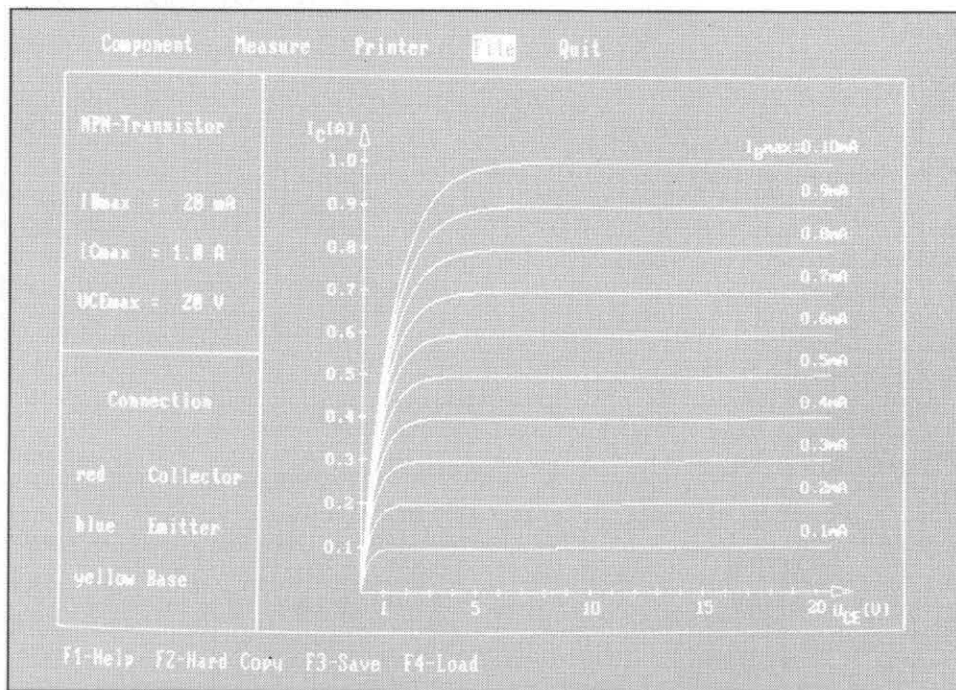
**D**ISCRETE semiconductors, and in particular transistors, form an important component group in today's electronics scene. The PC-TT90 was developed by ELV to test discrete semiconductors with the aid of an IBM PC-XT/AT or compatible computer. The design of the tester follows the lines of the IC tester (Ref. 1), of which large numbers have been built.

Apart from bipolar n-p-n and p-n-p transistors, the tester is also simple to use with FETs, diodes, LEDs, zener diodes, triacs and thyristors. A complete test run takes less than a second to complete, and produces a plotted characteristic composed of up to ten individual curves.

The complete circuit of the PC-TT90 is built on a single card, which is inserted in a free slot in the PC. The three coloured wires that leave the card at the rear are connected to the device to be tested. The actual connection is made by three crocodile clips.

The easy-to-use control software for the tester allows comprehensive tests to be performed on all previously mentioned types of discrete semiconductor. The results of the tests are pretty conclusive. In the case of transistors, for instance, the so-called output characteristic is measured and presented on the screen as ten individually plotted curves. The test procedure is completely automatic. All you have to do is connect the transistor, select n-p-n or p-n-p, set the maximum collector current, and start the test. After a second or so, the output characteristic and the co-ordinate system appear on the screen. All further settings, such as the selection of the optimum measurement range, the required base currents, the scale factors in the co-ordinate system, etc., are performed automatically, ensuring that the device under test can not be damaged by overloading or in any other manner.

With transistors, for instance, the collector current,  $I_{CE}$  (on the Y axis) is plotted as a



**Fig. 1. Screen photograph of a transistor characteristic measured and plotted by the PC-TT90.**

function of the collector-emitter voltage,  $U_{CE}$  (on the X axis), with 10 values of the base current,  $I_B$ , as parameters. The resultant screen is shown in Fig. 1.

Before discussing the operation of the PC-TT90, an understanding is required of the basic electrical properties and behaviour of the components we want to test. Hence the following sections cover some fundamentals of discrete semiconductors.

### The group

Discrete semiconductors come in many shapes and sizes, and with a plethora of functions. Field-effect transistors (FETs), for instance, now form an important and widely

used sub-group of the larger class of transistors. Disregarding a possible sub-classification according to power, the group of FETs may be divided into no fewer than six basic types. Similarly with diodes: here, we only mention a few special types such as capacitance diodes, PIN diodes, tunnel diodes, field-effect diodes, four-layer diodes, and fast recovery diodes. Adding the photoelectric and wave devices we may mention the photodiode, the laser diode and the light-emitting diode. Also in common use these days, and testable with the PC-TT90, are the large classes of thyristors and triacs.

Unfortunately, it is beyond the scope of this article to discuss the basic characteristics

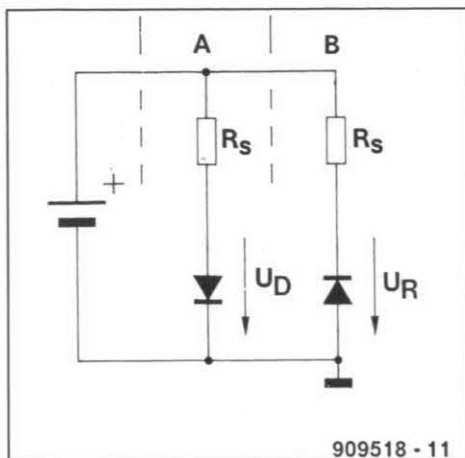


Fig. 2. Basic d.c. conditions of a diode.

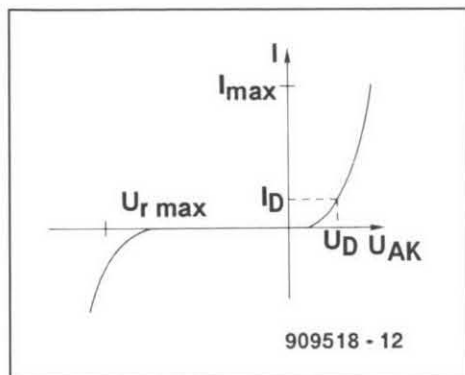


Fig. 3. Voltage-current characteristic of a typical small-signal diode.

of all currently available discrete semiconductors. Therefore, we will concentrate only on the most frequently used types.

**Diodes**

Diodes are devices that pass a current flowing in one direction without significant losses, and block current that flows in the reverse direction. As you are probably aware, this property allows a diode, in conjunction with a reservoir capacitor, to turn an alternating voltage into a direct voltage.

The diagram in Fig. 2 shows the two basic direct-voltage operating conditions of a diode. The left-hand drawing, Fig. 2a, shows the diode in its conductive state, i.e., passing a forward current. This current causes a forward voltage drop,  $U_D$ , across the device. Typically, at about one tenth of the maximum permissible forward current,  $U_D$  lies between 0.2 V and 0.4 V with germanium diodes, and 0.5 V to 0.8 V with silicon diodes.

The right-hand part of Fig. 2, marked 'b', shows the same diode, connected to a reverse voltage. In the permissible voltage range, the reverse, or leakage, current of small-signal diodes lies in the  $\mu A$  range with germanium types, and in the nA range with silicon types. When the permissible reverse voltage is exceeded, the resultant leakage current can rise to values of the order of the forward current. For most diodes, this leads to destruction of the device. The curve in Fig. 3 shows the relation between the voltage and the current of a typical small-signal diode.

The PC-TT90 uses only the emitter and

the collector lead to test diodes. The yellow (base) lead is not used in this case. The diode is connected in the conductive direction (red clip to the anode, and blue clip to the cathode). Next, the maximum current is set, and the measurement started. The computer plots the characteristic of the diode, taking into account the set maximum forward current.

**Zener diodes**

The so-called avalanche effect causes the reverse current to rise rapidly when the maximum reverse voltage is exceeded. This property of almost any semiconductor element is exploited in the zener diode, with the aid of a current limiting resistor. To avoid excessive local heating and subsequent destruction of the device, the reverse current is distributed equally on the semiconductor crystal. In general, a zener diode is operated in its safe electrical area as long as the power dissipation caused by the reverse current does not exceed the maximum permissible 'forward' power dissipation. The reverse voltage at which the current rises suddenly is called the zener voltage,  $U_Z$ .

Circuit section 'a' in Fig. 4 shows a zener diode connected in forward, i.e., conductive, direction. The electrical behaviour of a zener diode in this configuration is almost identical to that of a normal diode. The reverse connection, illustrated in the circuit 'b' in Fig. 4, is the more common for a zener diode. When the voltage applied via series resistor  $R_s$  is sufficiently high, the zener voltage can be measured across the diode. The typical  $U$ -vs- $I$  characteristic of a zener diode is shown in Fig. 5. In the forward direction, zener diodes can be tested just as ordinary diodes, as described earlier.

The zener voltage,  $U_Z$ , may be determined by connecting the zener diode in the reverse direction, i.e., just as they are normally used. It should be noted, however, that the maximum reverse current may be much smaller than the maximum forward current.

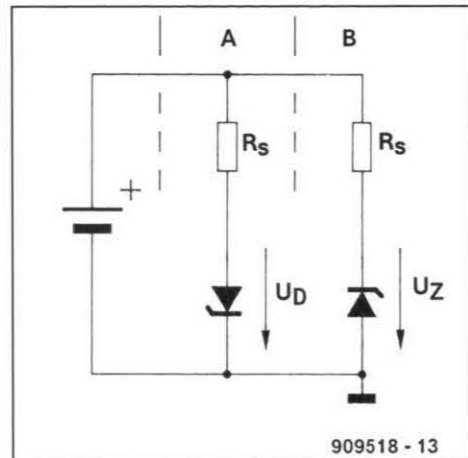


Fig. 4. Basic d.c. conditions of a zener diode.

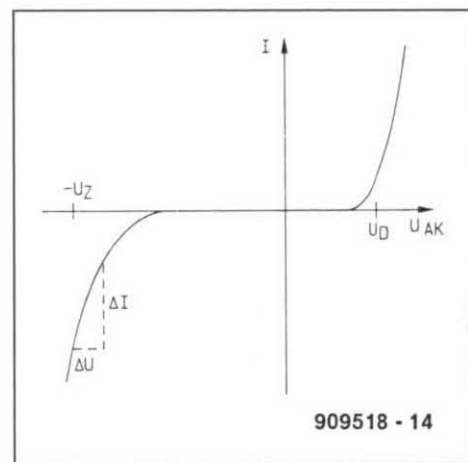


Fig. 5. Voltage-current characteristic of a zener diode.

Hence, this setting may have to be changed (on the computer) before connecting the zener diode. As a rule of thumb, the maximum permissible reverse current is roughly the maximum permissible power dissipation divided by the zener voltage. After starting the measurement cycle, the stabilization curve of the zener diode is plotted and displayed on the screen.

The PC-TT90 does not require a resistor

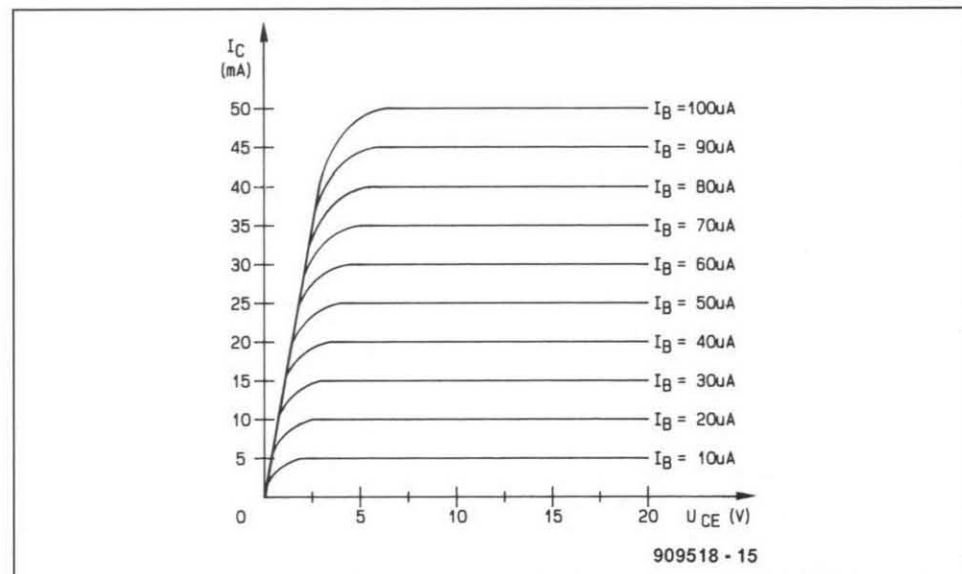


Fig. 6. Typical transistor characteristic. The graph shows the collector current,  $I_C$ , as a function the collector-emitter voltage,  $U_{CE}$ , with the base current,  $I_B$ , as a parameter.

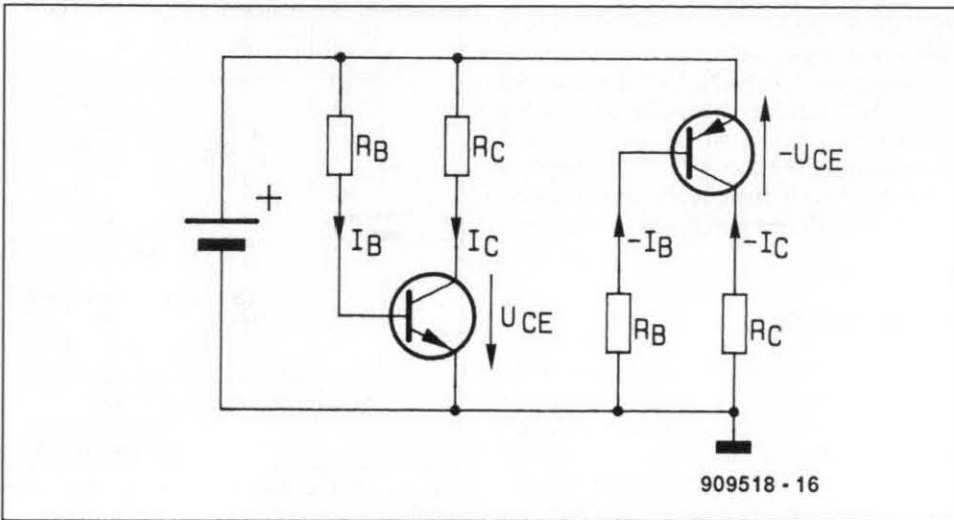


Fig. 7. Basic test circuits of n-p-n transistors (left) and p-n-p transistors (right).

to be connected in series with the zener diode. In fact, such a resistor would cause an unwanted off-set in the stabilization curve. Thus, the zener diode to be tested is connected direct between the red and the blue test lead.

## Transistors

When we speak of a transistor, we usually have a bipolar type in mind. In most cases, special types such as the FET are referred to by their group name, i.e., not by the term transistor.

Transistors are semiconductors with three terminals. They are used mainly to switch and amplify electrical signals. Silicon transistors have now almost completely superseded germanium types that marked the beginning of the semiconductor era. Both silicon and germanium transistors are available in n-p-n and p-n-p versions.

The outstanding feature of the bipolar transistor is its ability to act as a current amplifier. A base current,  $I_B$ , is internally multiplied by the amplification factor, and gives rise to a collector current,  $I_C$ . The current gain,  $h_{FE}$ , is thus defined as the ratio of the collector current to the base current (see also Ref. 2).

As an example, Fig. 6 shows the output characteristic of a typical small-signal n-p-n transistor. The collector-emitter voltage,  $U_{CE}$ , is given on the horizontal axis in the range between 0 V and 20 V. The vertical axis indicates the collector current,  $I_C$ .

The ten curves describe the relation between these two voltages, with 10 base currents,  $I_B$ , as parameters. The first curve ( $I_B = 10 \mu\text{A}$ ) shows that a collector current of 5 mA flows when  $U_{CE}$  increases from about 2.5 V to 20 V. It is seen that the collector current drops rapidly to virtually nought when  $U_{CE}$  is made smaller than about 1 V.

The magnitude of the collector current rises with the base current. In fact, the collector current appears to settle at a certain multiple of the base current. Hence, a constant base current causes a collector current that remains virtually constant within a fairly large range of  $U_{CE}$  (roughly between 5 V and 20 V). The collector current drops to small

values only with small voltages.

The basic circuits of the n-p-n and the p-n-p transistor are given in Fig. 7. The left-hand circuit shows an n-p-n transistor in common-emitter configuration. Series resistor  $R_B$  sends a constant current into the base. The resultant collector current, which flows through  $R_C$ , is the product of the base current and the current gain factor,  $h_{FE}$ , of the transistor. The collector and base current are added when they leave the transistor via the emitter terminal.

Typical current gain factors of small-signal transistors lie in the range between 100 and 1,000, and those of power transistors between 10 and 50. Hence, the base current is usually small with respect to the collector current, and may be neglected. So, for all practical purposes, the collector current equals the emitter current.

The curves in Fig. 6 are obtained by sending a constant current into the base of the transistor under test, and increasing the collector-emitter voltage from 0 V to the maximum value (here, 20 V) within a certain period (here, 100 ms). As the voltage is increased, the collector current is measured to enable the PC to compute the first curve. Next, the base current is set to the next high-

er value (here,  $20 \mu\text{A}$ ), and the process is repeated to produce the second curve. After having computed all ten curves, the computer plots them in a graph as shown in Figs. 1 and 6. One advantage of the use of a computer here is that each curve needs to be measured only once. Hence, the process is completed fairly quickly, and thus prevents damage to the transistor, which inevitably heats up as a result of its own dissipation. In practice, even power transistors do not need a heat-sink when connected to the PC-TT90.

## Field-effect transistors

A FET is a type of transistor that can be driven, virtually without power, via an electric field. In this respect, FETs behave very much like thermionic valves, and the similarity of these two component types is frequently noted in electronics textbooks.

The category of FETs falls into six basic types, whose circuit symbols are brought together in Fig. 8. The gate, G, is the input electrode that allows the current flow between the drain and the source to be controlled. The gate voltage,  $U_{GS}$ , exists between the gate and the source. The input resistance of a FET is typically very high, with values between  $10^{10} \Omega$  and  $10^{15} \Omega$  for junction FETs, and  $10^{13} \Omega$  and  $10^{15} \Omega$  for MOSFETs.

Analogous to the division into n-p-n and p-n-p classes of transistor, FETs come in n-channel and p-channel versions. Figure 9 shows the basic operation of an n-channel FET (left-hand circuit) and that of a p-channel FET (right-hand drawing). Both types of FET conduct at  $U_{GS} = 0 \text{ V}$ , and are therefore called depletion devices.

The circuit with the n-channel FET shown in Fig. 9 is taken as an example here to explain the basic operation. A typical example of an n-channel depletion FET is the well-known BF245. Similar to a bipolar transistor, the drain current (the 'FET' equivalent of the collector current) is virtually constant for values of the drain-source voltage,  $U_{DS}$ , between 5 V and the maximum value. Since the gate forms a very high resistance, it is volt-

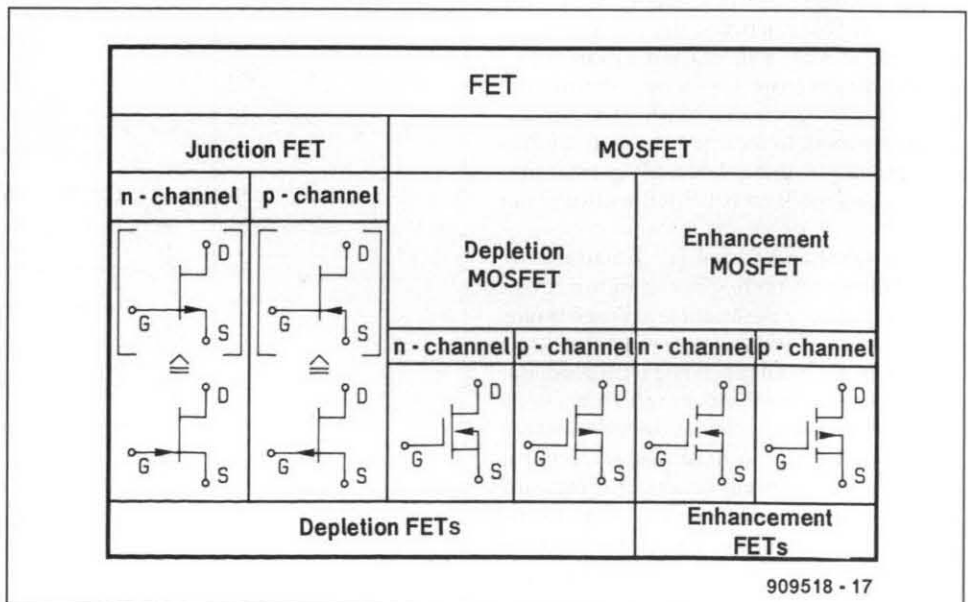


Fig. 8. Overview of field-effect transistors.



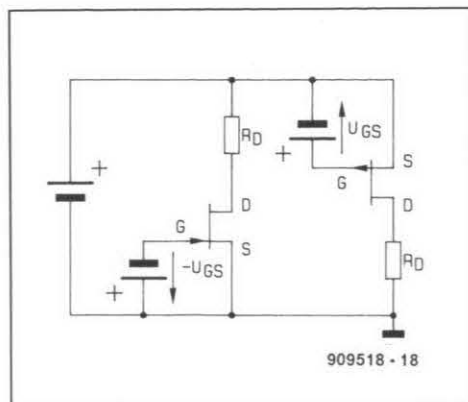


Fig. 9. Basic d.c. circuits of an n-channel FET (left) and a p-channel FET (right).

age-driven rather than current-driven like the base of a bipolar transistor. Hence, the voltage applied to the gate determines the drain current. A gate voltage of 0 V causes full conduction in a depletion FET. The drain current may be reduced by making the gate negative with respect to the source, as illustrated by the transfer characteristics in Fig. 10.

P-channel FETs are driven by a positive gate voltage. As shown in Fig. 9, the source is connected to the positive supply voltage, and the drain is, therefore, negative with respect to the source.

MOSFETs are also available as depletion types. In general, their extremely high input resistance is achieved by a thin isolation layer of  $\text{SiO}_2$ , which separates the gate from the drain-source channel. The electrical characteristics of depletion MOSFETs are largely similar to those of normal depletion FETs, discussed above. Depletion MOSFETs are typically used for high-frequency and digital circuits.

Enhancement-mode MOSFETs, or enhancement MOSFETs, require a voltage to be applied to the gate before conduction can occur, i.e., they are off when  $U_{GS} = 0$  V. The n-channel enhancement MOSFET does not draw drain current until  $U_{GS}$  exceeds a certain threshold, when the drain is positive with respect to the source. This characteristic is reversed with p-channel types, i.e., the drain must be negative with respect to the source, while a negative gate-source voltage must be applied for the FET to conduct.

It should be noted that there are also FETs which seem to fall between the depletion and enhancement-mode classes. These devices are marked by a drain current of about half the maximum value when  $U_{GS} = 0$  V, allowing the gate voltage to be made positive or negative with respect to the source.

Some MOSFETs have a fourth terminal, which is connected to the substrate. In most cases, the electrical function of this electrode is similar to that of the gate, although it must be noted that the substrate connection has only one isolation layer between it and the drain-source channel. The connection is usually indicated by the letter S (for substrate) or B (bulk).

The power MOSFET is a semiconductor from the class of enhancement-mode devices that will be discussed in detail below. Like

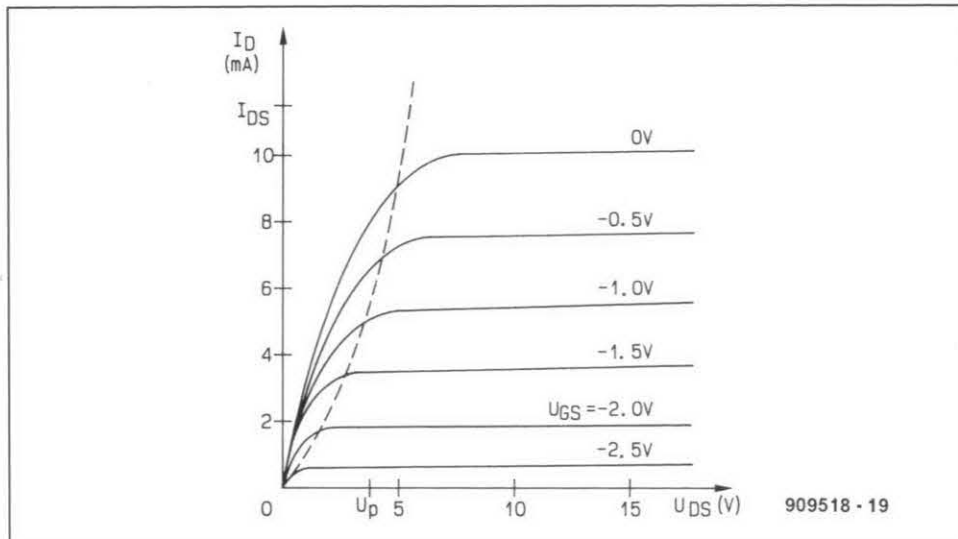


Fig. 10. Current-voltage transfer of a typical n-channel junction FET.

some types of bipolar transistor, power MOSFETs are capable of switching high voltages at high currents. Their drive characteristics, however, are fundamentally different and correspond to those of enhancement MOSFETs. N-channel power MOSFETs are driven by a positive gate voltage, when the drain is positive with respect to the source. Depending on the mode of operation, the gate voltage lies between 0 V and 20 V. The relevant transfer characteristics are shown in Fig. 11.

The number of n-channel FETs is greater than p-channel FETs, the reason being that electrons (in an n-channel) have a greater mobility than holes (in a p-channel). This gives n-channel FETs a higher gain than p-channel FETs. Also, in the case of power MOSFETs with an identical chip area and reverse voltage specification, the 'on' resistance of the drain-source channel in a p-channel type is roughly two times that of an n-channel type. Furthermore, the p-channel versions require a more complex production process, which shifts the price-performance ratio in favour of the n-channel types.

Returning to the transistor tester, the testing of any FET is started by selecting the relevant menu option, e.g., 'n-channel

depletion FET/depletion MOSFET', followed by the maximum drain-source current. The screen then indicates how the three wires of the tester are to be connected to the FET (red = drain; blue = source; yellow = gate). All further settings are provided automatically by the PC-TT90, which takes into account that FETs are driven with a control voltage, not a control current.

If you do not know which type of FET you are testing, select menu option 7, 'unknown FET'. After you have entered the maximum permissible drain-source current, the screen again indicates the connection of the test leads to the FET terminals. The yellow lead is connected to the gate. When the drain and the source are identified, the red wire goes to the drain, and the blue wire to the source. The connections of the drain and the source are reversed in the case of p-channel FETs. If you do not know the n- or p-channel classification, or the drain and source pinning, simply connect the drain and source in either way. The gate, however, must be connected correctly at all times.

When the test cycle is started, the PC-TT90 limits the drain current to the smallest value of 10 mA, and attempts to find a coherent transfer characteristic by varying the

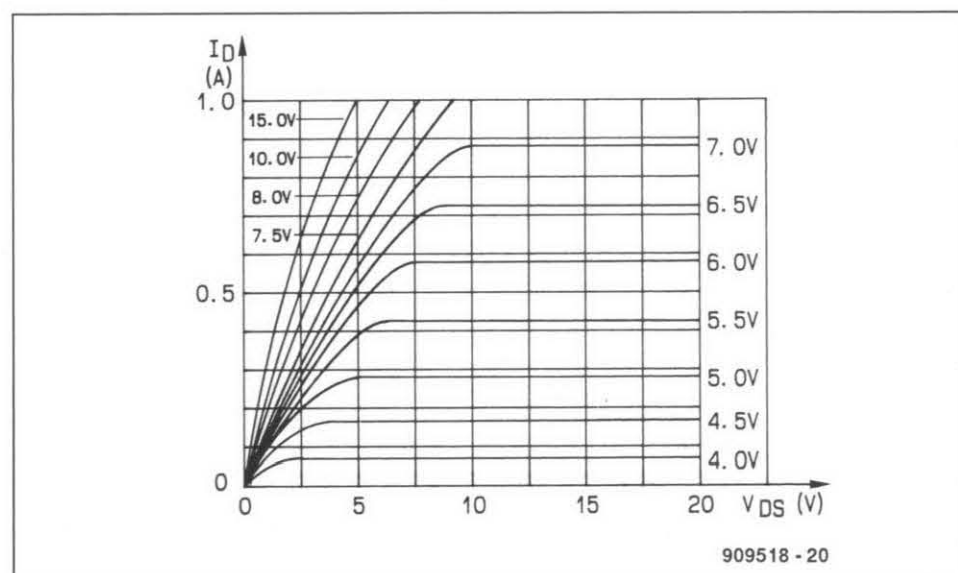


Fig. 11. Current-voltage transfer characteristic of a typical n-channel power MOSFET.

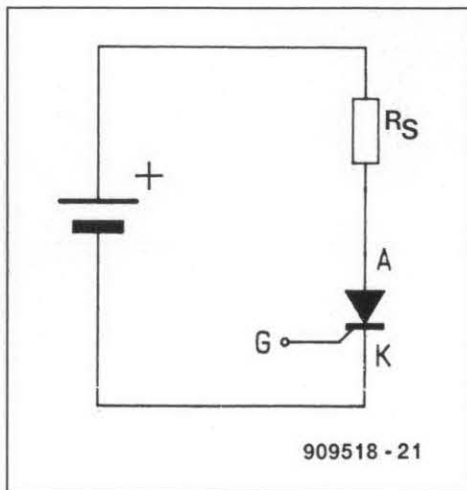


Fig. 12. Basic connection of a thyristor.

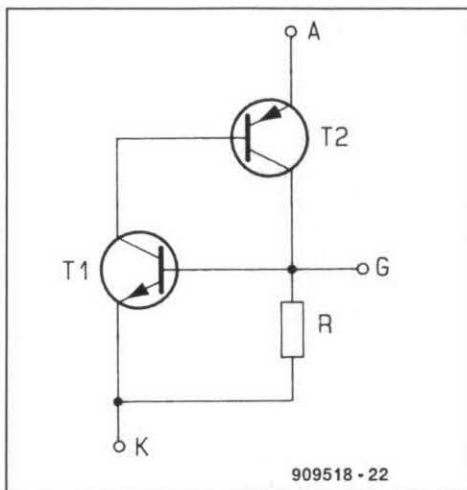


Fig. 13. Transistor-based equivalent of a thyristor.

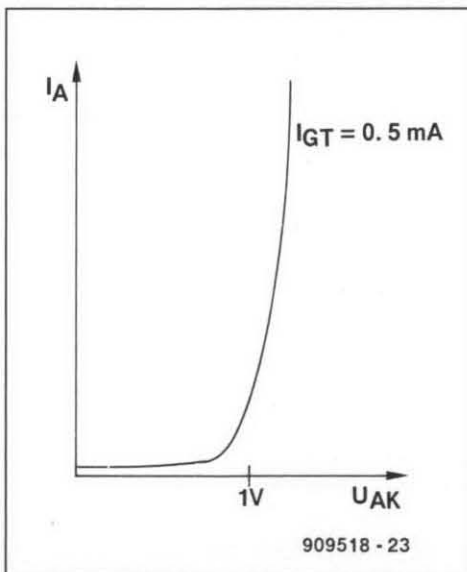


Fig. 14. Typical voltage-current characteristic of a thyristor.

control voltage between +5 V and -5 V. As soon as a clear indication is available about the operation of the device under test, the complete transfer characteristic is computed and subsequently displayed on the screen, along with the type classification of the FET. When this is not successful, the PC prompts you to swap the drain and source connection, and start a new test.

The trial-and-error test performed by the

PP-TT90 allows unknown FET types to be tested and classified. After the first test run, the complete transfer characteristic is measured, up to the maximum drain current specified by the user.

## Thyristors

Figure 12 shows the circuit symbol of a thyristor. Thyristor is the original name of the solid-state equivalent of the thyatron valve, but is now more commonly called silicon-controlled rectifier (SCR). A version of the SCR for switching a.c. is the triac, which is discussed further on.

The anode-cathode (A-K) junction of a thyristor is normally blocked, so that series resistor  $R_S$  does not pass current (see Fig. 12). When a positive voltage,  $U_{GK}$ , of about 1 V is applied to the gate terminal (G), the gate-cathode junction becomes conductive, and passes a current. This gate current is usually denoted by the term triggering current,  $I_{GT}$ , and is not dependent on the anode voltage or the anode currents. When  $I_{GT}$  exceeds a certain value (the trigger threshold) the thyristor is triggered ('fired'), and the anode-cathode junction conducts. Current will keep flowing through this junction even when the gate current is removed. The current is interrupted, however, when it drops below a certain level, the holding current,  $I_H$ .

The equivalent circuit of a thyristor, based on transistors, is shown in Fig. 13. In principle, a reverse-biased thyristor blocks current just as a diode.

Apart from the maximum reverse voltage, which is usually fairly high and therefore not achievable with the PC-TT90, the main specifications of a thyristor are the  $I_A-U_{AK}$  characteristic (Fig. 14) and the triggering current,  $I_{GT}$ .

The red test terminal of the PC-TT90 is connected to the anode of the thyristor, the yellow lead to the gate, and the blue lead to the cathode. The instrument automatically and gradually raises  $U_{AK}$  to the maximum value before going back to nought and increasing the triggering current by one step. When the thyristor triggers, the relevant characteristic is computed, and the triggering current indicated on the screen. Since this current represents the minimum value of  $I_{GT}$ , the indication should be increased for practical purposes to ensure reliable triggering under all 'real' working conditions of the device. In most cases, it is best to use a value of 2 to 5 times the minimum, as long as the maximum permissible triggering current is not exceeded.

## Triacs

A triac consists basically of two thyristors connected in anti-parallel, sharing a common control input. The circuit symbol is shown in Fig. 15.

When a small voltage is applied between the anode (+) and the cathode (-), the triac, like the thyristor, can be triggered with a positive gate current. A further similarity is that the triggering voltage exists between the

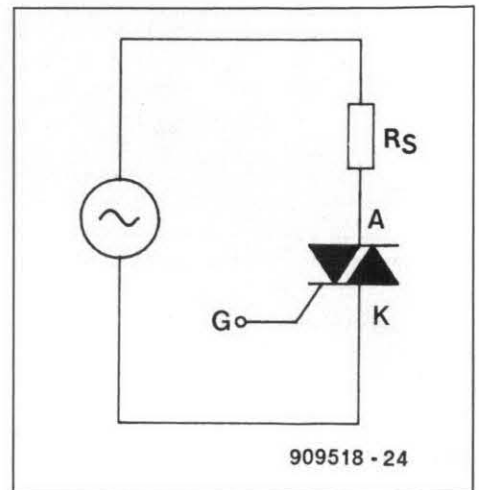


Fig. 15. Circuit symbol and basic connections of a triac.

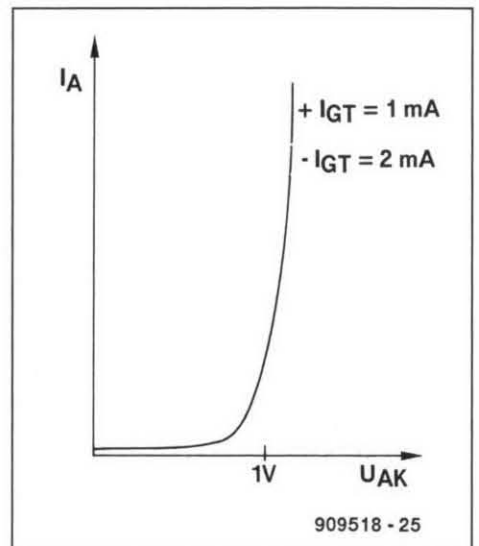


Fig. 16. Typical transfer characteristic of a triac.

gate and the cathode. Contrary to a thyristor, however, a triac can also be triggered with a negative gate voltage, both when the anode is positive with respect to the cathode, and vice versa. This characteristic allows a thyristor to be used as a switch for alternating current, controlled by triggering pulses that may occur in all four quadrants.

Most triacs require a relatively small triggering current when the anode and the gate voltage have the same polarity with respect to the cathode. More triggering current is generally needed when the gate voltage is positive, and the anode voltage negative. Thus, when direct-voltage triggering pulses are used with a triac in an alternating voltage circuit, the triggering voltage must be negative with respect to the cathode to enable the triac to be fired with a relatively small current.

The main characteristics of a triac are its transfer characteristic, i.e., the current-voltage response of the anode-cathode channel, and the gate current at which the device is triggered. Figure 16 shows a typical transfer characteristic.

The red test lead is connected to the anode, the yellow test lead to the gate, and the blue test lead to the cathode of the triac. The

PC-TT90 raises the supply voltage slowly while increasing the gate current in small steps. When the triac triggers, the  $I_A-U_{AK}$  characteristic is measured, and the required triggering current indicated. Next, the test procedure is repeated with reversed polarity of the triggering current. The  $I_A-U_{AK}$  characteristic is not measured, however, since it does not depend on the polarity of the triggering current. Once the triac is triggered, the required (reverse) triggering current is measured and indicated.

The characteristics of a triac may be tested as explained with reversed anode and cathode polarity also, simply by swapping the red and the blue test leads. In all cases, the monitor of the PC shows the main characteristics of the device under test. The main electrical properties measured allow you to classify the device, if it is an unknown type, or, if it is a known type, to check whether it is functional or not.

## Working with the PC-TT90

As already mentioned, the PC-TT90 is simple to use because the component tests are performed virtually automatically, under the control of a computer program. Before we can use the PC-TT90, however, the instrument must be installed on the PC.

### Hardware installation

The complete instrument is accommodated on a single printed-circuit board that is inserted in a free bus extension slot in your PC. The PC-TT90 may be used in PC-XT as well as PC-AT computers, and compatibles. It will be clear that an AT-type computer with a hard disk has certain advantages here.

The three test leads, each of a length of about 1 m, are fed out of the rear of the PC, and the small crocodile clips at the ends are located such that they are easily connected to the devices to be tested.

### Software installation

The user software consists of a number of files, and is supplied on a 5¼-inch, 360-KByte diskette. The programs on this disk automatically identify the video adapter in the PC, and are suitable for Hercules, EGA, and VGA systems.

The control software for the PC-TT90 may be run under the control of a shell called ELV-DOSBATCH. This shell, or user-interface, offers menus and single-letter commands that take you off the DOS level, affording a less cumbersome way to work with the PC.

The software installation is straightforward. To begin with, insert the diskette supplied with the kit into drive A:. Make A: the current drive. If you do not have a hard disk, or do not want to use it for the PC-TT90, type

### DOSBATCH

followed by a carriage return (CR). The shell is loaded, and the main menu appears on the screen after a few seconds. The transistor tester is loaded from this menu by typing '1'

and a CR. The program loads and is ready for use after a few seconds. The screen shows a menu bar that allows you to enter certain maximum values for the device to be tested. These values will be reverted to in the description of the test procedure.

The installation on a hard disk is equally simple. Type

```
INSTALL <CR>
```

from the A: prompt, and answer the questions regarding the language and the name of the subdirectory on the hard disk. If you are satisfied with the defaults offered by the installation program, a subdirectory called 'ELV' is created on the hard disk, and subsequently used to hold DOSBATCH and all other ELV programs. When the installation is complete, DOSBATCH appears on the screen. As described above, the transistor tester is run by typing '1' and a carriage return.

### Practical use

The actual use of the program is straightforward, and is largely self-explanatory. Figure 17 shows the main menu. Items and options presented on the screen are selected in the usual way by pressing the arrow keys and the return key, or, if applicable, by typing the selection number. The maximum device current (for transistors, 10, 20, 50, 100, 200, 500 or 1000 mA) is selected in this way. The lower half of the screen indicates the function of the three test leads. For an n-p-n transistor, for instance, the leads are connected as follows:

blue:	emitter
yellow:	base
red:	collector

In most cases, the red lead is positive with respect to the blue lead, while the yellow lead carries a control voltage, and can be at positive or negative potentials depending on the reference.

After connecting the device to be tested, start the actual test by pressing the space bar. The previously discussed transfer characteristics are computed and plotted in a co-ordinate system with automatically adapted scale factors. In the case of transistors, the appropriate base currents are also set automatically, depending on the maximum collector current. The maximum base current is set at 10% of the maximum collector current, while the maximum collector-emitter voltage is limited to 20 V. If smaller values are required for these parameters, call up a submenu by pressing the <CR> key instead of the space bar. Next, enter the values you require, and run the test by pressing the space bar.

In the case of transistors, the transfer characteristic consists of a maximum of 10 curves. Depending on the electrical behaviour of the transistor under test (TUT), fewer curves may appear. For instance, only six curves appear when the smallest meaningful collector current is caused by a base current of 1 mA, and the TUT draws its

A complete kit of parts for the PC-controlled semiconductor tester is available from the designers' exclusive worldwide distributors:

**ELV France**  
B.P. 40  
F-57480 Sierck-les-Bains  
FRANCE

Telephone: +33 82837213  
Facsimile: +33 82838180

maximum collector current at a base current of 6 mA.

In principle, the following maximum values of the base current are available, each with a subdivision factor of 10:

10, 20, 50, 100, 200, 500  $\mu$ A  
1, 2, 5, 10, 20, 50, 100 mA.

this means that the smallest current range offers the values 1  $\mu$ A, 2  $\mu$ A, 3  $\mu$ A, and so on, up to and including 10  $\mu$ A. Similarly, the next higher range starts at 2  $\mu$ A, and ends at 20  $\mu$ A.

The plotted characteristic is static, i.e., it remains on the screen until the space bar is pressed again to run a new test on the same or another component. A minimum interval of 4 s must be allowed between subsequent tests, while care should be taken to avoid overheating of power semiconductors. If necessary, allow a longer pause, say, 10 s, between tests on these devices.

When another semiconductor type is to be tested, or when different parameters are required, press the ESC (escape) key to return to the main menu. Finally, on-line help is available and may be called up by pressing function key F1. To exit the transistor tester program, simply press ESC twice.

### Storing measured characteristics

Hard copy of the computed characteristics may be obtained on a matrix printer set to 'Epson' mode. Press the F2 key to use this feature.

The curves and the associated co-ordinate system may also be written to a file. To use this option, press F3, enter the file name, followed by a <CR>. Files stored in this way may be retrieved later by pressing F4 and entering the file name.

### I/O base address

The default I/O address setting of the PC-TT90 card is 300H. If you require a different address, load the program with the command

```
TRTEST [address] <CR>
```

where [address] is a hexadecimal number. This address must match that set in hardware on the card. More information on this setting is available in the 'README' documentation file. □

Continued next month

# HEADPHONE AMPLIFIER

## WITH DIGITAL VOLUME CONTROL

from an idea by U. Habschied

**It is often socially not acceptable to turn up the volume of your amplifier, receiver or television set. In such cases a pair of headphones is the perfect medium for listening to your favourite record, tape or television programme. Also, headphones have a decided advantage over loudspeakers: their quality/price ratio is at least five times better**

Normally, headphone amplifiers consist of a simple purpose-designed output stage. The one presented here is rather more sophisticated: it is not just a good-quality miniature stereo amplifier, but also offers a volume control that uses digital switches. Just two push-button switches enable the loudness to be set in 16 discrete steps. It also has two switch-selectable inputs. The design is based partly on that of the "All solid-state preamplifier" we published just over a year ago\*. It is therefore particularly suitable for use with that unit, but may also be used in conjunction with other preamplifiers or integrated amplifiers without any problem. It may also be constructed in a stand-alone box with its own power supply.

### The circuit

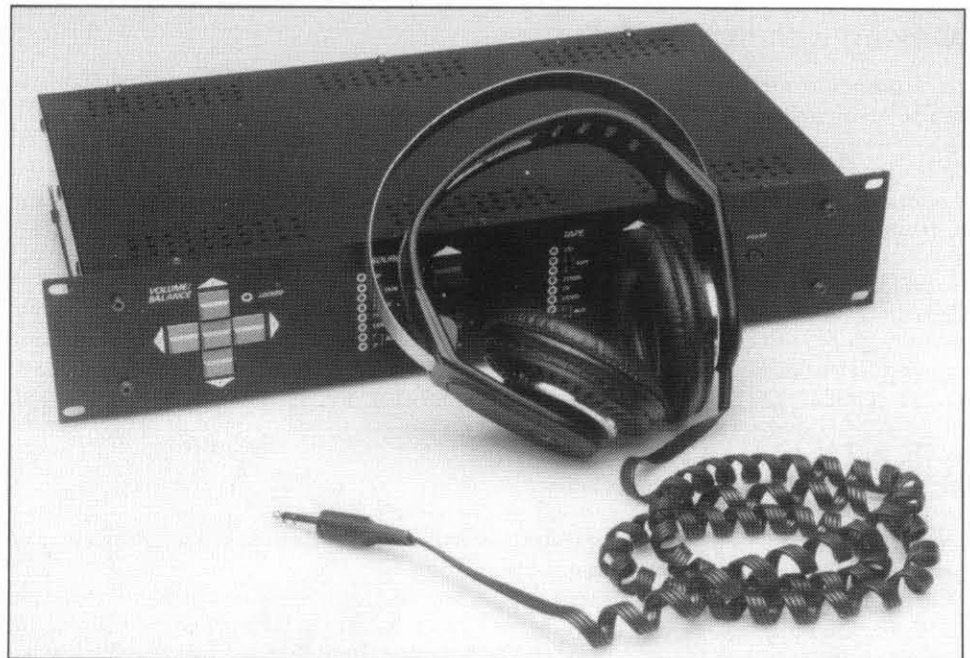
The circuit diagram shows the input selectors, step attenuators and amplifier stages for both stereo channels. The other components serve to control the input stages and the step attenuators.

At the top left are the four input sockets,  $K_1$ – $K_4$ . A logic level provided by electronic switches  $IC_{1b}$ – $IC_{1d}$  enables switching between the tape and line inputs: a sort of tape monitor switch as it were.

The switching signal is provided by push-button switches  $S_1$  and  $S_2$  via an R-S bistable (flip-flop),  $IC_{2a}$ – $IC_{2b}$ . This stage retains the last selected position and at the same time prevents chaos if  $S_1$  and  $S_2$  were pressed simultaneously. Network  $R_1$ – $C_1$  ensures that it is always set to position "line" when the supply is switched on.

The input signal is also applied to a potential divider connected across the inputs of a 16-channel multiplexer. The divider for the left-hand channel consists of resistors  $R_{14}$ – $R_{29}$ , and that for the right-hand channel of  $R_{38}$ – $R_{53}$ . The junctions of the successive resistors are connected to the 16 inputs of  $IC_5$  ( $IC_6$ ). The common output of the multiplexer is connected to the non-inverting input of opamp  $IC_7$  ( $IC_8$ ).

Since the FET switches on board the 4067



are in series with the fairly high input resistance of the opamp, they introduce virtually no distortion.

The logic combination at inputs A–D of the multiplexer determines which of its inputs is connected to its output (pin 1).

The output stage consists of an opamp with two separate output transistors,  $T_3$  and  $T_4$  for the left-hand channel. These transistors are driven by the output of  $IC_7$  via quiescent-current diodes  $D_1$ – $D_3$ . The quiescent-current circuit also contains current sources  $T_1$ – $R_{32}$  and  $T_2$ – $R_{33}$ . These sources provide sufficient current for the output transistors even in high-drive conditions, so that the distortion is kept low right up to the maximum drive level.

The output stage is a class A type operating with a quiescent current of 50 mA. Negative feedback takes place via  $R_{30}$  and  $R_{31}$ . The stage uses no capacitors so that no loss of quality is caused by such components.

The output stage operates from a higher supply,  $\pm 15$  V, to ensure a good dynamic range even if fairly insensitive headphones are

used. This arrangement ensures that an output voltage of up to 8.5 V r.m.s. is available with a distortion of not greater than 0.01%. The bandwidth is 400 kHz.

Any offset compensation for the opamp has been omitted purposely. The offset voltage at the output varies by a couple of millivolts, which is caused by the relatively high bias current of the 5534 that flows through the feedback resistors. Compensation would, therefore, be largely ineffectual.

The output of the amplifier is protected by two parallel-connected resistors of 120  $\Omega$  to give an output resistance of 60  $\Omega$ . This value has been chosen to ensure that the power delivered to the headphones remains about the same, irrespective of whether a low- or high-impedance type is used. If it is felt that this arrangement does not provide optimum sound quality, the value of the resistors may be altered to personal taste. Bear in mind, however, that the values depend to a large extent on the impedance characteristic of the headphones.

The control stage for the multiplexers

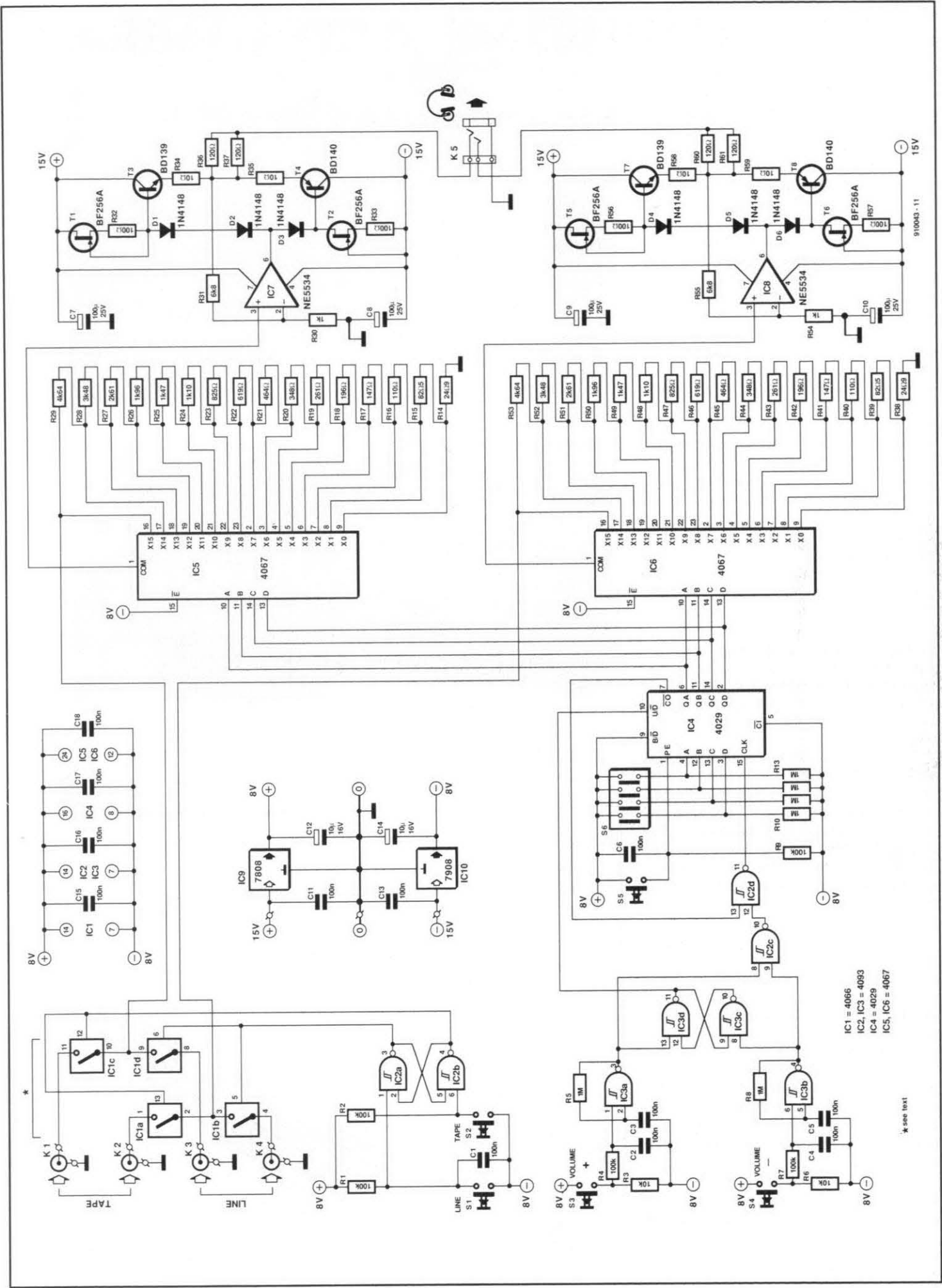


Fig. 1. Circuit diagram of the headphone amplifier.

IC1 = 4066  
 IC2, IC3 = 4093  
 IC4 = 4029  
 IC5, IC6 = 4067

\* see text

consists of the circuit based on IC<sub>3</sub>, IC<sub>4</sub>, and (partly) IC<sub>2</sub>. This section also contains two push-button switches, S<sub>3</sub> and S<sub>4</sub>, to provide, respectively, an increase or a reduction in the volume. Each of the switches operates an oscillator, IC<sub>3a</sub> and IC<sub>3b</sub> respectively. When either of these switches is kept pressed, the volume is increased or reduced in pre-defined steps (see Table 1).

The oscillators are followed by an R-S bistable (flip-flop), IC<sub>3c</sub> and IC<sub>3d</sub>, that arranges for counter IC<sub>4</sub> to count up or down depending on which of the switches is pressed.

The signal generated by IC<sub>3a</sub> or IC<sub>3b</sub> is also applied via gates IC<sub>2c</sub> and IC<sub>2d</sub> to the clock input (pin 5) of IC<sub>4</sub>. Circuit IC<sub>2d</sub> ensures that when the highest or lowest volume is reached the counter is disabled.

The counter may also be preset to a given position with the aid of the DIP switches contained in S<sub>6</sub>. Whenever the amplifier is switched on afterwards, the counter automatically assumes the preset position. The position is read via R<sub>9</sub> and C<sub>6</sub>. Push-button switch S<sub>5</sub> enables the preset position to be selected during operation.

The power supply has been kept simple, since normally the present unit will be integrated into an existing amplifier, which almost certainly has a regulated  $\pm 15$  V supply available. All that is necessary to obtain a +8 V and -8 V supply for the circuit other than the output stages, therefore, is the addition of regulators IC<sub>9</sub> and IC<sub>10</sub>.

### Some practical points

No printed circuit has been designed for the amplifier, but its construction on a prototype board should not present undue difficulties.

The electronic input switches cause very slight distortion. If the switching between line and tape is not required, it is therefore advisable to omit IC<sub>1</sub> and its associated control circuitry to reduce the distortion. This may also be achieved by using Texas Instruments Type TLC4066 LinCMOS input switches instead of the standard 4066 types. Note that the TLC4066 ICs require 6 V instead of 8 V voltage regulators.

The values of the resistors in the voltage dividers as shown in the circuit diagram result in 2.5 dB steps in volume. This gives an overall volume range of 40 dB. If steps of different magnitude are required, the values of the resistors must be altered as shown in the examples in Table 1.

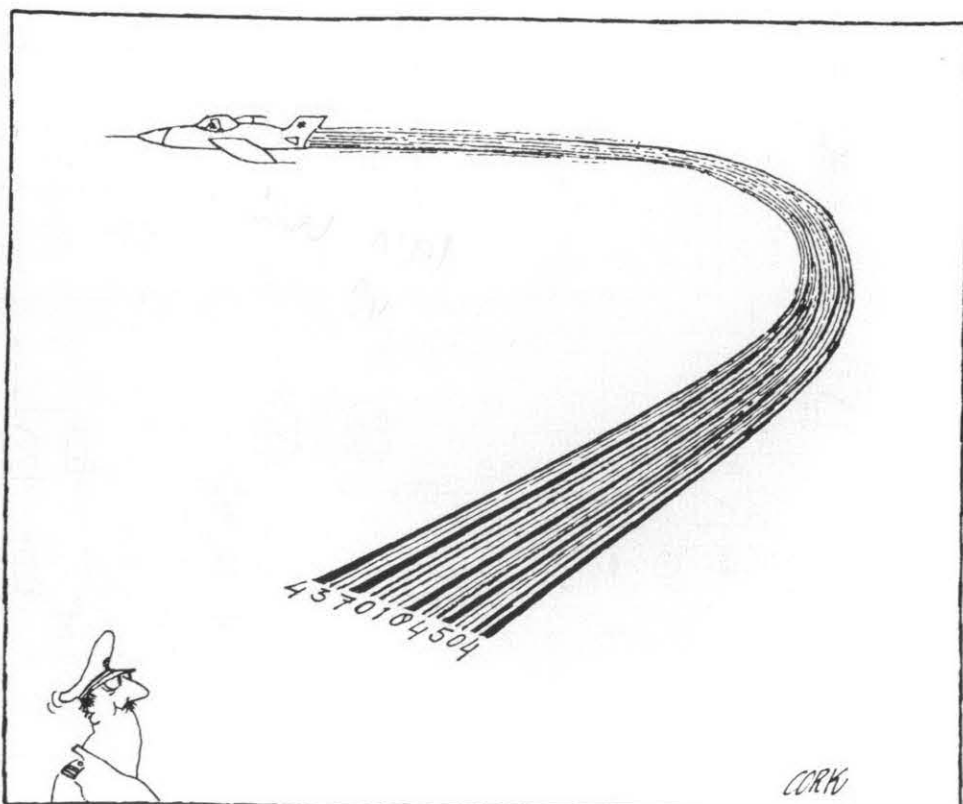
Although the BD139 and BD140 output transistors get pretty warm during normal operation, they do not need a heat sink. If, nevertheless, you are worried by their temperature, there is, of course, no harm in using a heat sink.

Circuit IC<sub>7</sub> may be a Type NE5534 or a Type OP37. Of these two, the OP37 is the slightly better, but it is also much dearer. ■

\* *Elektor Electronics*, December 1989 and January 1990.

Table 1

Resistors	Step size			
	2.5 dB	3.0 dB	4.0 dB	5.0 dB
	value in $\Omega$			
R <sub>29</sub> , R <sub>53</sub>	4640	3650	4220	11000
R <sub>28</sub> , R <sub>52</sub>	3480	2610	2670	6190
R <sub>27</sub> , R <sub>51</sub>	2610	1820	1690	3480
R <sub>26</sub> , R <sub>50</sub>	1960	1270	1050	1960
R <sub>25</sub> , R <sub>49</sub>	1470	909	681	1100
R <sub>24</sub> , R <sub>48</sub>	1100	649	422	619
R <sub>23</sub> , R <sub>47</sub>	825	464	267	348
R <sub>22</sub> , R <sub>46</sub>	619	332	169	196
R <sub>21</sub> , R <sub>45</sub>	464	232	105	110
R <sub>20</sub> , R <sub>44</sub>	348	162	68.1	61.9
R <sub>19</sub> , R <sub>43</sub>	261	115	42.2	34.8
R <sub>18</sub> , R <sub>42</sub>	196	82.5	26.7	19.6
R <sub>17</sub> , R <sub>41</sub>	147	56.2	16.9	11.0
R <sub>16</sub> , R <sub>40</sub>	110	40.2	10.5	6.19
R <sub>15</sub> , R <sub>39</sub>	82.5	28.7	6.81	3.48
R <sub>14</sub> , R <sub>38</sub>	249	69.8	11.5	4.42
R <sub>total</sub> (abt)	18.5 k $\Omega$	12.0 k $\Omega$	11.5 k $\Omega$	25.0 k $\Omega$



# CENTRAL HEATING CONTROLLER

## PART 2: CONTROL SOFTWARE, CONSTRUCTION AND PROGRAMMING

K. Browne

continued from the February 1991 issue

### Control software

Table 4 shows how the available RAM memory has been allocated in the control system. The first 64 bytes are allocated to system variables such as the current time, the date, etc., and the state of the system.

The largest slice of RAM memory is allocated to the user program store. This is where the instructions you input, e.g., 'heating ON Monday at 10.30' is stored. There is sufficient storage capacity for up to 255 program steps.

The final 64 bytes of the RAM memory are used for the Z80 stack.

The flowchart shown in Fig. 7 provides an overall view of how the program works. The first section deals with initializing the system from a cold start, i.e., the first time the CH controller is powered up. Since the system has a battery backup, the initialization would only take place again if the battery were removed and the system powered down. After initialization, the program enters the main program loop.

A separate section of the flowchart shows the timekeeping interrupt sequence. The CPU is diverted from the main program loop to the interrupt subroutine every 20 milliseconds by the 50 Hz synchronizing signal. As already noted in part 1 of this article, this signal is derived from the mains supply frequency. After completing the interrupt subroutine, the CPU returns to where it left off in the main program loop.

Each box in the flowchart represents at least one small subroutine in the timeswitch program. Note, however, that the flowchart is by no means complete, as there are over 80 separate subroutines in the heating controller program.

Unfortunately, it is beyond the scope of this article to give a full insight into the programming techniques of the Z80 microprocessor. Much has been written on this subject, however, and two useful references are given at the end of this article. Moreover, the Z80 has been with us for many years now, and has been used in many projects carried in this magazine.

To illustrate the basic steps in programming the present unit, three examples are given of subroutines used in the heating controller program. All subroutines below are written in assembler format.

Table 3

Codes written to the LCD instruction register

Data line								Instruction
7	6	5	4	3	2	1	0	
0	0	0	0	0	0	0	1	Clear display and home cursor
0	0	0	0	0	0	1	*	Home cursor and return shift
0	0	0	0	0	1	i	s	Entry mode set
0	0	0	0	1	m	c	b	Display on/off
0	0	0	1	0	d	*	*	Shift cursor position
0	0	0	1	1	d	*	*	Shift entire display
0	0	1	z	1	0	*	*	Function set (used once to initialize)
0	1	a	a	a	a	a	a	Set the user defined character RAM area
1	a	a	a	a	a	a	a	Set the display RAM address

#### Notes

- \* Bit has no effect
- a Address in character generator (range 00 to 3F hex)  
Address in display RAM (range 00 to 4F hex)
- b Cursor character flashes (0 = no flash; 1 = flash)
- c Cursor (0 = off; 1 = on)
- d direction (0 = left; 1 = right)
- i Increase or decrease address (0 = decrease; 1 = increase)
- m Display mode (0 = off; 1 = on)
- s Shift display on entry (0 = no shift; 1 = shift)
- z Set number of data bits (0 = 4 bits; 1 = 8 bits)

Codes read from the LCD instruction register

Data line								Instruction
7	6	5	4	3	2	1	0	
f	a	a	a	a	a	a	a	Read busy flag and address

#### Notes

- a current address in either character generator or display RAM, depending on previously set instruction
- f busy flag (1 = busy; 0 = ready)

Address (hex)	Number of bytes	Use
3000 – 303F	64	System variables
3040 – 363F	1536	User program store (256 items)
3640 – 37BF	384	spare
37C0 – 37FF	64	stack (32 items)

Table 4. RAM memory allocation.

**Example 1: zero RAM routine**

This routine is used as part of the initialization of the system, to set all 2,048 bytes of RAM memory to zero.

LD HL, #3000	load the HL register pair with the first RAM address (see Table 1)
LD BC, #0800	load the BC register pair with 2048 (count value)
loop: LD A, #0	load A register with zero
LD (HL), A	load the RAM address pointed to by HL with the contents of A (zero)
INC HL	increase the HL register pair by one
DEC BC	decrease the BC register pair
LD A,B	load A register with contents of B
OR C	'OR' the contents of A register with C and leave result in A (i.e., check if both B and C are zero)
JR NZ, loop	jump if the result of the check is not zero, to a point called 'loop' (i.e., test Zero Flag)
RET	finish subroutine and return

**Example 2: display a character**

This routine is used extensively in the controller program to display a character pattern on the LC display. On entry to this routine, the A register contains a valid display code.

CALL busy	call the 'busy' subroutine (see below)
LD (#9001),A	load the LCD data register with contents of A register (see Table 2)
RET	finish subroutine and return

**Example 3: the busy subroutine**

This routine checks that the LC display is ready to receive an instruction. The program will wait until the display module is ready.

busy: PUSH AF	start here with saving AF registers on the stack
wait: LD A,(#9002)	load 'A' with contents of LCD instruction register (see Tables 2 and 3b)
BIT 7,A	test bit 7 of the A register (the busy bit)
JR NZ, wait	jump back to 'wait' if bit 7 was not zero (i.e., wait until the LC display is ready for data)

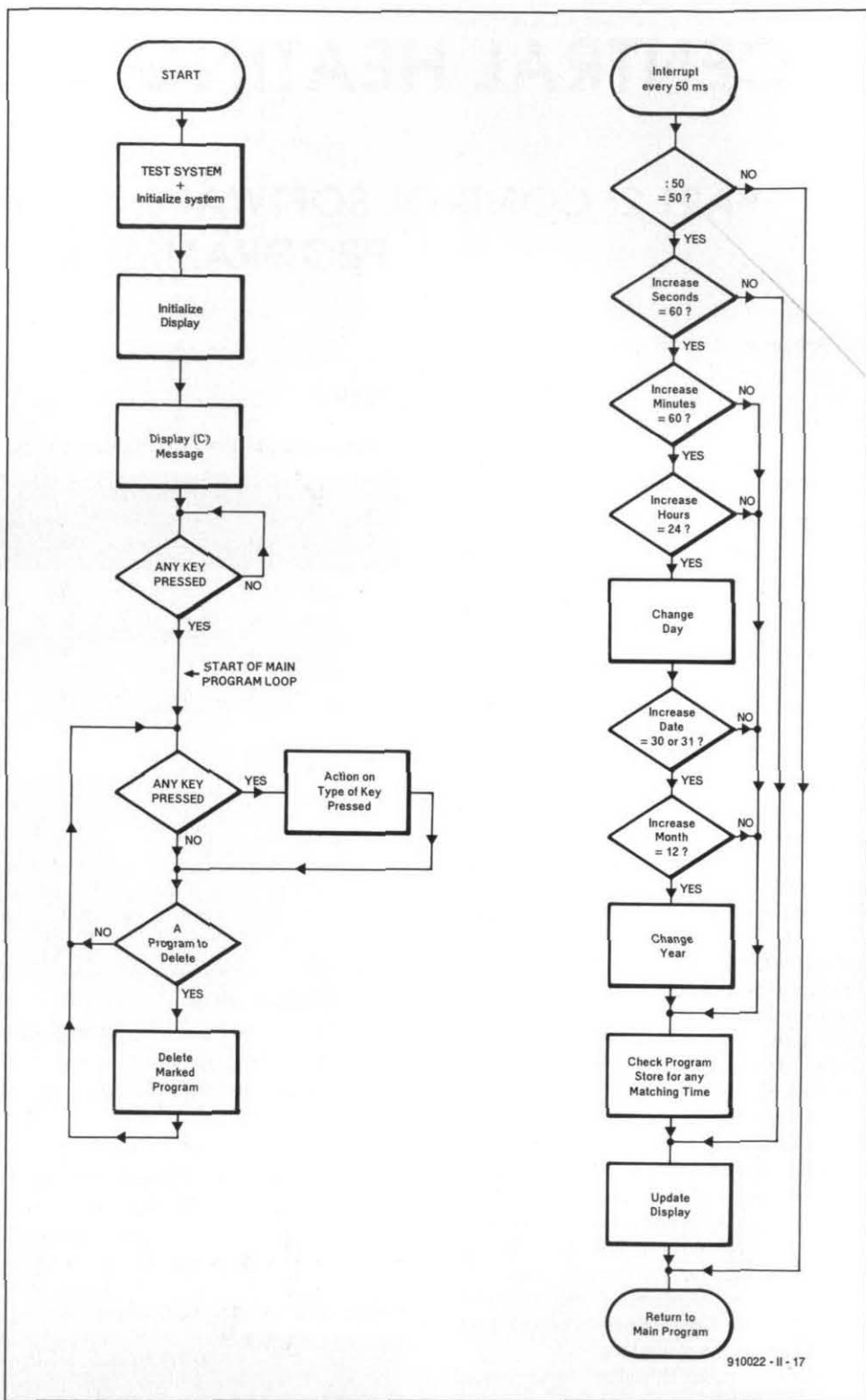


Fig. 7. Flowchart of the control program. The interrupt servicing routine is shown separately to the right.

POP AF	restore the AF registers
RET	finish subroutine and return to the character display routine

The mnemonic listing for the timeswitch program runs to over 15,000 characters in 1,400 lines of assembler text. The final object code produced by the assembler has just over 2,900 bytes of Z80 instructions and data. is given in Fig. 8. Details on ordering a copy of the hexdump listing of the control program are given at the end of this article.

**Construction and adjustment****Main PCB assembly**

The assembly of the main PCB is fairly straightforward. First, fit the 14 wire links as shown on the component overlay. It is essential that these links are fitted first, and checked, because some of them go beneath ICs, and it would be difficult to make changes later. The components can then be fitted on to the PCB, starting with the smaller ones such as the resistors and diodes. IC sockets should be used for all the integrated circuits, but at this stage, do not fit the ICs into the sockets. Lengths of stranded wire should



## COMPONENTS LIST

## MAIN CONTROLLER PCB

## Resistors:

1	1k $\Omega$	R1
4	47k $\Omega$	R2;R5;R8;R11
1	27k $\Omega$	R3
2	10k $\Omega$	R4;R14
1	see text	R6
1	22k $\Omega$	R7
2	1k $\Omega$	R9;R12
1	300 $\Omega$	R10
1	270k $\Omega$	R13
2	4k $\Omega$	R15;R16
1	47k $\Omega$ preset H	P13

## Semiconductors:

6	1N4001	D1-D4;D12;D13
7	1N914	D5;D7-D11;D14
1	BZY88C9V1	D6
1	TIL111	IC1
1	78M05	IC2
1	74HC14	IC3
1	Z84C00A	IC4
1	27C64	IC5
1	6116	IC6
1	74HC373	IC7
1	4011	IC8
1	7555	IC9
3	BC108	T1;T2;T3

## Capacitors:

1	10nF ceramic	C1
1	220 $\mu$ F 25V radial	C2
3	100nF ceramic	C3;C7;C8
1	1nF ceramic	C4
1	22 $\mu$ F 25V radial	C5
1	270pF ceramic	C6

## Miscellaneous:

1	2 MHz quartz crystal	X1
1	250mA 20-mm fuse	F1
2	fuse clip	
1	40-way IC socket	
1	28-way IC socket	
1	24-way IC socket	
1	20-way IC socket	
2	14-way IC socket	
1	8-way IC socket	
1	case type AB13, (Maplin LF14Q)	
1	mains transformer 12V @ 250 mA	
2	miniature mains relay (Maplin YX97F)	
1	12-way 2A connection strip	
1	battery (see text)	

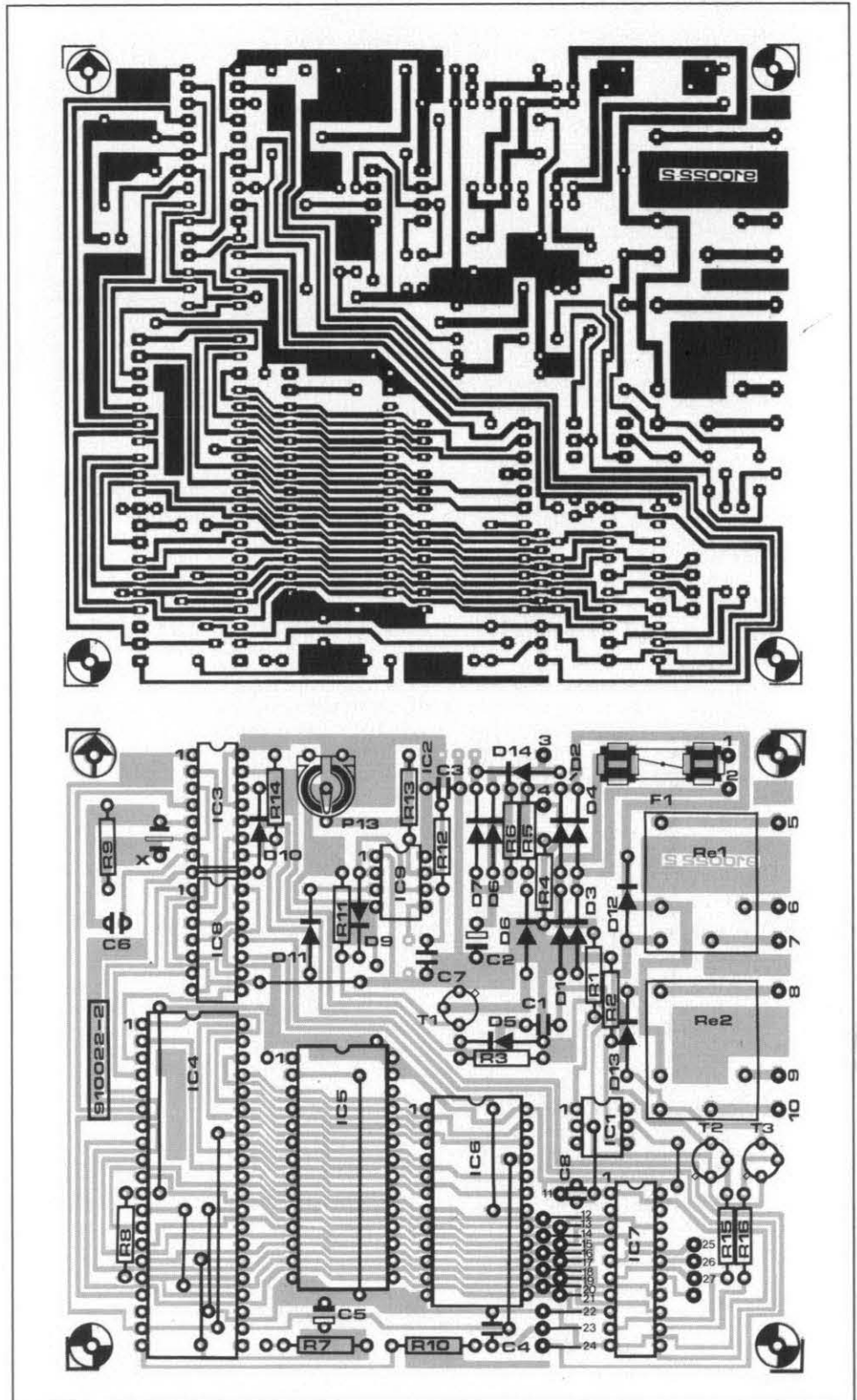


Fig. 8. Author's design of the main controller printed circuit board.

be soldered to the various connection points as shown.

At this stage it is advisable to do a number of preliminary checks. First, carefully check the PCB for short-circuits and dry joints, as any faults, particularly on the address and data lines of the CPU are difficult to trace, and could prove fatal to the CPU. Connect up the transformer, or an AC bench supply, to the circuit. Check the 5 V and 12 V supplies. Also check that a 5-V supply is present at all the IC sockets. Refer to the circuit diagrams to locate the supply terminals.

Disconnect the power, then insert IC1,

IC3, IC8 and IC9 into their respective sockets. Reconnect the power and check for the following pulses using either a logic probe or an oscilloscope.

- Pin 6 of IC4 socket: a 2-MHz clock pulse;
- Pin 17 of IC4 socket: 50 Hz very short duration pulses.

The next step is to disconnect the AC power supply and connect instead a 9-V DC supply to the points 3 and 4 on the main PCB (+Ve to point 3). Next, check the presence of 50 Hz very short duration pulses to pin 17 of the socket for IC4.

## Display PCB assembly

Fit all the components, except the LEDs, to the display PCB as shown in Fig. 9. Start with the resistors, diodes and transistors. Next, fit the key switches, complete with the caps, ensuring the correct orientation. The pins of the switches should be pushed through the PCB only far enough to enable them to be soldered. You may find it easier to solder only two diagonally opposite pins at first. Once the switch alignment is satisfactory, the remaining pins may be soldered.

Mount the LCD display unit to the PCB

# PROGRAMMING THE HEATING CONTROL UNIT

The control unit is programmed by way of the six control keys. Each key has a number of different functions, dependent on the menu shown on the display module. The basic key functions are as follows:

## Arrow keys

These keys are used to step through the various options shown on the display module. When setting the time, the keys increase or decrease the displayed time, one count at a time. If a key is held pressed for more than two seconds, the displayed time is rapidly advanced or retarded until the key is released.

## ENTER key

The 'enter' key is used to confirm a selection.

## DELETE key

This key is used to cancel a selection.

## HEATING/HOT WATER key

These keys are used to manually change the status of the heating and hot water outputs.

## Initial power-up

When power is first connected to the control unit, it performs various self checks. If these checks are satisfactory, the display shows a continuously scrolling copyright message. It is only at this point in the program that entry can be made to the calibrate mode by pressing the HEATING key.

Assuming that calibration of the system has been completed successfully as described earlier in the text, there should be no further need to enter the calibrate mode.

If any key other than the HEATING key is pressed when the copyright message is showing, the display will show the current time. Initially, this time is set to 00:00 Monday 1st January 1990.

It is probably a good idea at this stage to fit the standby battery. This will preserve the time, and any programs you may enter, if the power is accidentally disconnected.

## Setting the time and date

To set the system time and date, first press the TIME SET (down arrow) key to enter the time setting mode. The display will change to the hours and minute indication, with the hours shown between two arrow symbols. These arrows indicate the part of the display which is being edited at the moment, i.e., the hours. Press either of the arrow keys to change the hours display to the current time. Note that holding the arrow key pressed for more than two seconds will cause the display to advance rapidly.

When the correct hours indication is shown on the display, press the ENTER key. This will confirm the hours setting, and move the indicating arrows on the display to the minutes indication. Set the minutes to the correct time, again using the ARROW keys. Press the ENTER key.

Carry on setting the DAY, MONTH and YEAR in the same way, using the arrow keys to select the choice, and the ENTER key to confirm the choice. After the YEAR has been set, and the ENTER key pressed, the display will revert to the normal time display. Note that it is possible to set a non-existent date, i.e., 30th of February. The system will automatically correct this at midnight, however, making the next day the first of March.

## Displaying the seconds

To change the display mode from the normal time and date display to hours, minutes and seconds, press the DISPLAY SECONDS (up arrow) key. To synchronize the seconds, press the ENTER key. The seconds count will be zeroed to the nearest minute. To return to the normal display mode, again press the DISPLAY SECONDS key.

## Programming a switching operation

From the normal display time mode, press the PROGRAM SET (cancel) key to enter the program mode. The display will show 'Set a program'. Press the ENTER key to select this option. The display will then change to show either 'C heating' or 'Hot Water'. Use either of the arrow keys to select the option you wish to program. Again use the ENTER key to confirm your choice. Next, set the 'switch on' time, and the 'switch off' time, confirming your choice with the ENTER key. Then, again using the arrow keys, select the day(s) when switching is to take place. The choice is between any single day, every day, weekdays (i.e., Monday to Friday) or weekend (i.e., Saturday and Sunday). Again confirm your choice with the ENTER key. Finally, the display will show either 'once only' or 'repeat'. If you

require the switching to take place every week at the same time, select 'repeat'. Selecting 'once only' will cause the program to cancel itself automatically after execution. The final pressing of the ENTER key will return the display to the normal time display mode. A switching operation has now been programmed.

## Displaying the switching programs

To display the switching programs, press the DISPLAY PROGRAM (ENTER) key to enter the display program mode. The display will then show part of the first program stored. Using the arrow keys, the display can be scrolled left or right to read the various parameters of the program. To select the next program, press the ENTER key. Once the last program has been displayed, the indication will revert to the normal time display.

## Deleting a program

To delete a program, first display it as explained above. Press the CANCEL key. The display will then show 'ENT to Delete'. Press the ENTER key to delete the program, or press the CANCEL key again to revert to the program display mode.

## Using manual override

A facility exists to manually switch the system on or off with the aid of the HEATING and HOT WATER keys. Each press of a key changes the status of the appropriate output in the sequence shown below. A LED indication is given of the current state of the outputs.

Assuming the output is off:	LED not lit.
Press an override key:	the output selected changes to on; LED flashes.

In this state the output will be turned off automatically when the next programmed 'off' time is reached.

Assuming the output is on:	LED flashing.
Press an override key:	the output selected changes to 'permanent on'; LED is on.

In this state the output will ignore any programs, and remain permanently on.

Assuming that the output is permanently on:	LED on.
Press an override key:	the output selected changes to off; LED not lit.

In this state the output will respond to programmed controls as normal.

## System inhibit

A further facility exists to suspend all switching operations for a period of time. This facility could be useful for instance, when on holiday or during the summer when the system is not required to operate. Although programs in the system are still retained, they are ignored until the inhibit is cancelled. A LED indication is given when the system is inhibited.

To inhibit the system, press the PROGRAM SET (cancel) key. The display will show 'Set a Program'. Use either of the arrow keys to change the display to 'set inhibit'. Press the ENTER key. The inhibit LED will light and the display will revert to the normal time display.

To cancel the inhibit, press the PROGRAM SET (cancel) key. The display will show 'set a program'. Use either of the arrow keys to change the indication to 'Inhibit Cancel'. Press the ENTER key. The inhibit is now cancelled. The display returns to the normal time display and all the programmed switching operations are re-enabled.

## System errors

The only error possible is 'Memory Full' which will occur if you attempt to insert more than 255 programs in the system.

If this error occurs, the display will continue to show the error until the ENTER key is pressed. The display will then revert to the normal time indication mode.

## Power failure

If a mains power failure occurs, the control unit is no longer able to control the heating system. However by using the standby battery, the current time and all the stored programs are preserved in the memory. Once the power is restored, the control unit will restore the correct status to the control outputs, and control of the central heating system will resume.

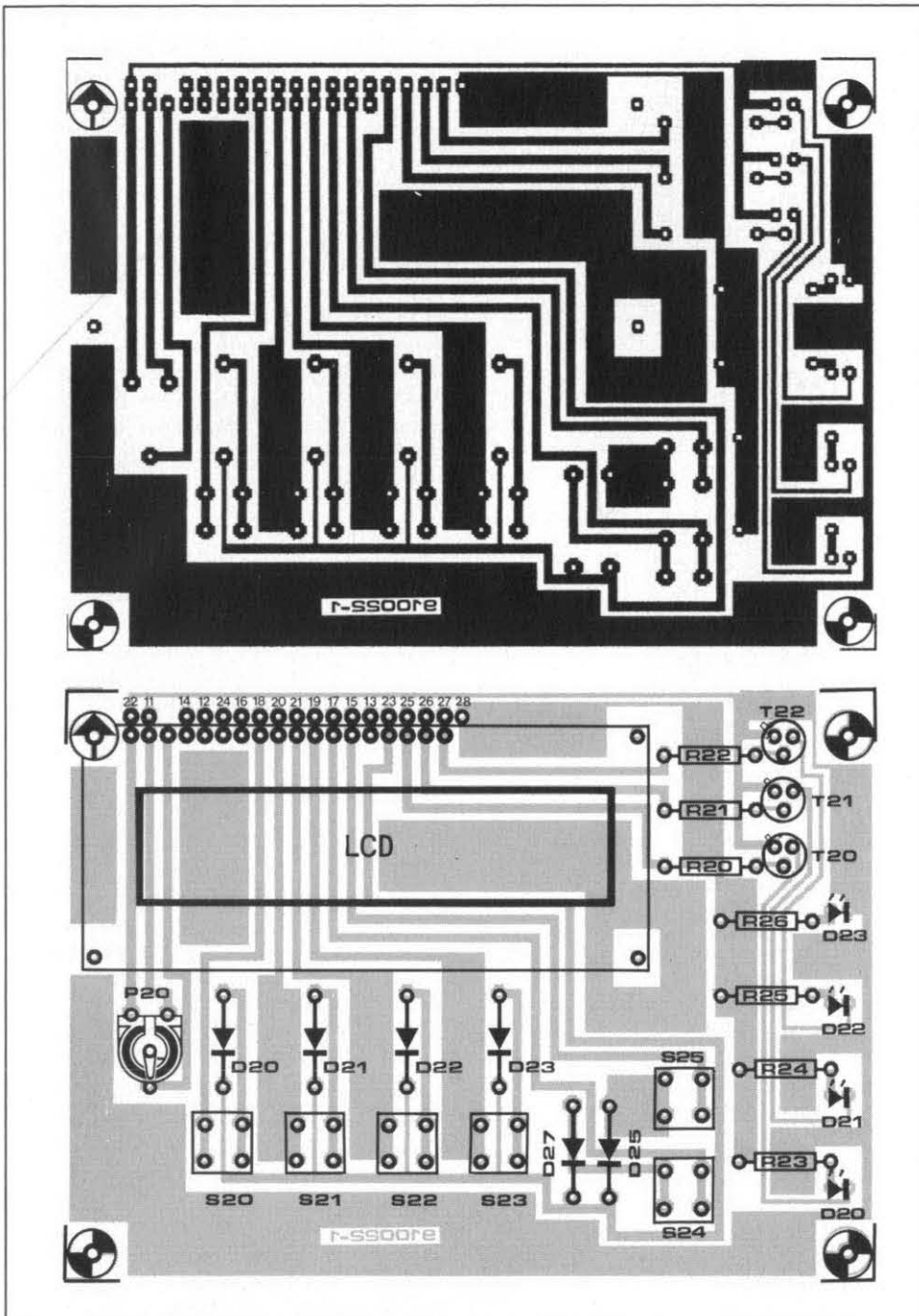


Fig. 9. Author's design of the display printed circuit board.

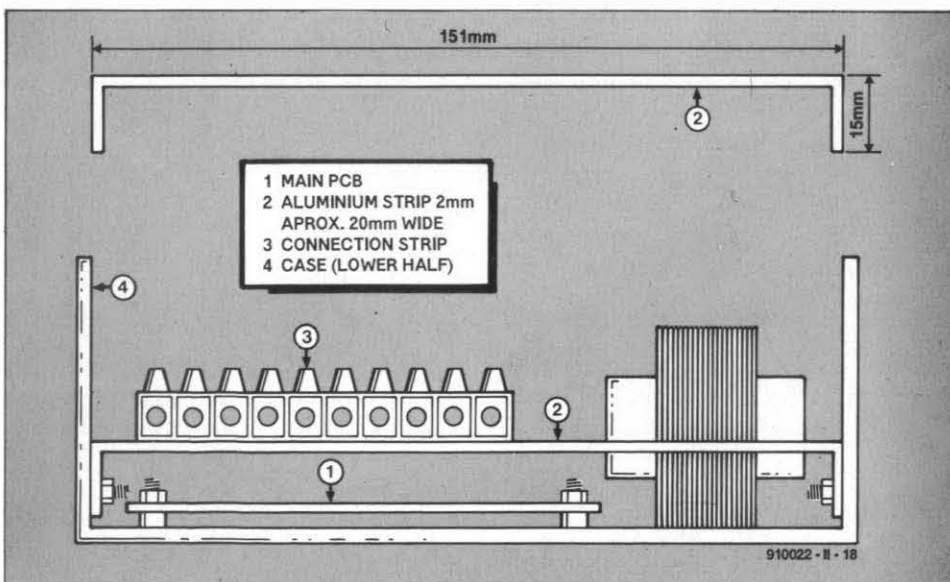


Fig. 10. Internal construction of the central heating controller.

## COMPONENTS LIST

### DISPLAY PCB

#### Resistors:

3	22k $\Omega$	R20;R21;R22
4	1k $\Omega$	R23-R26
1	10k $\Omega$ preset H	P20

#### Semiconductors:

6	1N914	D20-D25
3	BC108	T20;T21;T22
2	yellow LED 5 mm	D20;D21
1	red LED 5 mm	D22
1	green LED 5 mm	D23

#### Miscellaneous:

1	EA-D16015AR LCD module (Epson UK; STC part no. 029662B)	
6	click-effect push-button	S20-S25
4	black key cap (Maplin FF88V)	
2	white key cap (Maplin FF49C)	
4	LED clip 5 mm	

with four small nuts and bolts, using 1/8-in spacers between the module and the PCB. Connect the LCD module to the PCB with the aid of short lengths of tinned copper wire. Note that the LCD module is a CMOS device, and precautions should be taken to prevent damage caused by static electricity. Before handling the LCD module, discharge yourself to an earth point, and use an earthed soldering iron bit. Once the display is wired to the PCB, treat the whole PCB with the same care.

Finally, wire the display PCB to the main PCB with stranded wire as shown in Fig. 11. Then check the wiring and soldering very carefully.

## Testing and adjustment

At this stage in the assembly, further testing is advisable. In order to do this, the remaining ICs should be inserted into their respective sockets on the main PCB.

Connect up the power, and check the LCD module for the display message:

-(C) 1990 ....

If the display remains blank, or shows blank squares, adjust the contrast with P20 until the displayed message is clear. The usual setting for P20 is close to the minimum. Should, however, the display show random patterns, or remain totally blank, regardless of the contrast adjustment, switch off and check both PCBs for short circuits, dry joints, etc. The data and address lines are particularly suspect at this point.

### Standby timing adjustment

If all is well so far, the standby timing circuit may be adjusted. The heating control system software helps you at this point by providing a calibration routine.

Connect a 9-V supply to points 3 and 4 on the main PCB (+Ve to point 3). Ensure that the copyright message is scrolling across the display. Next, press the HEATING switch, SW24. The the display will change to

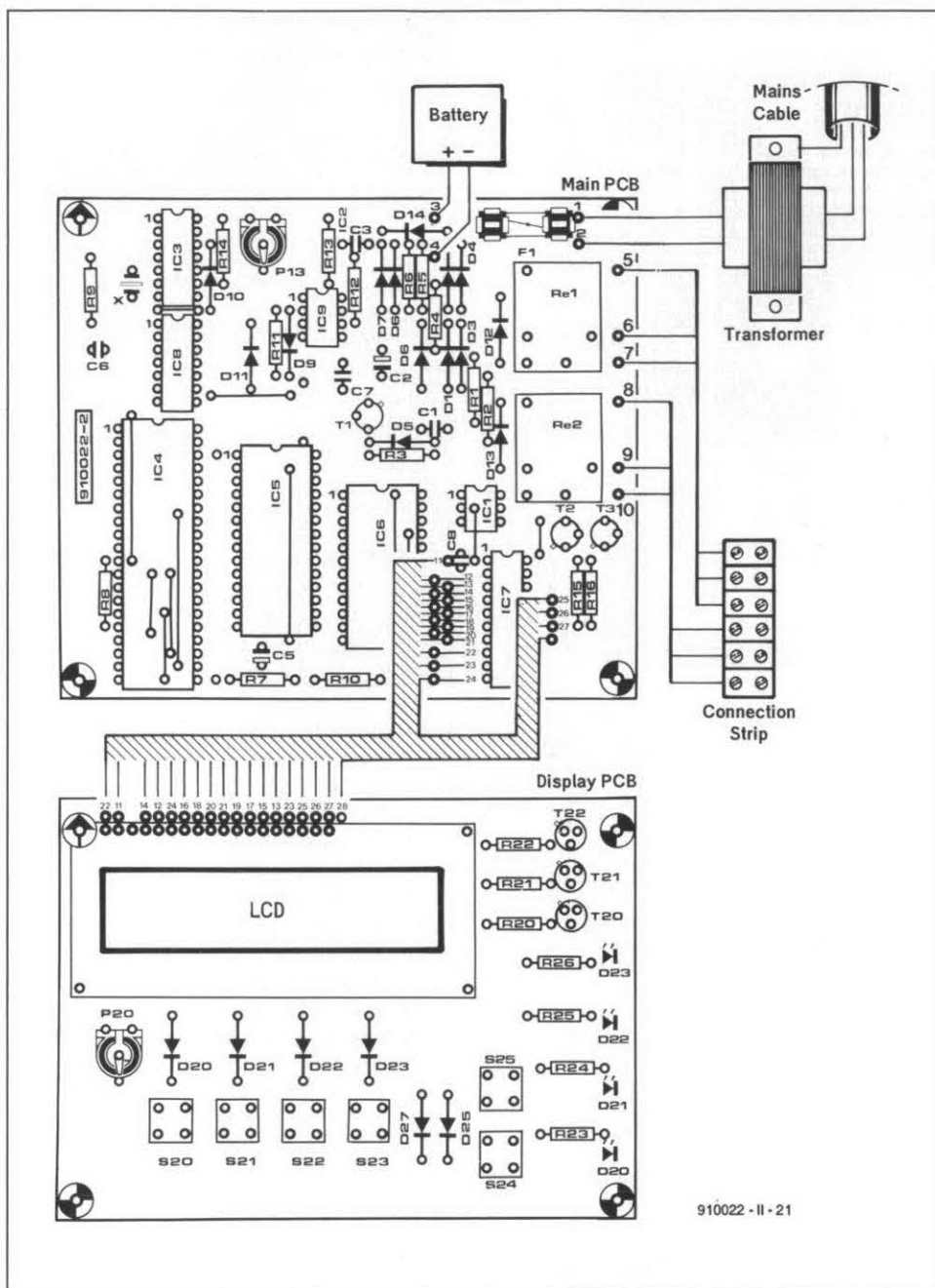


Fig. 11. Interconnection diagram for the two printed-circuit boards.

Wire number	Use	Wire number	Use
1	12 V AC supply	17	Data D5
2	12 V AC supply	18	Data D1
3	Battery +	19	Data D4
4	Battery -	20	Data D2
5	Relay 1 Hot water control	21	Data D3
6		22	Ground
7	Relay 2 Heating control	23	KEY (key enable)
8		24	$\bar{E}$ (display enable)
9		25	LED20
10		26	LED21
11	+5V supply	27	LED27
12	Address A1	28	+12V supply
13	Data D7	29	Mains (Live)
14	Address A0	30	Mains (neutral)
15	Data D6	31	Mains (earth)
16	Data D0	32	

### Calibrate - 000

Adjust preset P13 until the digits show as near as possible a constant zero. The arrows next to the number indicate if an increase or decrease in resistance is required. Allow the circuit to settle for a few seconds between each adjustment.

Once you are satisfied with the adjustment of P13, disconnect the power. The calibration of the timing circuit is now complete.

### Standby battery circuit

A suitable standby battery should be selected for the control unit. The type selected must be able to supply 50 mA whilst maintaining at least 7 V. The author used an 8.4 V PP3 style nickel-cadmium battery (Maplin HW31J), which gave a standby capacity of 2 hours.

In order to find the correct value of resistor R6 for the type of battery chosen, connect a 10 k $\Omega$  preset or potentiometer and an ammeter in place of R6 on the circuit board. Connect the power and adjust the preset until the recommended trickle charge current flows. Replace the preset with a standard resistor of approximately the set value.

### Final assembly

The box suggested for the project is a low-cost aluminium type (size approx. 150 x 100 x 50 mm) from Maplin (order code LF14Q). The top of the box should be removed and cut as shown in Fig. 13. The base of the box should also be drilled to mount the main PCB and the transformer. Check the assembly of all parts of the box, then disassemble it before painting. The author used four or five coats of white cellulose spray paint of the type used to touch up cars. Allow the paint to dry for at least 24 hours before applying the 'Letraset' panel markings as shown. Ensure the letters are well rubbed down, then apply two coats of clear cellulose lacquer as used on 'metallic paint' cars. Allow these last two coats to dry for a further 24 hours.

Complete the inter-PCB wiring as shown in Fig. 11. Fit the transformer and the main PCB in the case, and secure them with small nuts and bolts as shown. It is recommended to use 1/4-inch spacers to support the PCB. The mains cable should enter the case through a small hole in the rear panel, and be fitted with a rubber grommet.

A length of 2-mm thick aluminium strip should be bent as shown in Fig. 10. Mount this just above the main circuit board to support a 12-way strip of connectors.

Next, fit the four LED clips to the top panel, and push the LEDs into place, ensuring that the leads align with the relevant PCB holes. Do not, however, fit the securing collars. Glue a thin piece of perspex sheet to the inside of the panel to form a protective window for the LC display.

Position the PCB behind the top panel, feeding the LED leads through the appropriate holes in the PCB at the same time. Secure the PCB with the aid of four small nuts and bolts with the appropriate spacers as required, so that the display module is pressed

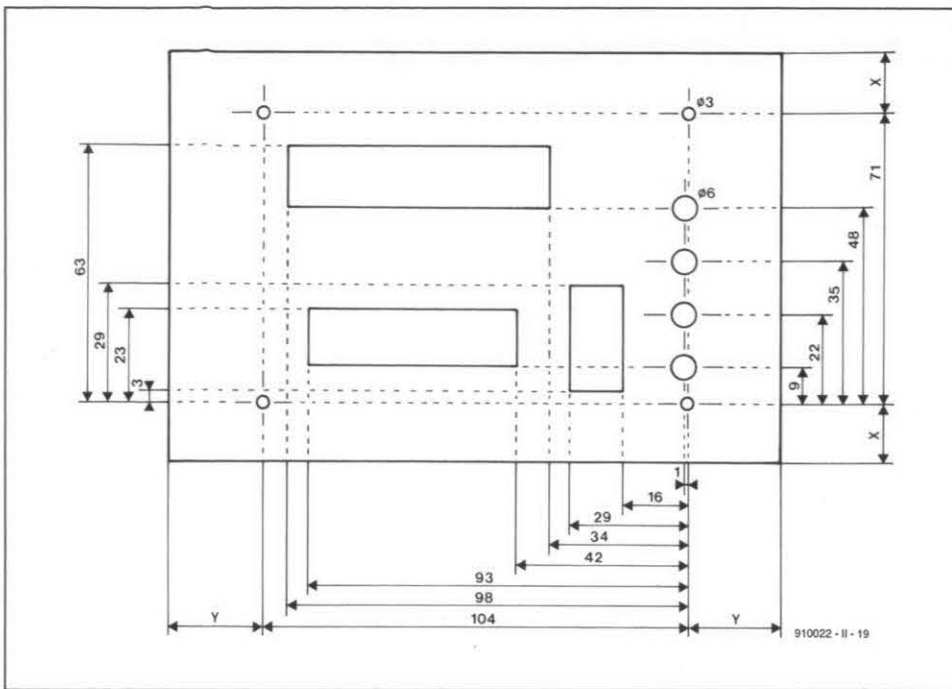


Fig. 12. Construction details of the front panel.

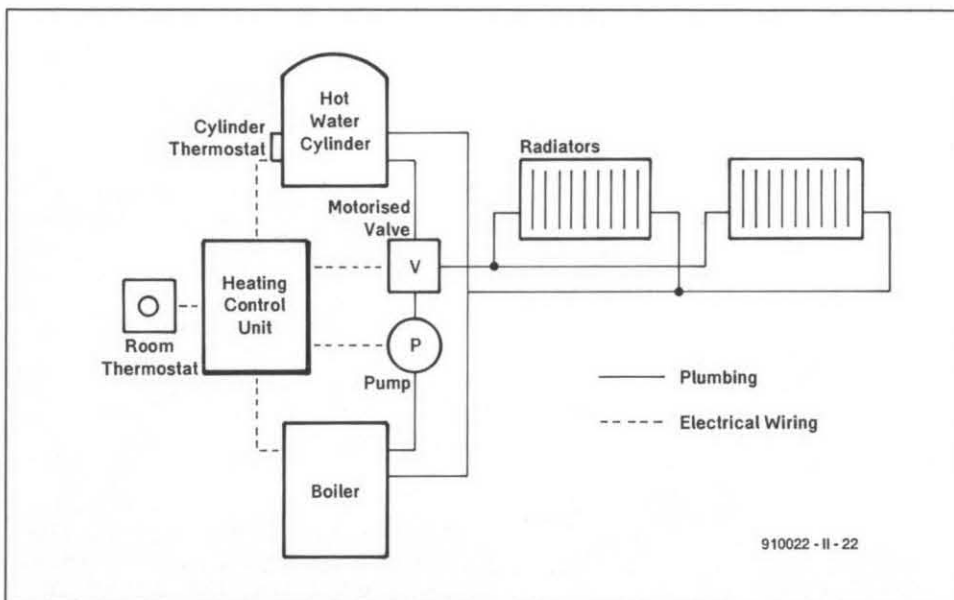


Fig. 13. Typical central heating system.

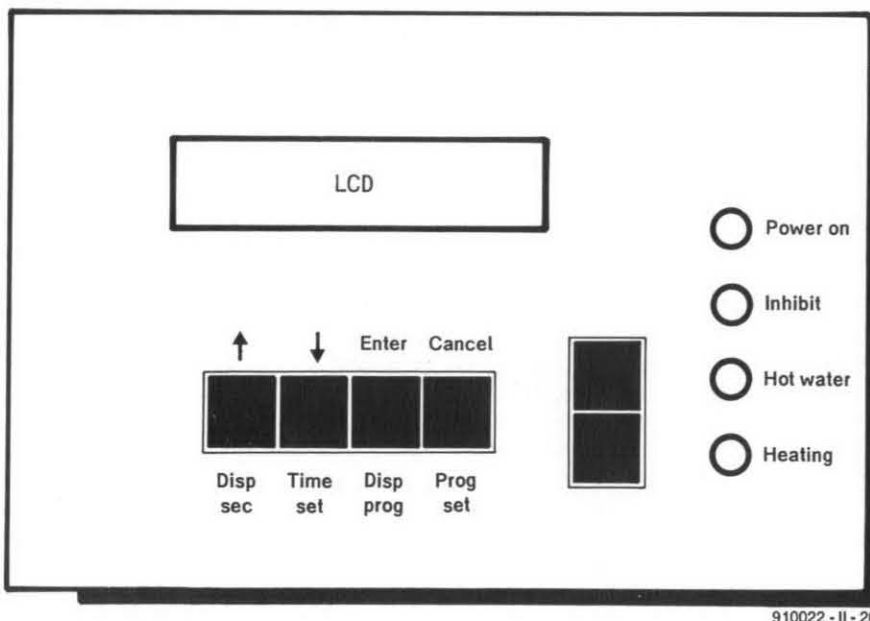


Fig. 14. Suggested front panel design (see also the introductory photograph in part 1).

against the perspex window. Finally, solder the four LEDs into position, to complete the assembly.

## Typical central heating system

A typical central heating system is shown in Fig. 13. Individual control of the hot water and heating system is only possible if a suitable motorized valve is fitted in the system. Where such a valve is not fitted however, it is still possible to use the heating controller described here. The separate hot water control function is then ignored. ■

### References:

The following reference material has been used in the preparation of this project:

1. Data sheets: Epson EA-D LCD modules (Epson UK Ltd., 081 902 8892); Z80 CPU (Maplin Electronics, 0702 552911).
2. Z80 programming: *Machine language programming made simple for your Sinclair* (Melbourne House Publishers).

### Note:

photocopies of the control program hex-dump listing may be obtained free of charge from our London office.

Readers in the UK should send a self-addressed, stamped envelope. Overseas readers should send a self-addressed envelope and two International Reply Coupons (IRCs), which may be obtained from the post office.

## COMPONENTS LIST

## MAIN CONTROLLER PCB

## Resistors:

1	1k $\Omega$	R1
4	47k $\Omega$	R2;R5;R8;R11
1	27k $\Omega$	R3
2	10k $\Omega$	R4;R14
1	see text	R6
1	22k $\Omega$	R7
2	1k $\Omega$	R9;R12
1	300 $\Omega$	R10
1	270k $\Omega$	R13
2	4k $\Omega$	R15;R16
1	47k $\Omega$ preset H	P13

## Semiconductors:

6	1N4001	D1-D4;D12;D13
7	1N914	D5;D7-D11;D14
1	BZY88C9V1	D6
1	TIL111	IC1
1	78M05	IC2
1	74HC14	IC3
1	Z84C00A	IC4
1	27C64	IC5
1	6116	IC6
1	74HC373	IC7
1	4011	IC8
1	7555	IC9
3	BC108	T1;T2;T3

## Capacitors:

1	10nF ceramic	C1
1	220 $\mu$ F 25V radial	C2
3	100nF ceramic	C3;C7;C8
1	1nF ceramic	C4
1	22 $\mu$ F 25V radial	C5
1	270pF ceramic	C6

## Miscellaneous:

1	2 MHz quartz crystal	X1
1	250mA 20-mm fuse	F1
2	fuse clip	
1	40-way IC socket	
1	28-way IC socket	
1	24-way IC socket	
1	20-way IC socket	
2	14-way IC socket	
1	8-way IC socket	
1	case type AB13, (Maplin LF14Q)	
1	mains transformer 12V @ 250 mA	
2	miniature mains relay (Maplin YX97F)	
1	12-way 2A connection strip	
1	battery (see text)	

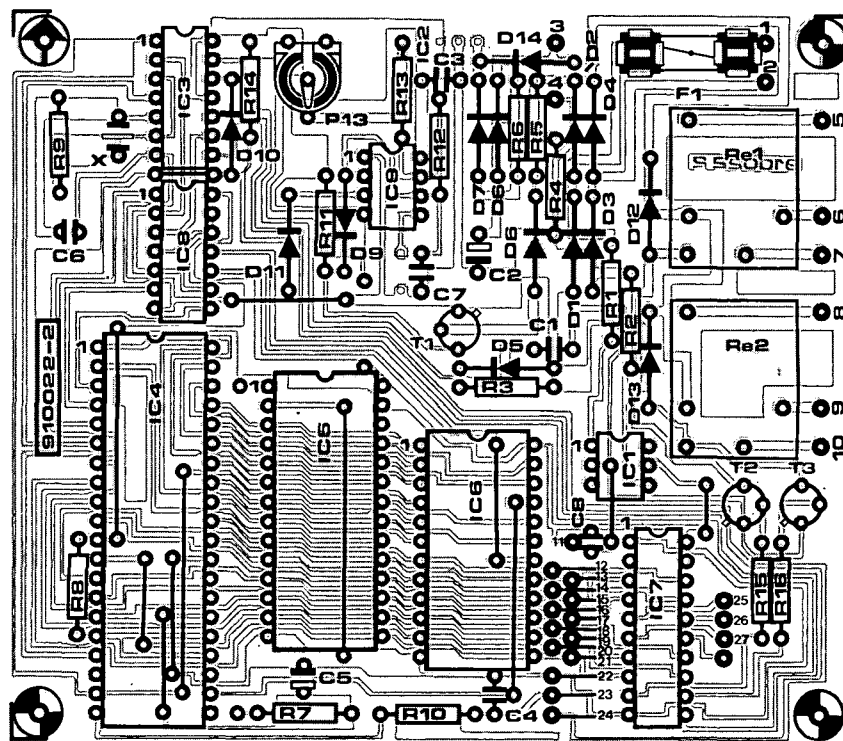
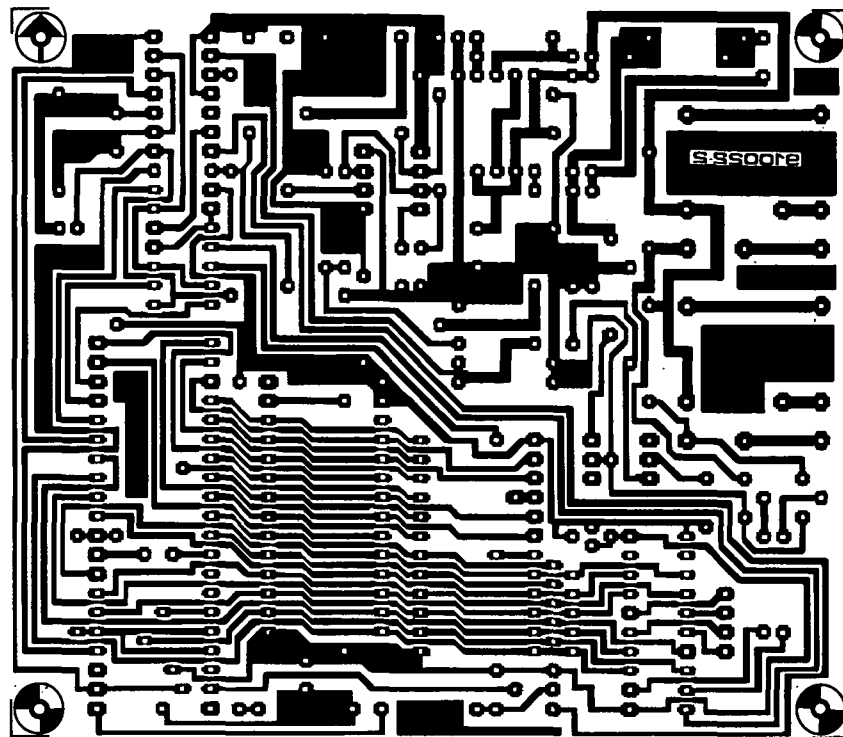


Fig. 8. Author's design of the main controller printed circuit board.

be soldered to the various connection points as shown.

At this stage it is advisable to do a number of preliminary checks. First, carefully check the PCB for short-circuits and dry joints, as any faults, particularly on the address and data lines of the CPU are difficult to trace, and could prove fatal to the CPU. Connect up the transformer, or an AC bench supply, to the circuit. Check the 5 V and 12 V supplies. Also check that a 5-V supply is present at all the IC sockets. Refer to the circuit diagrams to locate the supply terminals.

Disconnect the power, then insert IC1,

IC3, IC8 and IC9 into their respective sockets. Reconnect the power and check for the following pulses using either a logic probe or an oscilloscope.

- Pin 6 of IC4 socket: a 2-MHz clock pulse;
- Pin 17 of IC4 socket: 50 Hz very short duration pulses.

The next step is to disconnect the AC power supply and connect instead a 9-V DC supply to the points 3 and 4 on the main PCB (+Ve to point 3). Next, check the presence of 50 Hz very short duration pulses to pin 17 of the socket for IC4.

## Display PCB assembly

Fit all the components, except the LEDs, to the display PCB as shown in Fig. 9. Start with the resistors, diodes and transistors. Next, fit the key switches, complete with the caps, ensuring the correct orientation. The pins of the switches should be pushed through the PCB only far enough to enable them to be soldered. You may find it easier to solder only two diagonally opposite pins at first. Once the switch alignment is satisfactory, the remaining pins may be soldered.

Mount the LCD display unit to the PCB

## COMPONENTS LIST

## DISPLAY PCB

## Resistors:

3	22k $\Omega$	R20;R21;R22
4	1k $\Omega$	R23-R26
1	10k $\Omega$ preset H	P20

## Semiconductors:

6	1N914	D20-D25
3	BC108	T20;T21;T22
2	yellow LED 5 mm	D20;D21
1	red LED 5 mm	D22
1	green LED 5 mm	D23

## Miscellaneous:

1	EA-D16015AR LCD module (Epson UK; STC part no. 029662B)	
6	click-effect push-button	S20-S25
4	black key cap (Maplin FF88V)	
2	white key cap (Maplin FF49C)	
4	LED clip 5 mm	

with four small nuts and bolts, using 1/8-in spacers between the module and the PCB. Connect the LCD module to the PCB with the aid of short lengths of tinned copper wire. Note that the LCD module is a CMOS device, and precautions should be taken to prevent damage caused by static electricity. Before handling the LCD module, discharge yourself to an earth point, and use an earthed soldering iron bit. Once the display is wired to the PCB, treat the whole PCB with the same care.

Finally, wire the display PCB to the main PCB with stranded wire as shown in Fig. 11. Then check the wiring and soldering very carefully.

## Testing and adjustment

At this stage in the assembly, further testing is advisable. In order to do this, the remaining ICs should be inserted into their respective sockets on the main PCB.

Connect up the power, and check the LCD module for the display message:

- (C) 1990 ....

If the display remains blank, or shows blank squares, adjust the contrast with P20 until the displayed message is clear. The usual setting for P20 is close to the minimum. Should, however, the display show random patterns, or remain totally blank, regardless of the contrast adjustment, switch off and check both PCBs for short circuits, dry joints, etc. The data and address lines are particularly suspect at this point.

## Standby timing adjustment

If all is well so far, the standby timing circuit may be adjusted. The heating control system software helps you at this point by providing a calibration routine.

Connect a 9-V supply to points 3 and 4 on the main PCB (+Ve to point 3). Ensure that the copyright message is scrolling across the display. Next, press the HEATING switch, SW24. The the display will change to

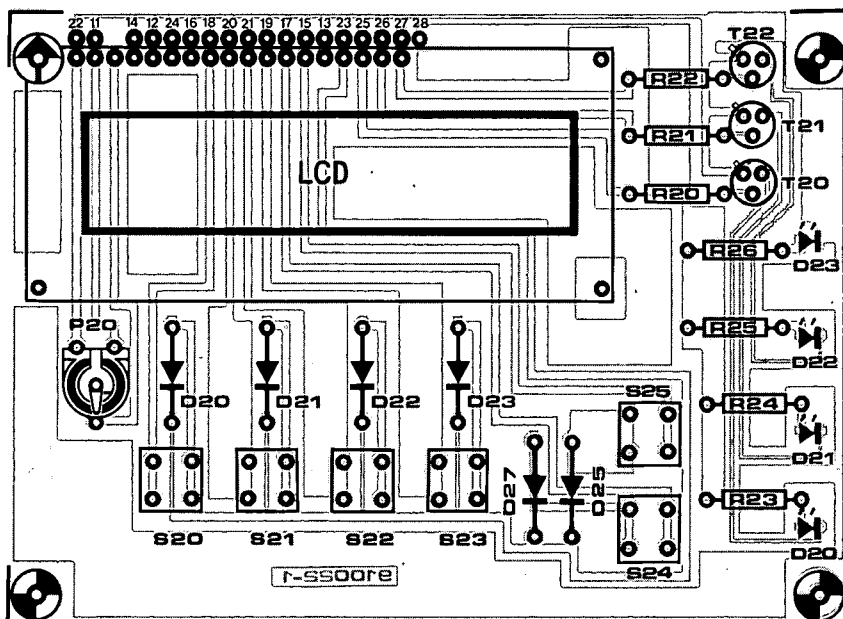
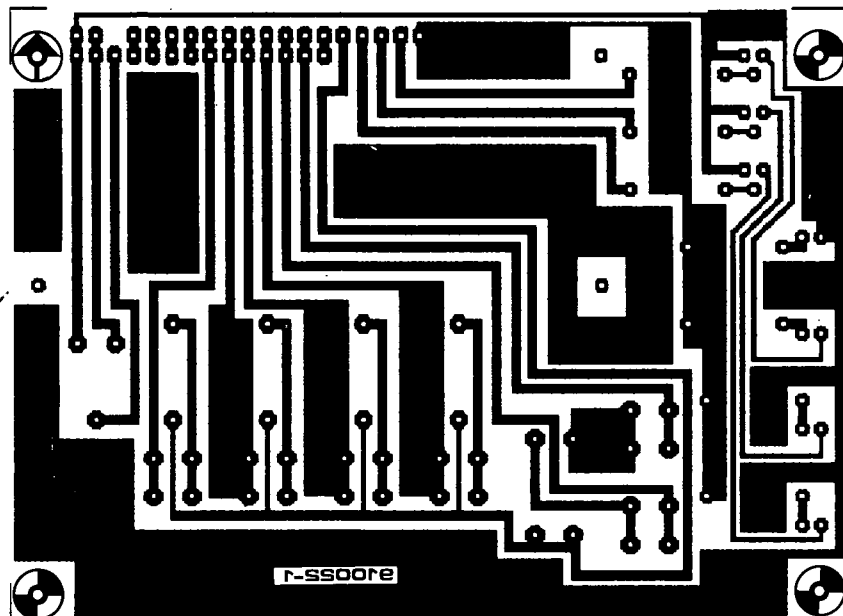


Fig. 9. Author's design of the display printed circuit board.

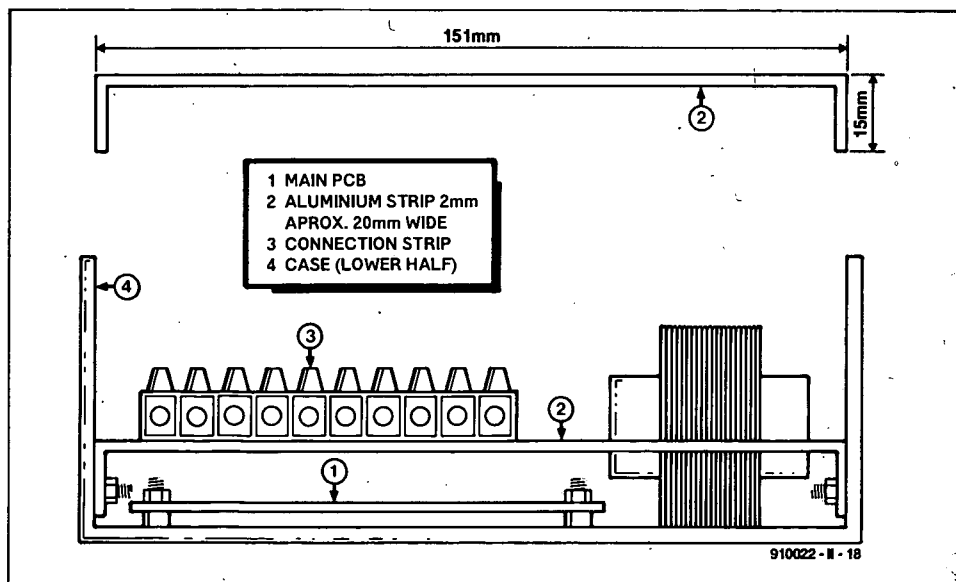


Fig. 10. Internal construction of the central heating controller.

# RADAR DETECTOR

**Radar signals are used in nautical navigation systems for vessel positioning and distance readings where visibility is restricted. Unfortunately, radar equipment is pretty expensive, so that many owners of small yachts have to make do without an 'electronic eye'. With the aid of the detector presented here these ship owners can, however, implement a basic warning and positioning system by making use of radar signals from other ships.**

M.R. Ebbell 

**R**ADAR installations make it possible to survey large areas with the aid of electromagnetic waves. Not surprisingly, most radar equipment is produced for the avionics, military and nautical industries. Since a radar system includes a transmitter, its activity can always be detected. Most radars emit a pulsating RF signal at a frequency between 2 GHz and 12 GHz, and receive their own signals, which are reflected by objects within the covered area. The relative strength and the delay of the reflections are measured and used to determine the distance and the size of the object. This system allows the area around the radar installation to be mapped and surveyed.

For non-professional applications, such as pleasure craft, radar is often too expensive. Consequently, most pleasure craft can not sail when there is heavy rain or fog.

The radar detector presented here is a low-cost way of using the radar signals of professional craft to prevent collisions, and provide a basic way of ship positioning where visibility is restricted. A LED indicator starts to flash, and an audible warning is given, when a radar system is detected within the receive range of the detector. To the navigator, these signals are a sign that another ship is approaching. The detector is directional, that is, it can be aimed at the radar source for an approximate distance and position reading.

## Frequency bands

Since the peak pulse power emitted by a radar transmitter is of the order of kilowatts, a relatively simple receiver can be used to detect the pulsating RF signals. Parts of the frequency bands listed in Table 1 have been reserved for radar systems. It should be noted that certain frequencies may be shared with other services, such as radio and TV microwave links, satellites, mobile services and radio amateurs. The primary or secondary services in a particular band are determined at a local (often national) level by the relevant telecommunication authorities. For example, although radio amateurs are



Fig. 1. Prototype of the radar detector, seen from the solder side of the PCB.

allowed to use certain sections of the 23 cm and 24 cm bands (L-band), they are forced to share them, on a secondary basis, with powerful radar transmitters used for automatic aircraft identification systems installed near military airports. Since the radio amateur service has a secondary status in these sections of the band, the interference caused by such radar stations has to be put up with.

Radar systems for nautical applications usually work in the X band or the S band. More precisely, in the X band the section from 8.5 GHz to 10.68 GHz is assigned to radar, while in the S band two sections are used: 2.3 GHz to 2.5 GHz, and 2.7 GHz to 3.7 GHz.

Although designed to detect X band signals, the present circuit will also work with S band radar systems, so that it is suitable for all conventional nautical radars.

The effective range of a nautical radar depends on the transmit power and the height of the antenna. Table 2 lists the most important characteristics of currently used radar systems. It should be noted that the transmit powers are peak pulse values, not continuous levels. The radar transmitter is pulsed to enable distances to be measured (when the transmitter is off, the receiver is on to detect the reflected signal). The transmitter pulse rate determines the maximum distance that can be measured. The longer the pulse spacing, the longer the signal will have to travel to cause a reflection that can be measured reliably. Because of the pulsating operation, the continuous power rating of most radars is only a fraction of the peak pulse power.

In practice, the range of a radar system depends on a number of factors, including the transmit power, the directivity of the antenna, the propagation characteristics of the



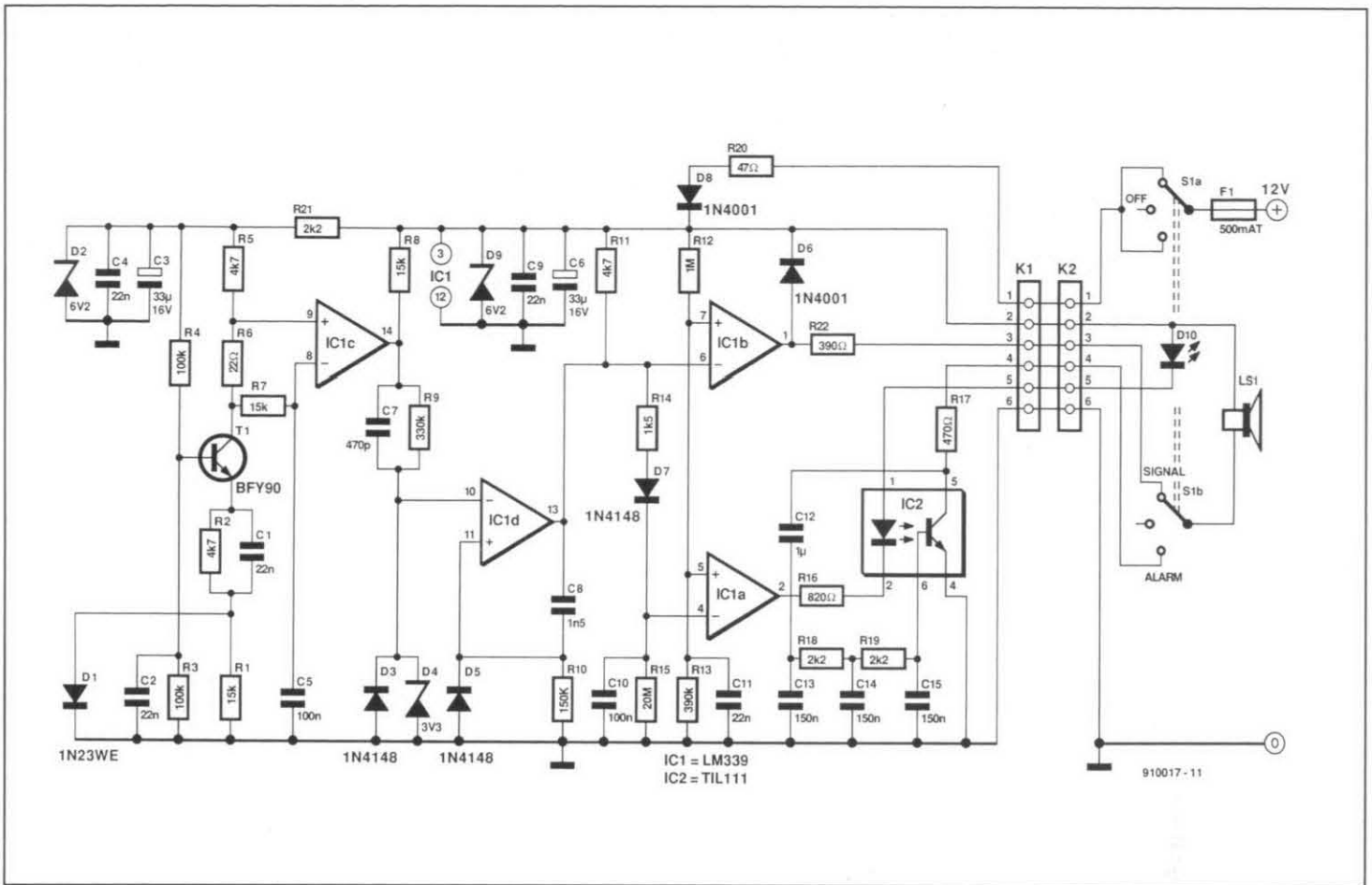


Fig. 2. Circuit diagram of the radar detector.

band used, and atmospheric conditions. The frequencies used for radar are so high that the propagation of the signals is largely similar to that of light. This means that a microwave radar can not, in principle, see objects over the horizon. In practice, however, diffraction, scattering and partial reflection in some atmospheric layers give a radar system a range that extends just over the horizon.

### Circuit description

The circuit diagram of the radar detector is given in Fig. 2. Although the circuit is designed to receive very high frequencies, it is relatively simple. The only RF parts in the circuit are a detector diode Type 1N23 and a rudimentary type of antenna which is constructed with the aid of the diode fitting. To achieve maximum sensitivity, a small forward current is sent through the 1N23. This current is supplied by transistor T1. The diode current rises considerably when an RF pulse is received on the antenna. The resultant current pulse causes T1 to conduct harder and supply a voltage pulse at its collector. In this way, the pulsating SHF radar signal is converted into a pulse train that can be processed by low-frequency circuitry. The pulse rate and duration depend on the radar system received by the detector. In general, the pulse rate will lie between 400 Hz and 4 kHz.

The large changes in the collector current of T1 cause the voltage at the +input of opamp IC1c to drop considerably. The voltage at the inverting input remains stable

much longer because of capacitor C5. The output of the opamp goes low when a radar signal is received. Components R9 and D4 limit the output signal of IC1c to a value of 3.3 V.

A further opamp, IC1d, is used to convert the short pulses into a signal with a fixed pulse length of 1 ms. The output of this monostable multivibrator is applied to two sub-circuits. Opamp IC1b amplifies the pul-

Table 1

Band designation	Nominal frequency range	Specific radiolocation (radar) bands (ITU Assignments for Region 2)
VHF	30 – 300 MHz	138 – 144 MHz
UHF	300 – 1000 MHz	420 – 450 MHz
L	1 – 2 GHz	1,215 – 1,400 MHz
S	2 – 4 GHz	2,300 – 2,500 MHz
		2,700 – 3,700 MHz
C	4 – 8 GHz	5,250 – 5,925 MHz
X	8 – 12 GHz	8.5 – 10.68 GHz
Ku	12 – 18 GHz	13.4 – 14.0 GHz
K	18 – 27 GHz	24.05 – 24.25 GHz
Ka	27 – 40 GHz	33.4 – 36.0 GHz
V	40 – 75 GHz	59 – 64 GHz
W	75 – 110 GHz	76 – 81 GHz
		92 – 100 GHz
mm	110 – 300 GHz	126 – 142 GHz
		144 – 149 GHz
		231 – 235 GHz
		238 – 248 GHz

Table 2

Vessel type	Beamwidth (degrees)	Antenna height (metres)	Power (kW)	Range (naut. miles)
river transport	1.5°	4	5	2.5
yacht	3°	4	3	1.5
trawler	2°	6	10	3
coaster	1.5°	8	10	5
container/bulk vessel (X-band)	1°	30	50	8
container/bulk vessel (S-band)	3°	30	50	3

ses supplied by IC1d, and drives a small loudspeaker. The output signal of IC1d is also fed to a single-phase rectifier that consists of R14, R15, C10 and D7. Capacitor C10 is charged via R14 and D7 as long as the output of IC1d supplies positive pulses. The capacitor can only be discharged via R15. Since R15 has a much higher value than R14, C2 can not be discharged completely until the pulse train from IC1d has ceased. When C2 is kept charged, the inverting input of IC1a is at a higher voltage than the non-inverting input. Consequently, the LED in optocoupler IC2 lights, and causes an oscillator based on the transistor in IC2 to operate. The generated AF signal is fed to the loudspeaker via resistor R17. At the same time, LED D10 lights.

Switch S1 allows the loudspeaker to produce either the detected pulses or the continuous warning signal. The same switch is also used to switch the detector on and off.

The battery voltage is filtered with the aid of R20 and C11. Diode D9 limits the circuit supply voltage to about 13 V and prevents the circuit being damaged by overvoltage.

The supply voltage of the detection diode is reduced to about 8 V by D2 and R21, with capacitors C11 and C3 providing additional filtering, and C4 and C6 ensuring the required RF decoupling of the power supply.

### Construction

As shown in the photograph of the prototype, the detection diode is mounted centrally at the track side of a round printed-circuit board. The crucial part in the circuit, the 1N23, is a point-contact diode with an extremely low stray inductance. The device, which is probably familiar to those of you who have 'microwave' experience, has a white ceramic body and gold-plated terminals. Since the device is easily damaged by overheating, it must never be soldered. Always secure the diode with the appropriate fixing sockets, which can be salvaged from surplus SHF military equipment such as the famous APX-6 transponder (a visit to an electronics surplus shop will probably secure the 1N23 and the associated fixing soc-

kets as spare items). It should be noted that there exist a number of equivalent or near-equivalent types of the 1N23, all of which can be expected to work in the circuit. One near equivalent, the DC1504 from NEC, is shown in the photograph of the prototype, Fig. 1.

The antenna of the radar detector consists of a 15-mm dia. plate soldered to the anode connector as shown in Fig. 2. A short piece of wire connects the antenna to C1-R2 on the printed-circuit board. Although a purpose-designed PCB is shown in Figs. 2 and 3, the circuit should also work without problems when constructed on a piece of veroboard or stripboard.

The completed circuit board and the attached detector diode must be fitted in a metal enclosure with a small hole drilled in the front cover. The hole is drilled at a position facing the antenna fixed to the detector diode. The hole gives the radar detector a directivity of about 25°.

Depending on the mode selected with S1, the loudspeaker produces either the rattle of the received radar, or an intermittent alarm sound with pauses of about 1.5 s. As already noted, the frequency of the received radar pulses depends on the system used. In practice, you can expect almost any frequency between 400 Hz and 4 kHz. The sound is probably produced as short bursts because radar antenna rotates. Usually, the antenna has a speed of 22 rotations per minute, which results in bursts with a repeat rate of 3 seconds. You can tell the presence of more than one ship equipped with radar when the detector produces bursts with a repeat rate shorter than 3 seconds. To determine the approximate position of a radar source, hold the detector in your hand and slowly turn it horizontally, sweeping the horizon. ■

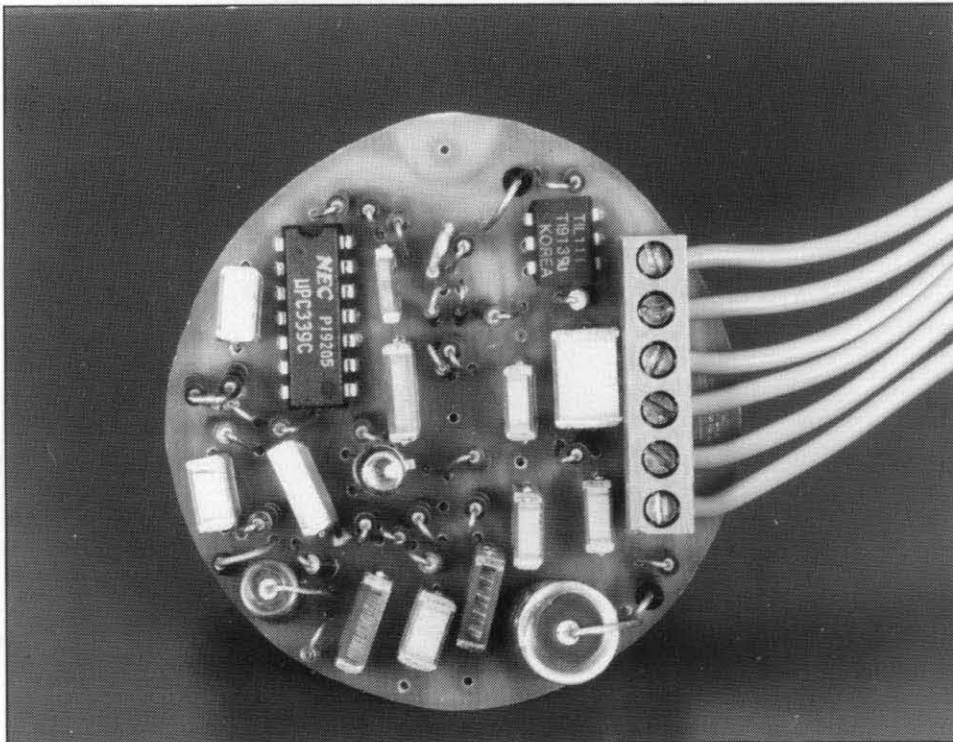


Fig. 3. Component side view of the radar detector PCB. A six-way terminal block is used to connect the supply, switch S1, the LED and the loudspeaker.