ELEKTOR ELECTRONICS

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DIGITAL AUDIO-VISUAL SYSTEM

Output amplifier for ribbon loudspeakers

Wheatstone bridge

Printer sharing unit

Differential thermometer

Spiral T/R HF antenna

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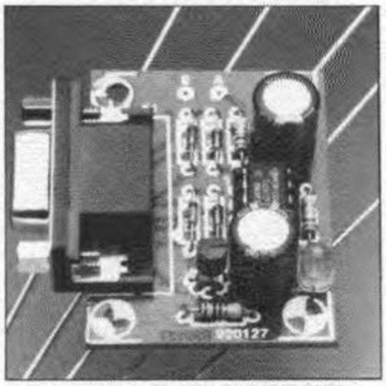

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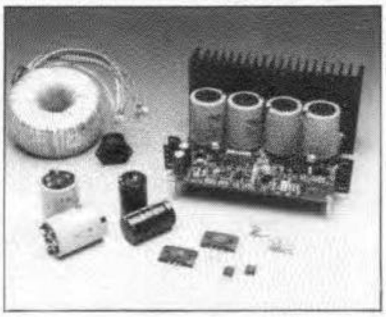

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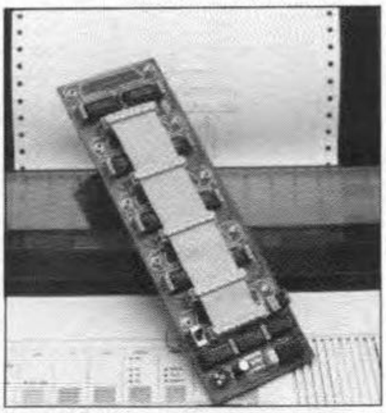

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A COMPACT SPIRAL T/R HF ANTENNA

This is a short, efficient, horizontal indoor spiral transmitting/receiving antenna, using 139 feet (approx. 42 m), that can be compacted into a length of about 15 feet (approx. 3 m). It is based on a pair of Slinkys. And, quite reasonably, you may ask "and what on earth is a Slinky?"

By Richard Q. Marris, G2BZQ

SLINKY was first met, by courtesy of the two sons of a colleague, while the author lived and worked in the U.S.A. for several years during the 1970's. Slinky is manufactured in the U.S.A. by James Industries Inc., Hollidaysburg, PA 16648. It consists of 90×2¾ in (90×7 cm) diameter turns of spring made of 67 ft (approx. 20 m) of flat bright steel wire. Each Slinky weighs about ½ lb (approx. 0.45 kg), and can be extracted to about 15 ft (4.5 m). However, it comes compressed into a 2¼-in (5.7-cm) length in a robust red carton on which we read that Slinky is 'a walking spring toy' for 'ages 6 and up!'. It was demonstrated to the author as a fascinating toy which would, among other things, walk down stairs!

Design background

It so happens that as a Slinky is expanded, it resonates as a ¼λ between 7 and 8 MHz. In fact, the retailers (Antenna West) offer suggestions, and kits of parts, for using it as a 7-MHz or 14-MHz delta matched dipole. Each dipole can be resonated by expanding or contracting the spring coil. It is estimated that the bandwidth would be comparatively narrow. Each kit comes with a Slinky, a transparent messenger line, transparent coil positioning tabs, ceiling hooks with hardware, transparent suction caps and white coaxial feedline.

Antenna description

The requirement was for a short efficient indoor multiband T/R antenna, which can be slung diagonally across a room, and used on most of the H.F. amateur bands.

As the primary, and lowest, frequency was for the 80-m (3.5-MHz) band, two Slinky coils (without accessories) were obtained, and electrically secured end-to-end. The long double Slinky was hung diagonally across a room, and end-fed with a short single feedline plugged into a suitable ATU (antenna tuning unit) which would resonate it on all amateur bands between 10 m (28 MHz) and 80 m (3.5 MHz). It was anticipated that the voltage and current distribution would be relatively uniform over the whole length, and that a sizeable section of each band could be used without retuning the ATU. As two coils weigh about 1 lb (approx. 0.9 kg), the whole spring was supported by thin nylon cord, enabling the antenna to be length adjusted, and compressed into a few inches when not in use. Also, it could be discreetly hidden in a corner of the room.

The final operating arrangement is shown in Fig. 1a, and the non-operational arrangement, in Fig. 1b. The 5-ft long feedline drops down from the room corner end, located over the equipment, the ATU. Various ATU types were tried, but the simple 'T' type shown in Fig. 2 proved to be the most effective. The earth connection was taken with about 15 ft (4.5 m) of stout

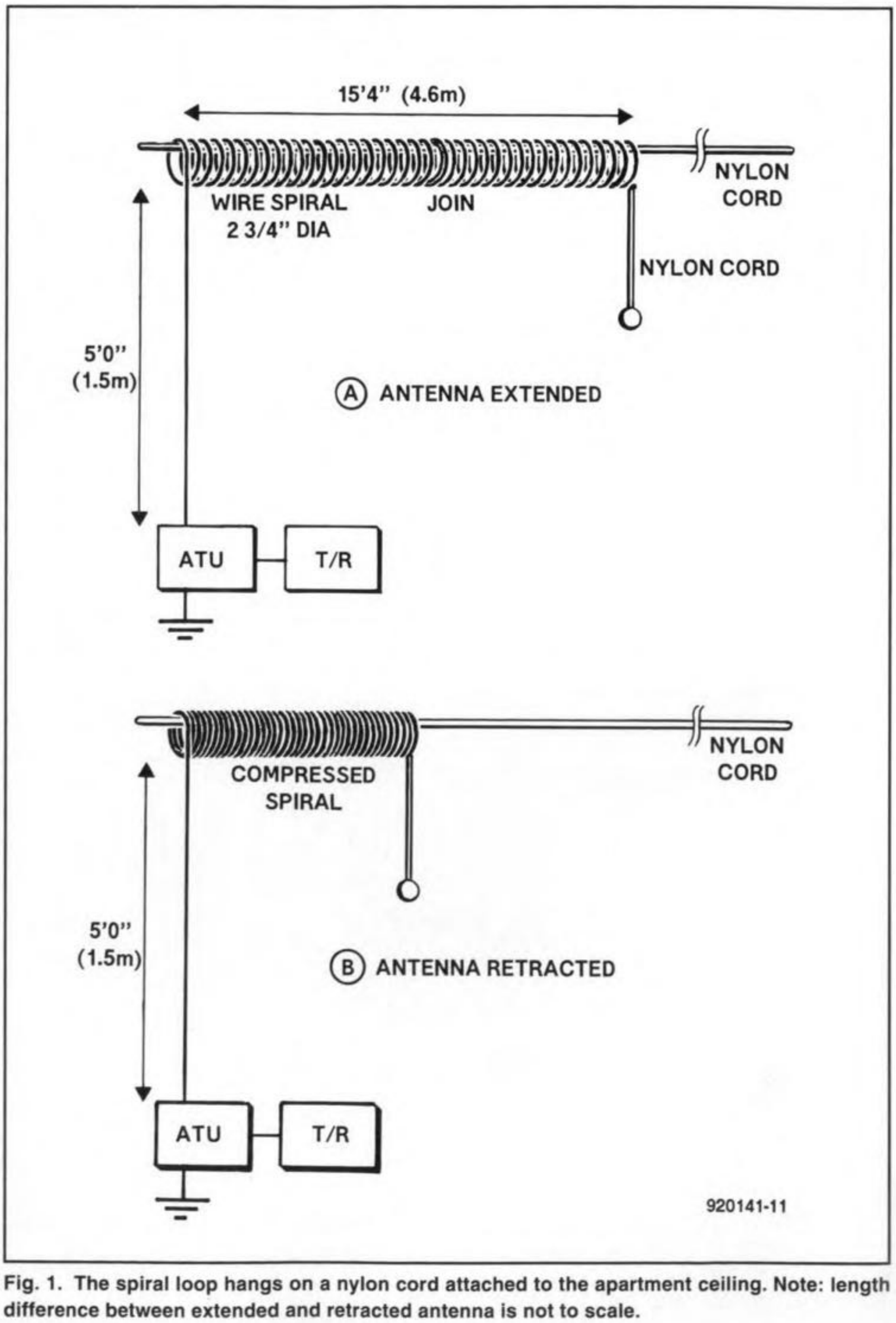


Fig. 1. The spiral loop hangs on a nylon cord attached to the apartment ceiling. Note: length difference between extended and retracted antenna is not to scale.

flex to a convenient water pipe. Though the final antenna is only 15'4" long (approx. 4.6 m), plus the 5-ft (1.5-m) drop-down feeder, there is actually a total of 139 ft (41.7 m) of wire, i.e., 2×67 ft plus 5 ft. The diagonal space across the room was 18 ft (5.4 m). The drop-down feedline is part of the antenna.

Antenna construction

A length of 1/16-in (1.6-mm) diameter white nylon cord is now suspended diagonally across the room, at least 9 ft (2.7 m) away from the ceiling, and carefully avoiding electric light fittings. Here, the length from corner to corner is 18 ft (5.4 m). The wire coil is now slipped over one end of the nylon cord, before it is securely fixed at one end. A stout 5-ft (1.5-m) long single-core flex feeder lead is soldered to one end of the coil, and dropped down to the ATU, as shown in Figs. 1a and 1b. A piece of nylon cord is tied to the other end of the coil, and terminated with a plastic ring or knob. By using this short nylon cord as a tow line, the coil can be expanded to a length of 15'4" (approx. 4.6 m), and a few turns of nylon cord wound and knotted at this point form an 'anchoring stop' for quickly expanding the antenna coil when in use. The last turn of the coil is slipped over this 'stop'.

When not in use, the coil can be pulled back to a discreet compressed coil at one end (see Fig. 1b). The horizontal length of nylon cord is nearly invisible against a white ceiling.

ATU construction

Possibly the reader has a suitable existing ATU, and this can be tried. Several ATU configurations were tried with the 'T' type, shown in Fig. 2, which was also the final design adopted. The inductor, L, is a length of B&W coil stock (see Components List), and C1 and C2 are both 250-pF good quality air-spaced variable capacitors. The whole is built into a convenient metal box, the maximum size of which will depend mainly on the type and size of the variable capacitor used. At least one diameter clearance should be left around L.

The spindles of C1 and C2 must be isolated from all metalwork. A convenient way of doing this is to mount C1, C2 and L on a sheet of perspex, or non-metallized fibre-glass board, which is mounted on four short pillars, just behind the metal front panel. Large clearance holes will be required in the metal box panel, so that the spindles of C1 and C2 do not touch the metalwork. Sockets Skt1 and Skt2 are coaxial types of convenient type to the user.

Taps should be made on L, for each band to be used. The ATU will match the antenna to the transmitter/receiver on the 80-m (3.5-MHz), 40-m (7-MHz), 20-m (14-MHz), 15-m (21-MHz) and 10-m (28-MHz) amateur radio bands. The author uses tapping clips, but some of you may prefer a ceramic wafer rotary switch. The method of locating the taps is described below.

Setting up, testing and operating

With the antenna extracted to 15'4" (4.6 m), and plugged into Skt1, and Skt2 connected to the transceiver with a short length of coaxial feedline, an earthing/grounding connection should be made to the ATU. Here, about 15 ft (4.5 m) of stout wire flex is firmly connected to a convenient metal water pipe. Other convenient grounding arrangements may be used depending on individual circumstances.

Do not connect the ATU to plastic water pipes, metal gas pipes, or metal electric wiring conduit. Do not connect it to the AC mains earthing pin either. Even though the mains earth will, no doubt, be connected to the transceiver, it must not be used as an RF earth connection to the ATU.

Tune the receiver to a convenient spot on the 80-m (3.5-MHz) amateur radio band. Set C1 and C2 to 50% capacity, and move the tap along the coil, L, for maximum signal. Adjust C2 for maximum signal — this will match the ATU to the receiver's input impedance. Next, repeat the adjustment of C1 for best antenna matching. Switch on the transmitter, and carefully re-adjust C1 and C2 for best loading and lowest SWR. Once you are satisfied with the results, secure the 80-m tapping point by either solder, switch or clip connection, depending on what has been decided. An SWR of 1:1 is obtainable with care. Repeat the process for the other bands selected.

It is also possible to match the ATU/antenna combination to Top Band (1.8 MHz), but it is presumed that performance would be suitable for the shorter range operation. It has not been tried.

As an example, the author has used this spiral antenna quite extensively, in the early morning, on the 80-m band, using a 14 watts input CW transmitter. An SWR of 1:1 has been achieved; no harmonics radiation or TVI detected, and the CW section of the band between 3.5 MHz and 3.6 MHz can be used without retuning C1 and C2. The antenna appears to be omnidirectional, with near uniform current/voltage distribution along the whole spiral coil. Tests on other bands have been similar. The results with the antenna diagonally across the room, in a first floor room, have been very satisfactory. For anyone who has not the full required length available, it is suggested that part of the far end of the spiral be dropped down, or taken off at an angle.

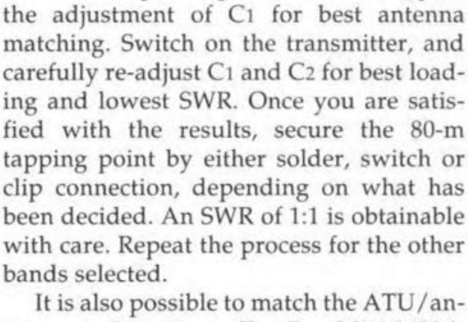


Fig. 2. Type 'T' ATU used.

COMPONENTS LIST

Antenna:
White nylon cord, approx. 1 mm diameter. DIY Stores (trade name in UK: Winchester).
Qty. 2 Slinky 2¾" diameter coils. Antenna West, 1500 North 150 West, Provo, UT 84604, U.S.A.

Note: at the time of writing, a Slinky coil (2¾" dia.) costs $10 each, plus $10 air mail (total $30). VISA and Mastercard accepted.

ATU:
L = 26µH indutance. B&W no. 3059 (available in the UK from RF Engineering, Main Street, Coln-St. Aldwyns, Cirencester, Glos GL7 5AN.
C1 and C2 = good quality 250-pF single-gang variable capacitor, with knob.
SKt1, Skt2 = see text.
Perspex or fibre glass board (see text).

Final considerations

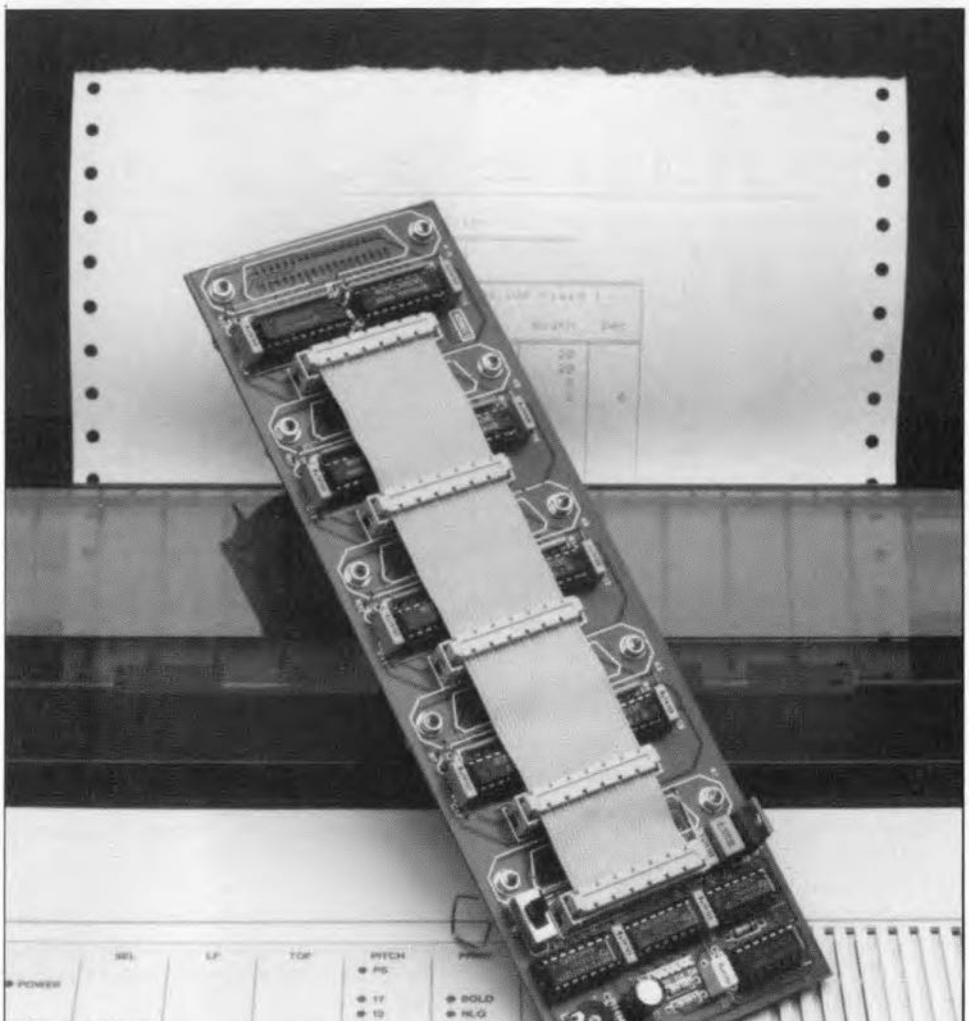
The spiral antenna has been designed for use indoors. It could, of course, be used outside, but being made of bright steel, would quickly corrode. This problem could probably be eliminated by any reader who has facilities to degrease and marine varnish each turn, inside and outside, and between turns. At least two coats of varnish would be necessary for protection. An expensive, and, alas, somewhat specialized, alternative would be to chromium-plate the whole spiral coil.

Assuming that this antenna will be used indoors (as designed and intended), in the interest of safety, only low transmitting power should be used. Good quality air-spaced receiver-type variable capacitors for C1 and C2 should be satisfactory with transmitter output levels of up to 25 watts. ■

Useful reading

Antennas — 2nd edition, 1988, by John. D. Kraus (McGraw-Hill Book Company).
Antenna Book — 16th edition, 1991 (American Radio Relay League).
W1FB's Antenna Notebook — by Doug De Maw, 1987 (American Radio Relay League).

PRINTER SHARING UNIT



A printer is an essential peripheral device for nearly every one using a PC. However, since a printer will rarely be used all the time, it is not necessary to have one with every PC within a range of, say, 10 m. The circuit described here is an automatically operating switching unit that allows up to four PCs to make use of a single printer.

Soumya Mitra

IN particular with fairly expensive printers it is common practice to set up some kind of sharing arrangement where there are several PCs. Not surprisingly, printer switching units are found in many small offices these days.

The basic operation of the printer sharing unit is illustrated by the block diagram given in Fig. 1. There are up to four Centronics inputs, each of which is connected to a bus that conveys the signals to the printer connected to K1. The block marked 'select' connects each of the four inputs to the output, at a repeat rate of ⅓ second. If a computer connected to a particular input does not send data at that time, the circuit switches to the next input. If the computer does send data during the time it is connected to the printer, this responds by making the BUSY line high. This event triggers a monostable multivibrator (MMV) which immediately disables the oscillator and the select block. As long as BUSY remains high, or goes high again within the MMV's monotime, the printer will remain connected to the computer that sends data. However, as soon as the computer is found waiting longer than the set monotime, the circuit starts to scan its inputs again for activity, i.e., another computer that may have data ready for the printer.

Some of you may wonder at this point why the BUSY line of the printer is used rather than the strobe pulse of the computer to detect if data is being conveyed. At first glance, using the strobe pulse would appear much more logical since that signal is supplied by the source of the data, i.e., the computer. There is, however, a snag: some computers may block the printer switch when they are switched off, because the strobe output then forms a low level (remember, the strobe pulse is active low). By contrast, a 'true' Centronics strobe output is an open collector driver without a pull-up resistor, and does not cause problems in this respect because it 'floats' when the PC is switched off. Unfortunately, not all printer card manufacturers abide by the Centronics standards, so that it is very well possible that the strobe line forms a 'low' level when the PC is switched off. Obviously, this causes problems on the printer sharing unit since in that case an active Centronics port is detected.

The above problems are prevented by using the printer's BUSY line. This allows the circuit to respond to the fact that data have already arrived at the printer, and this data can only originate from a computer that is switched on.

Still, the printer switch is not quite perfect. As far as we have been able to ascertain, there are two cases in which things can go wrong. This has to do with the structure of the software that runs on the computer.

In the first case, we refer to programs that check beforehand if a printer is available. In most cases, this check lasts long enough to allow the printer sharing unit to finish its input scanning cycle until it reaches the computer that wants to print at that time. By contrast, there are also programs that insist on finding a printer right at the first check. If the computer that runs such a program happens to be not selected during the check, the program will refuse to print (on some computers this occurs, for instance, with the 'print screen' routine). Fortunately, this can be solved manually: the scan rate of the printer switch inputs is indicated by LEDs, and slow enough for you to launch the print job at the right instant. The only proviso for this little trick is that you can see the printer sharing unit from your workplace.

The second problem arises when a program interrupts its printer output routine to calculate the next data to be printed. If this calculation lasts longer than the set MMV time on the printer sharing box, another computer may 'throw in' its data. If you are using such software, there is no option but to ask your fellow printer users not to send data before your PC is finished.

How it works

The circuit diagram, Fig. 2, shows five sub-circuits. The bus that connects these sub-circuits is a length of flatcable with five IDC sockets inserted into the even numbered headers. The use of the flatcable bus will be reverted to when we talk about the printed circuit board.

Four of the five sub-circuits are identical. They represent the four PC input connectors (K3, K5, K7 and K9) with the associated electronic switches. Here, the switches are formed by buffers with three-state outputs (IC6-IC13). When a particular input circuit is not selected, its buffer outputs are switched to high impedance, which means that all signals from the computer to the bus and the printer, and from the bus to the computer, are disconnected. Also, the bus-to-computer lines are then pulled to a logic level that tells the computer that the printer is not ready to receive data. This is achieved with the aid of pull-up and pull-down resistors. A normal Centronics link between computer and printer exists only on the selected input, since there the buffer outputs are switched to their active state.

The most interesting section of the circuit is the fifth sub-circuit. Electrically, this sits between printer connector K1 and bus connector K2. This is the central control of the printer sharing unit. Assuming the printer is not busy, and none of the PCs offers any data, the printer's BUSY line (pin 11 on K1) is logic low, and monostable IC4a is not triggered. In this condition, the pulse generator built around IC2d is enabled, and produces a short pulse every 0.33 s. The trailing edge of the oscillator pulse clocks two J-K bistables, IC5a and IC5b, which function as a counter. The counter continually cycles through states 0, 1, 2 and 3. The counter state is sent to four individual lines by decoders IC3a and IC3b. The four outputs of IC3a are used to select the buffers in the input circuits. This selection runs at a rate of 0.33 s. Decoder IC3b functions similarly to IC3a, but it controls LEDs instead of input buffers. These LEDs indicate the currently selected input. IC3a also controls LEDs fitted with each input connector. The purpose of these LEDs will become evident when the construction of the unit is discussed.

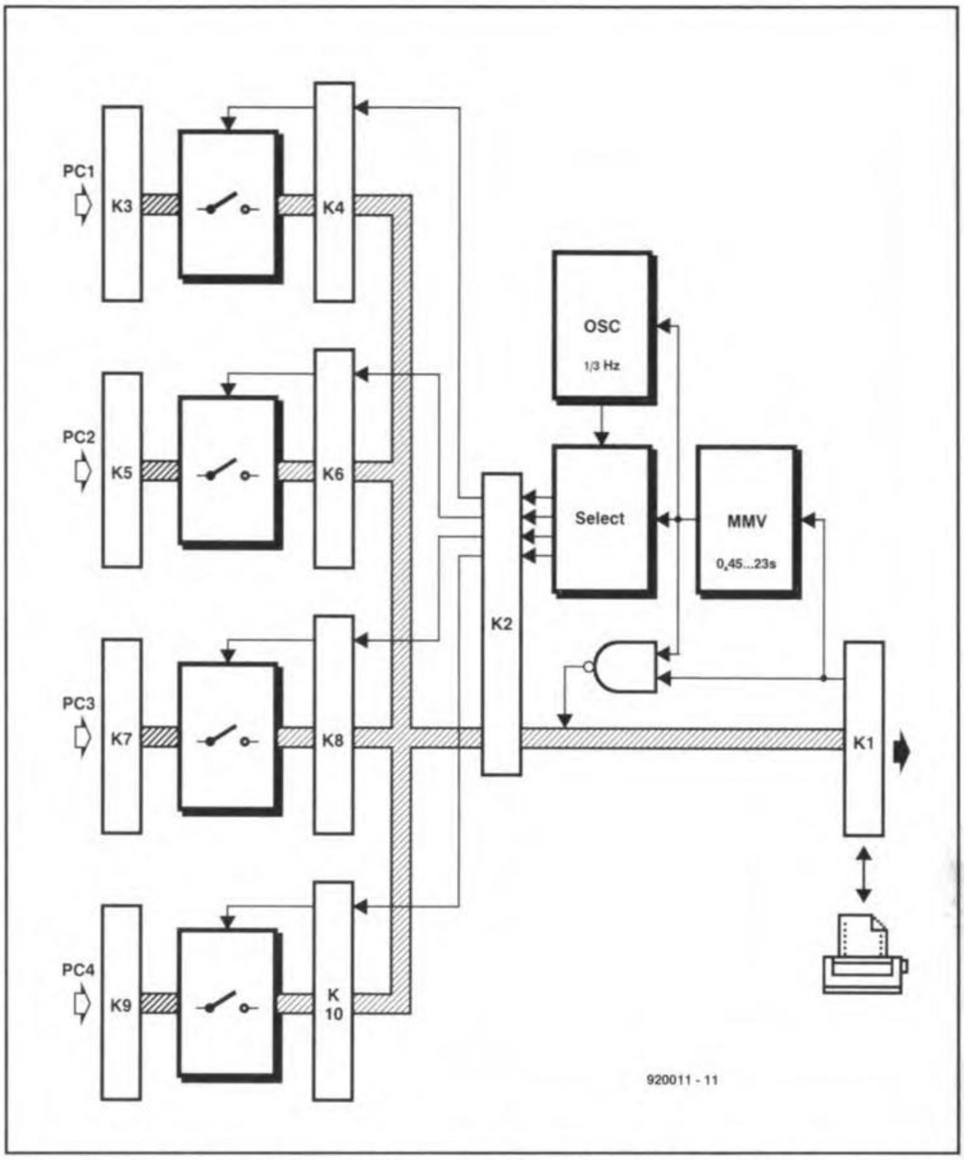


Fig. 1. Block diagram of the printer sharing unit. Four inputs are continuously monitored for the presence of printer data.

Gates IC2a, IC2b and IC2c are essential to prevent timing problems. Their logic function is

$$BUSY_{(out)} = BUSY_{(in)} + CLK \bullet Q\backslash$$

which means that the BUSY signal supplied by the printer ($BUSY_{(in)}$) is always conveyed directly to the connected computer ($BUSY_{(out)}$). However, it is also readily seen that the circuit, when it is not active (Q\ at '1') supplies a 'BUSY' signal to the computer when the clock pulse is high. From that moment on, the selected computer can not send data any more. But what happens if the computer has just before sent its first byte, and the printer has not responded to it by pulling the BUSY line high? Fortunately, the clock pulse is long enough to ensure that this first BUSY signal arrives before the end of the clock pulse. In that case, the circuit will keep the active computer 'hanging on'. i.e., selected. If no BUSY signal arrives from the printer in the mean time, the circuit can safely switch to the next computer input, which happens on the trailing edge of the clock pulse. After this edge, the selected computer is immediately supplied with a low (inactive) BUSY signal (neither the printer nor the circuit was busy). This is taken to indicate that new data may be sent. Since this data will not be ready for at least 0.5 µs, input switching can safely take place.

The moment the printer responds to the data with a BUSY signal, monostable multivibrator IC4a is triggered. The setting of the monostable determines how long the circuit waits for new data after the printer has stopped printing. Because IC4a is triggered, Q\ goes low. During the monotime, the clock generator and the counter are disabled, and gates IC2a, IC2b and IC2c simply convey the printer's BUSY signal. As long as the BUSY line remains high, or goes high again within the monotime, the MMV is triggered again. The monotime can be set to between 0.45 s and 23 s with the aid of preset P1. If the monotime passes without a BUSY signal arriving, Q\ reverts to high, and the counter and oscillator are enabled again. The circuit is then back in its stand-by state, scanning the

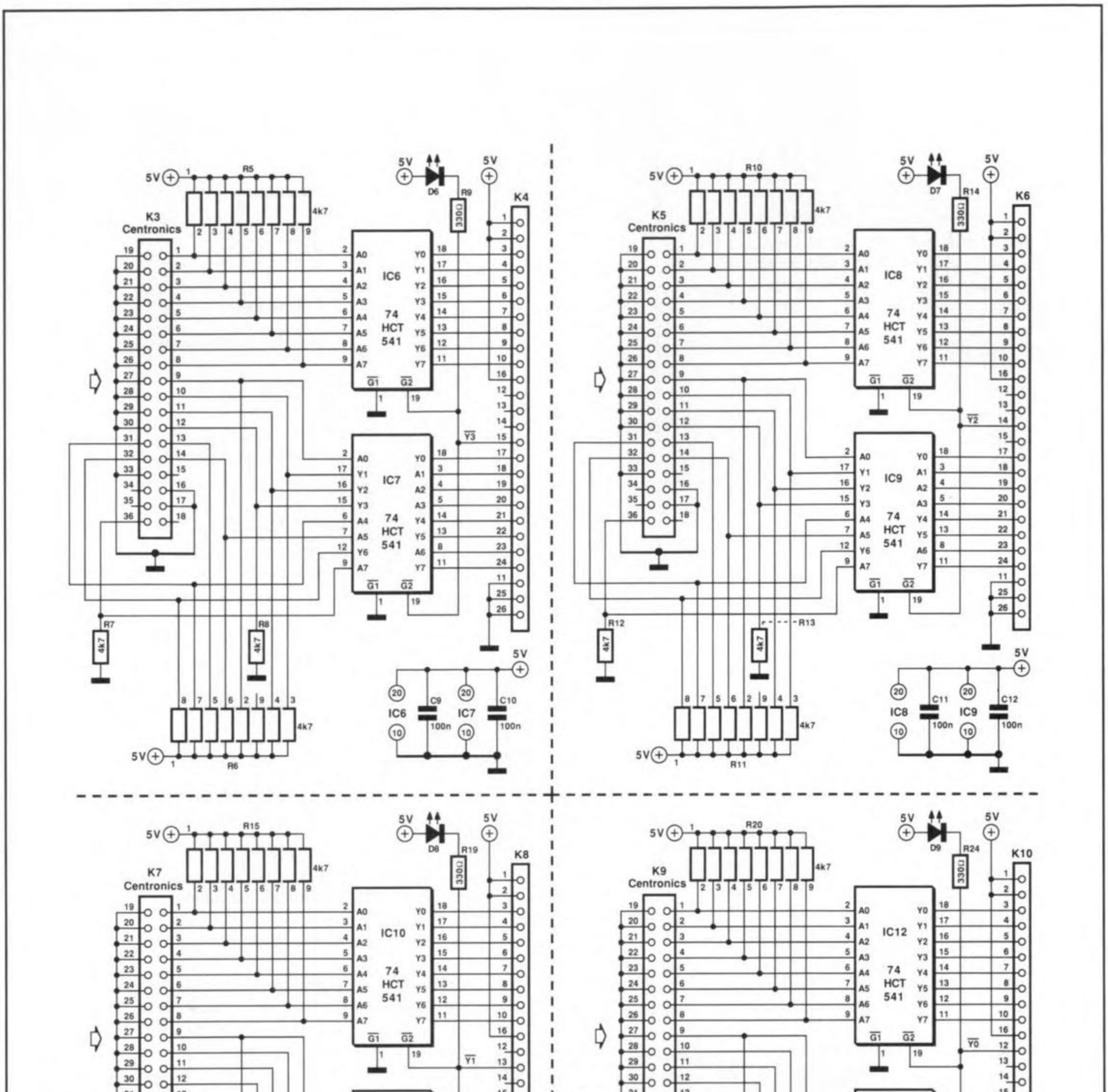
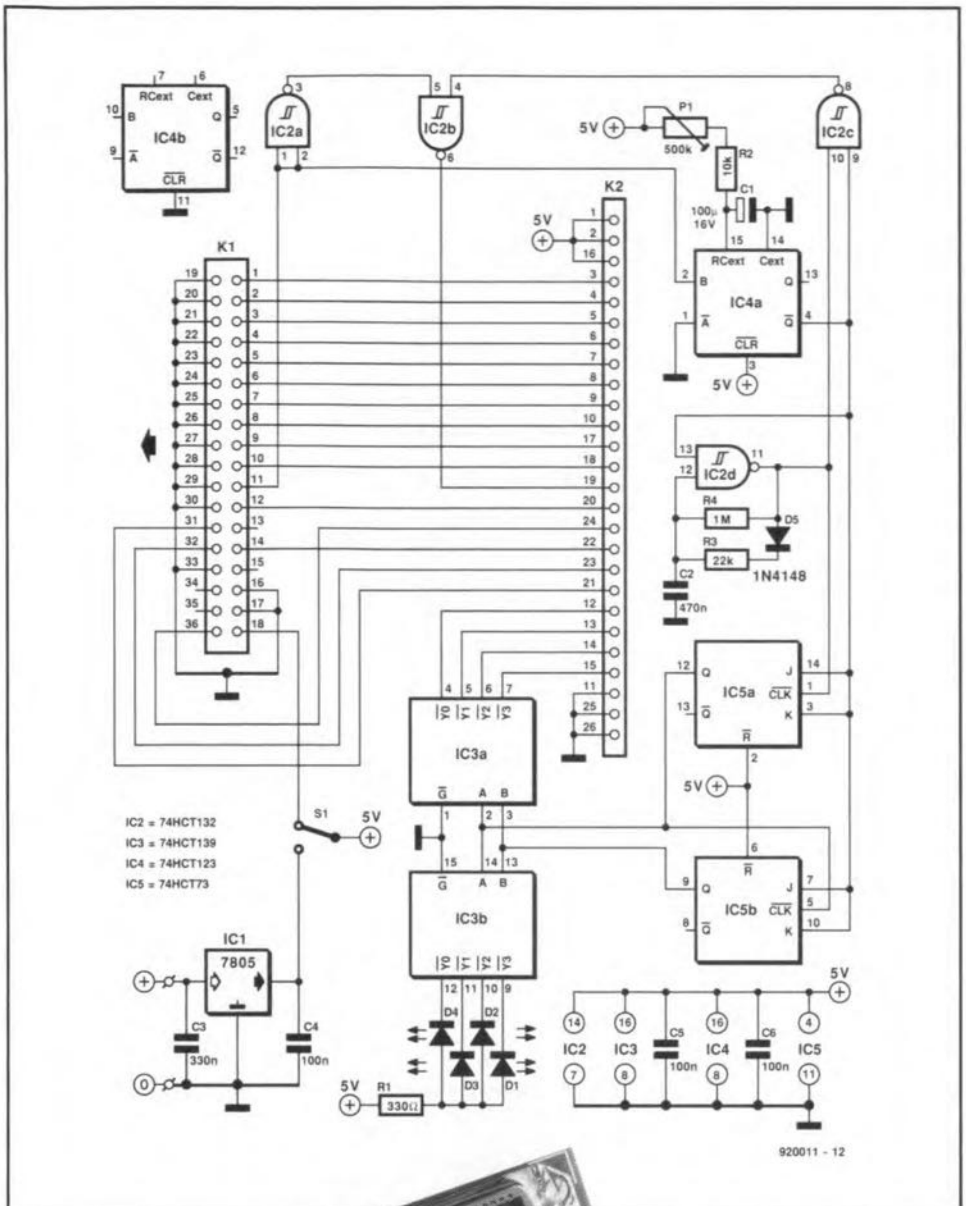
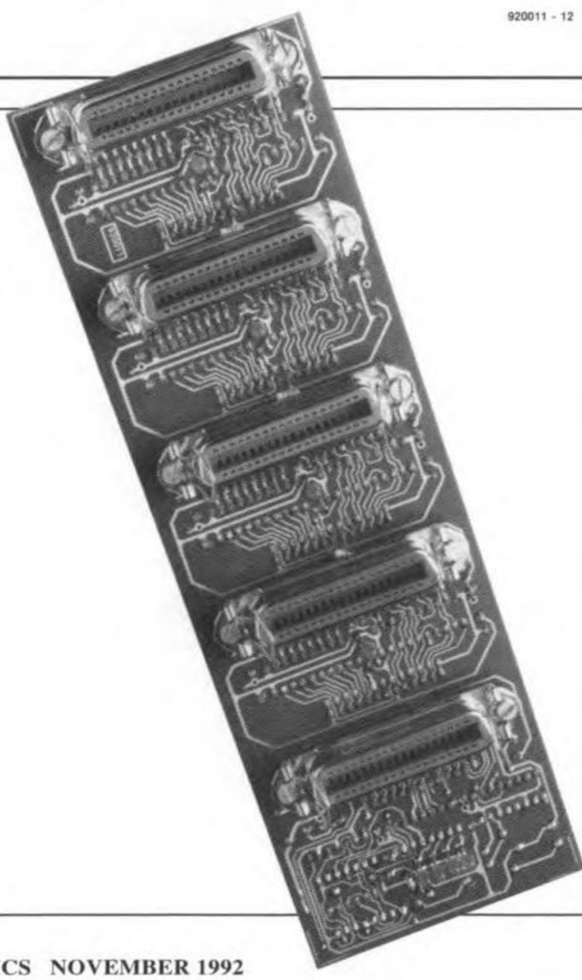


Fig. 2. The circuit diagram consists of five blocks: four identical input circuits, and a control/output circuit.





four inputs for data.

The power supply for the printer sharing units may be realized in two ways. With switch S1 set to the position shown in the circuit diagram, the supply voltage is obtained from the printer. Unfortunately, not every printer furnishes a suitable supply voltage, whence the external power supply option. Any external power supply may be used that supplies an unstabilized direct voltage between 8 V and 20 V. Regulator IC1 reduces this unstabilized voltage to a stabilized 5-V rail for the circuit. Incidentally, do not be surprised if you find that the circuit works perfectly with no power supply connected at all — in some cases, it can draw enough current from the computer outputs to build up its own supply voltage. Convenient as it may be, this situation does not guarantee reliable operation!

A large circuit board

The printed circuit board designed for the printer sharing unit consists of five smaller boards, which are interconnected via a flatcable (the previously mentioned bus). In spite of the 'modular' layout of the large PCB, it is by no means necessary to separate the sub-boards from another. Even when they are left together, they form a compact printer switch. However, if you wish to separate them, this is no problem at all — all that has to be done is to adapt the length of the flatcable as required.

A number of options are available for the LEDs that indicate the currently active input. An LED may be fitted next to each input connector. Alternatively, LEDs may be fitted next to the output connector. The decision on fitting or not fitting a certain LED depends on the way the printer switch is built into a case. For instance, you may fit a LED next to each connector on the rear panel (particularly useful for faultfinding purposes), and the other four LEDs on the front panel, for all users to see.

Apart from the flatcable, the Centronics connectors and the LEDs next to the input connectors, construction of the unit is all plain sailing. As always, fit the wire links first so that these are not forgotten later. Pins 1 to 18 of the connector are at the side of the associated LED. Before you start soldering the connector pins, fit the connectors on two 7.5-mm (0.3 in.) high pillars. Alternatively, if you can not find Centronics sockets for PCB mounting, you may use connectors with solder pins, fit these at the required height, and connect them to the PCB via short wires.

Assuming that you have not cut the PCB into modules, the next step is to make the flatcable. This is precision work, since the spacing of the IDC sockets on the cable is critical. If you fit them too close together, you will be unable to plug them on to the headers on the board. Likewise, if

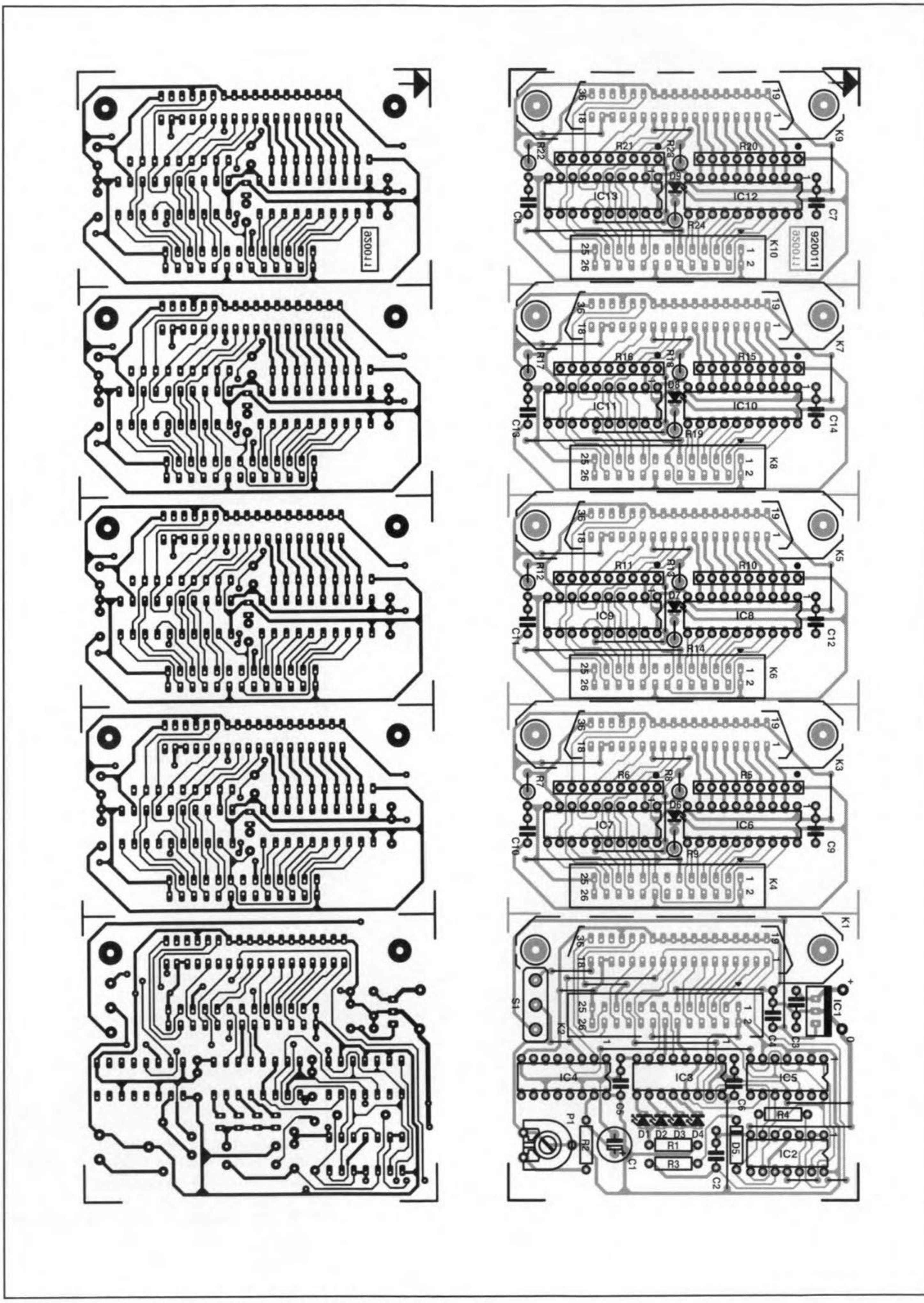


Fig. 3. The printed circuit board may be cut into five separate parts.

COMPONENTS LIST

Resistors:

5	330Ω	R1;R9;R14; R19;R24
9	4kΩ7	R7;R8;R12; R13;R17;R18; R22;R23
1	10kΩ	R2
1	22kΩ	R3
1	1MΩ	R4
8	4kΩ7 8-way SIL	R5;R6;R10; R11;R15;R16; R20;R21
1	500kΩ preset H	P1

Capacitors:

1	100µF 16V radial	C1
1	470nF	C2
1	330nF	C3
11	100nF	C4-C14

Semiconductors:

8	LED	D1-D4;D6-D9
1	1N4148	D5
1	7805	IC1
1	74HCT132	IC2
1	74HCT139	IC3
1	74HCT123	IC4
1	74HCT73	IC5
8	74HCT541	IC6-IC13

Miscellaneous:

1	SPST switch for PCB mounting (raster: 7.5 mm)	S1
5	36-way PCB-mount Centronics socket, straight pins	K1;K3;K5;K7; K9
5	26-way box header, straight pins	K2;K4;K6;K8; K10
5	26-way IDC flatcable socket	
17cm 26-way flatcable		
1	Printed circuit board	920011

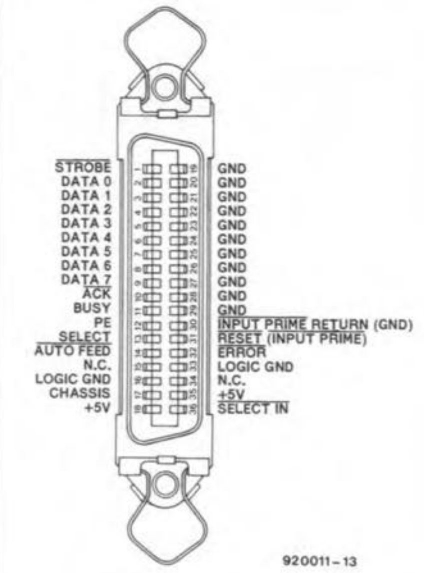


Fig. 4. Centronics connector pinning.

you fit them too far apart, the cable will bulge. That is not a problem in itself, however it does not look very good.

When the completed PCB is to be fitted behind a front or rear panel, this will have to be done from the inside. Note that the Centronics sockets used here are not really suitable for panel mounting, but it can be done. First, drill the holes for the fixing screws. Next, cut and file a rectangular clearance that is long and wide enough to pass the connector and the clamp springs (approx. 58×15 mm). The locations of the holes are easily pencilled out on the panel by making use of the (empty) printed circuit board, or a photocopy of the component layout.

The circuit has only one adjustment: preset P1. This has to be adjusted such that the printer sharing unit is capable of 'bridging' the longest time your software needs for calculations before it sends new printer data. In case you are not sure about what sort of times to expect, simply set P1 to maximum resistance (wiper towards IC4). ■

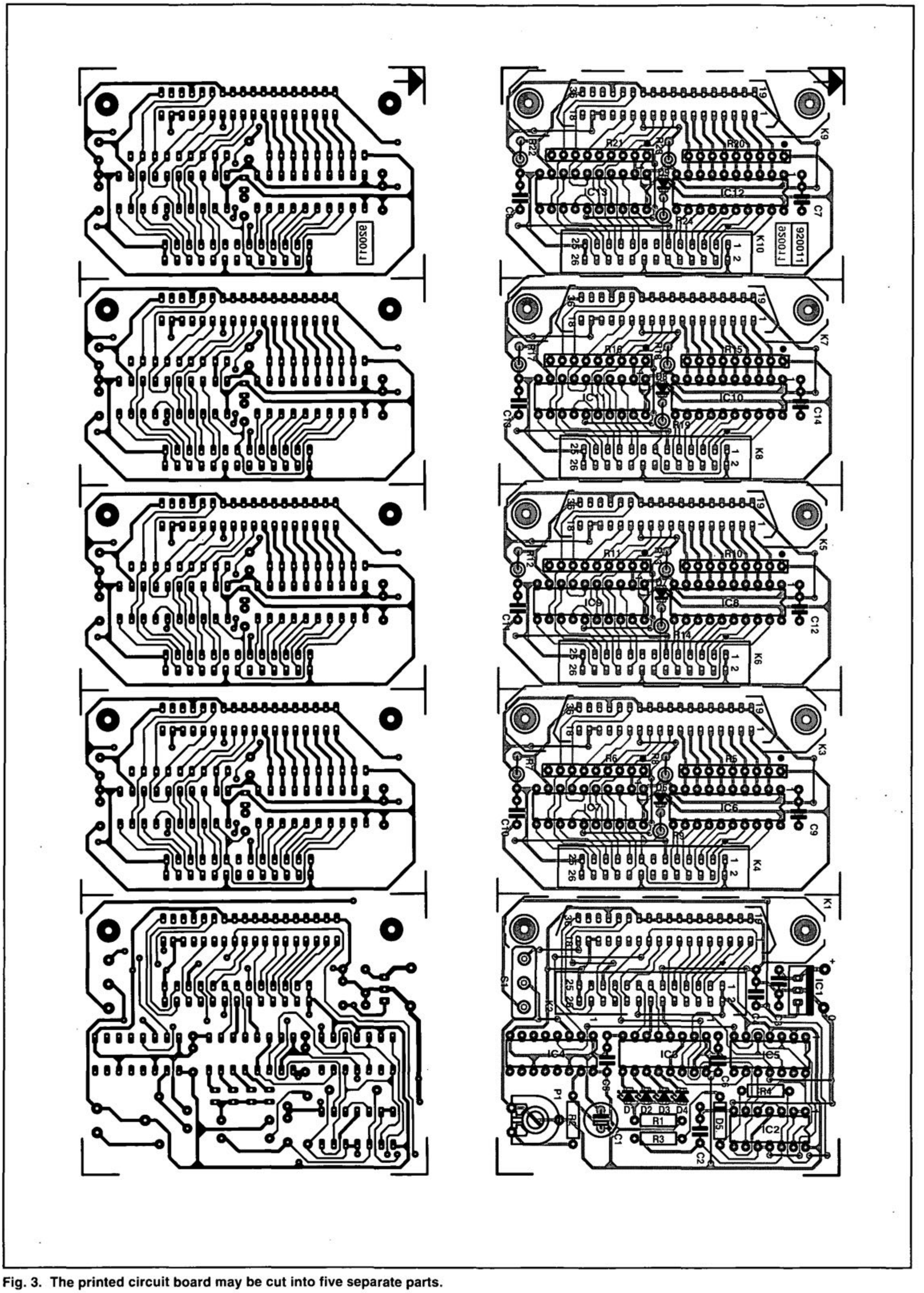
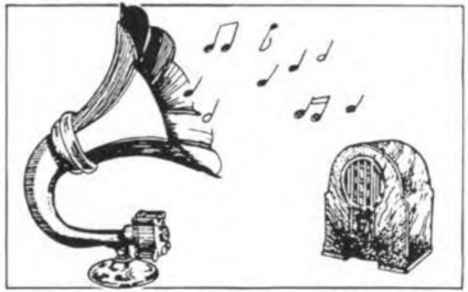


Fig. 3. The printed circuit board may be cut into five separate parts.

TAKE A TRIP DOWN MEMORY LANE



THE WIRELESS MUSEUM LINDFIELD

40 YEARS OF VALVE RADIO 1920-1960

Today, Radio or Wireless as we used to call it, has become so much part of our lives that is difficult to appreciate the fact that in earlier days it was considered almost a miracle that Music and Voices could come into our homes 'out of the air' by Wireless Waves.

The Wireless Museum in Lindfield, West Sussex, displays not only a fine collection of Vintage Wireless Sets and paraphernalia from the days before transistors and silicon chips, but it also attempts to capture some of the atmosphere of the early wireless days.

Have the thrill of hearing, on a pair of headphones, the music from a Cat's Whisker and Crystal Set.

Listen to music coming from a 'horn loudspeaker' connected to a 1930's home made valve receiver — a type that squeals when the volume is turned up very high.

Switch on some of the old-time valve sets that take an age to warm up.

Browse at leisure round other exhibits and talk about the old days of Wireless with the Curator.

There are many interesting milestones in Wireless Broadcasting history, and the following few early dates may be of interest:

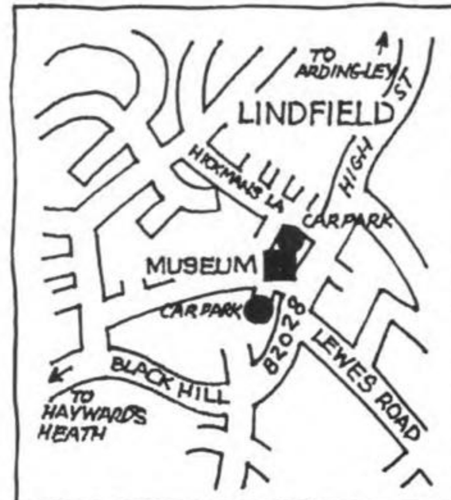
1901 Marconi successfully broadcasts signals by Wireless from Poldhu in Cornwall to Newfoundland.

1920 An experimental broadcast from the Marconi Works in Chelmsford included a concert by the famous soprano Nellie Melba.

1921 Marconi was licensed to broadcast using the famous callsign 2MT.

The museum is privately owned and non-profit making. The only source of income is from the vistor's generosity, which enables this nostalgic collection to be displayed to the public.

The Wireless Museum, The Old Brewery, 53 High Street, Lindfield, West Sussex RH16 2HN. Telephone: (0444) 484552. Collection owner and Curator: Mr. Ray Leworthy.



OUTPUT AMPLIFIER FOR RIBBON LOUDSPEAKERS PART 1

Design by T. Giesberts

This article describes an out-of-the-ordinary amplifier for driving very-low-impedance transducers such as ribbon loudspeakers. The amplifier is able to deliver 20 A_{rms} (with peaks up to 30 A) into a load of 0.4 Ω with low distortion.

The modern ribbon loudspeaker is among the most efficient transducers available. Its construction is very simple: the diaphragm consists of an aluminium foil ribbon suspended between the poles of a magnet—see Fig. 1. The nominal flux density in the gap is about 1.0 Tesla. A practical ribbon is 5–7 mm long, 8–12 mm wide, 3 μm thick and has a mass of 3–4 mg. Its resistance is 0.2–0.5 Ω. Such a unit is eminently suitable for use as a tweeter. However, over the past few years wide-range ribbon loudspeakers using much longer ribbons have become available, such as those of Strathearn (50 cm or 2 in) or, among others, Gold Ribbon and Speakerlab that measure a metre or more.

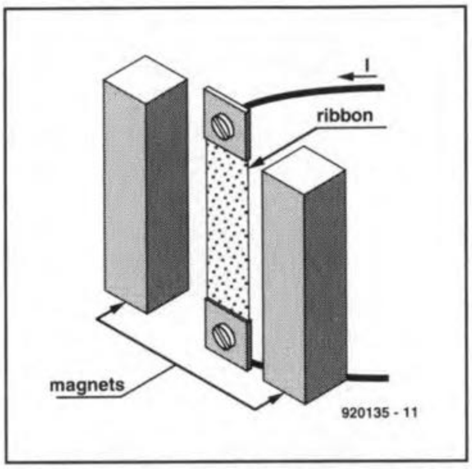


Fig. 1. Principle of ribbon loudspeaker.

Low impedance

Unfortunately, ribbon loudspeakers have such a low impedance that they are normally connected to the output stage via a suitable impedance transformer. This is, however, not beneficial for the reproduction of the higher audio frequencies.

The present amplifier enables direct driving of a ribbon loudspeaker: it can deliver up to 160 W into 0.4 Ω. The larger part of the transfer resistances in the connections are compensated by two separate sense lines. Although it is designed primarily for the Strathearn speaker, it is equally suitable for other transducers that have an impedance of 0.2–1 Ω (higher is possible, but the available power may then be insufficient owing to the low supply voltage used).

The concept

A current of 20 A_{rms}, corresponding to a power of 140 W into 0.4 Ω, was deemed sufficient for most applications. The output transistors are Sanken types which offer a combination of high current amplification, good bandwidth, and a high peak collector current.

To nullify the transfer resistances of the output connections (a cable resistance of 0.05 Ω is not negligible if the load impedance is only 0.4 Ω), the feedback point is as close to the loudspeaker as possible: a sort of sense input. The result is that the amplifier compensates for virtually all resistance between its output and the loudspeaker.

Problems also arose in the choice of the power-on delay that obviates the clicks resulting from switching the amplifier on. For a number of reasons, relays were discounted from the onset. Of the various electronic means, an optocoupler-triac solution was found to be the most efficient and satisfactory.

Block diagram

The block diagram of the amplifier given in Fig. 2 clearly shows the symmetrical design. Differential amplifiers T_1 and T_3, each giving an amplification of about ×100, form the input stage. They are followed by differential amplifiers T_2 and T_4 respectively, each of which has an amplification of ×20.

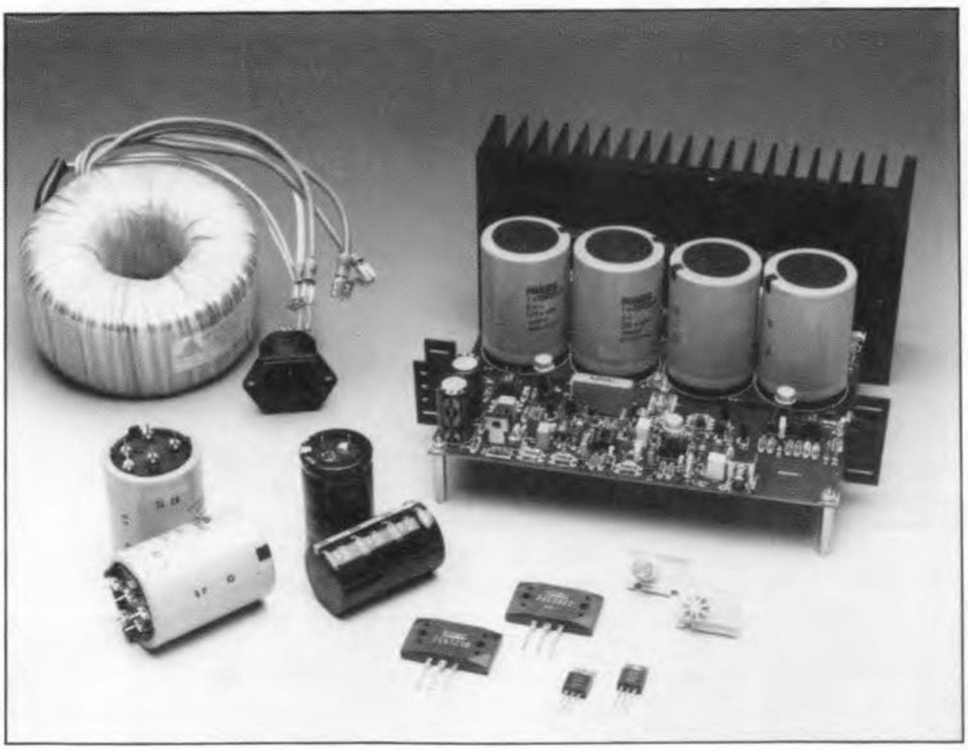
The optocouplers in the collector circuits of T_2 and T_4 serve to suppress clicks resulting from switching the amplifier on or off. The power-on delay ensures that the LEDs in the optocouplers light up slowly. Intially, therefore, impedance matching transistors T_{12} and T_{13}, and thus drivers T_{16} and T_{17}, are off so that no current flows in the output stage. Since in this way the opto-transistors are driven into conduction slowly, power to the output stages rises gradually. This arrangement effectively suppresses switching-on clicks.

Since the impedance matching transistors are current-driven by the differential amplifiers, any non-linear behaviour of the opto-transistors has no effect on the reprodcution quality.

Transistor zener T_{14}-T_{15} between impedance matching transistors T_{12} and T_{13} arranges the quiescent current through the output stages.

Each of the output stages consists of a driver, T_{16} and T_{17} respectively, which drives two parallel-connected output transistors, T_{18}-T_{19} and T_{20}-T_{21} respectively.

The current through the output transistors is monitored by the current limiting stage; if it rises above 30 A (dependent on the base-emitter voltage of T_{22}) and the mains fuse



does not blow, the optocouplers are switched off instantly and the fuses in the power supply lines blow because the protection circuit switches on two heavy-duty triacs between those lines and earth. The protection circuit is also actuated if a direct voltage should appear at the amplifier output.

The loudspeaker is connected to the output stages by four wires: two heavy-duty ones through which the high currents flow, and two sense lines that carry the feedback signals.

Circuit description

The input signal, normally provided by a preamplifier or active cross-over network, is applied to C_1. This capacitor and R_1 form a high-pass filter with a cut-off frequency of 9 Hz (this frequency may be lowered by giving C_1 a higher value). This is followed by a high-pass filter, R_2-C_2, with a cut-off frequency of 280 kHz, to prevent transient intermodulation distortion (TID).

The signal is then fed to differential amplifiers T_1 and T_3. Since the thermal stability of these amplifiers depends on the coupling between the two transistors, the types shown are ideal because the two transistors are housed on one chip. Unfortunately, there is a dearth of double transistors, so that the choice here is very limited.

Frequency compensation for these amplifiers is provided by R_5-C_3 and R_{10}-C_4 respectively. The values of the emitter and collector resistors shown give an amplification of around ×100.

The constant-current sources for the amplifiers are formed by T_5 and T_6, which use LEDs (D_1 and D_2) as reference. The current throught these diodes is held constant by ancillary current source T_9-R_{15}.

Since the amplification of T_1 differs from that of T_2, it is important that the offset voltage of the amplifier is kept is small as feasible. To this end, the base currents of these transistors are compensated by a negative voltage derived from regulator IC_4 via R_{55} and R_{74}. This negative voltage holds the base voltage at virtually 0 V. Any other drift, such as caused by temperature variations, is nullified by an integrator based on IC_3. This stage readjusts the base voltages of T_1 and T_3 if required. The supply lines of IC_3 are additionally buffered by C_{18} and C_{19}, which ensure that the stage remains operative for a short while after the amplifier has been switched off.

Then follow differential amplifiers T_2 and T_4 ($\alpha \approx 20$), whose frequency compensation is provided by C_9 and C_{10}. Transistors T_7 and T_8, together with diodes D_3 and D_4, form the constant-current sources for the amplifiers. The current through the LEDs is held stable by ancillary current sources T_{10}-R_{17} and T_{11}-R_{18}.

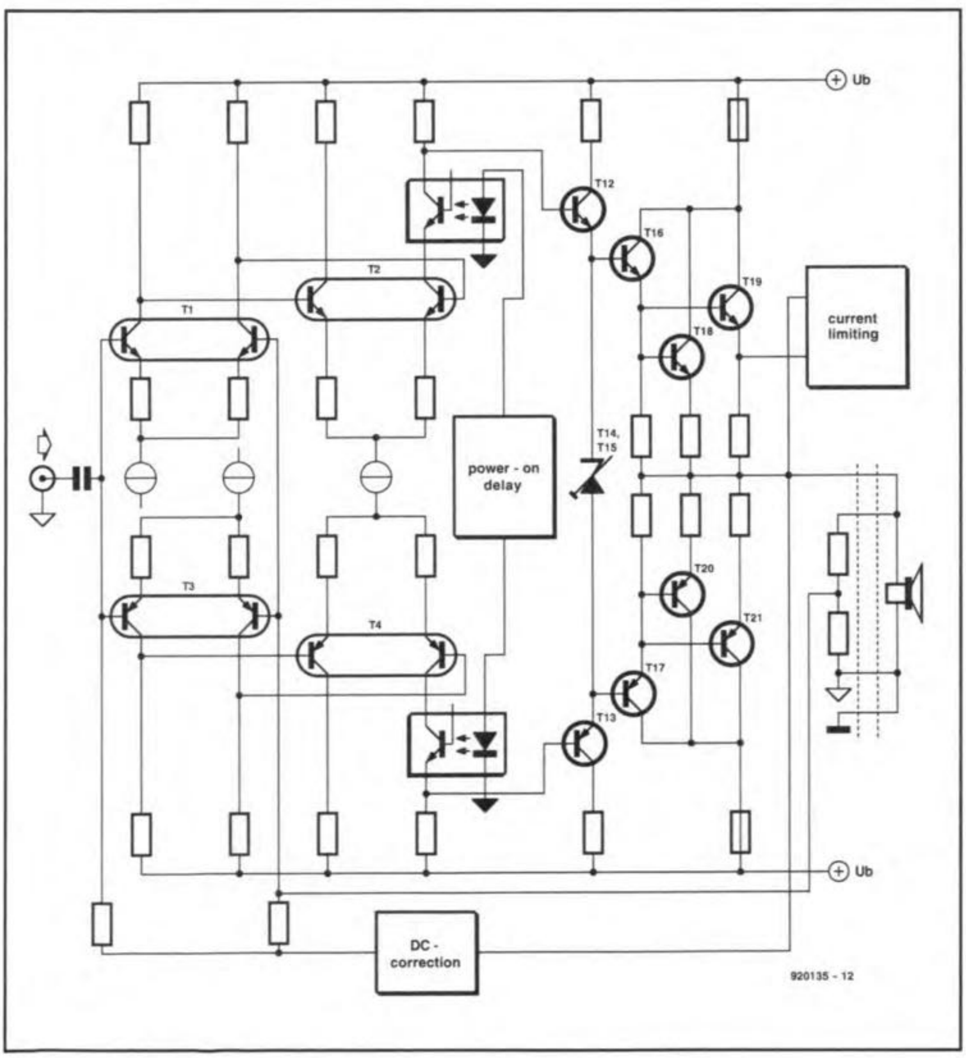


Fig. 2. Block diagram of the output amplifier.

Because of the arrangement of the ancillary current sources, it is essential that diodes D_1–D_4 have a forward voltage of 1.55–1.65 V.

The signal is then applied via the transistors in the (power-on delay) optocouplers to impedance matching transistors T_{12} and T_{13} that drive current amplifiers T_{16} and T_{17}. The collectors of T_{12} and T_{13} are linked by transistor-zener T_{14}-T_{15}. The voltage across this zener, and consequently the direct current through power transistors T_{18}-T_{19} and T_{20}-T_{21}, is preset with P_1.

The emitter resistances of the power transistors consist of parallel combinations of resistors. This is not because of dissipation, but rather to divide the large currents over a number of soldering points. Moreover, the arrangement lowers the spurious inductance, which is important with low-impedance loads.

Transistor T_{22} is switched on when the peak emitter current of T_{19} or T_{21} exceeds 30 A, whereupon the protection circuit is actuated.

Although fuses F_1 and F_2 are rated at 7.5 A, they can withstand currents of up to 30 A, since they carry only one-half of the output signal. The + and – terminals in series with them are connected to the protection circuit. If one of the fuses blows, the LED in parallel with it lights.

Resistor R_{47} and C_{12} form a Boucherot network. Inductor L_1 is for use only with traditional loudspeakers; if only ribbon types are used, it may be omitted.

The sense lines are connected to potential divider R_{48}–R_{50}, of which R_{49} and R_{50} determine the feedback factor, while R_{48} and R_{51} ensure that the feedback remains functional if the sense lines are not connected. The feedback signal is taken from junction R_{49}-R_{50} to the bases of T_{1b} and T_{3b}. Network R_{75}-R_{76}-C_{23}-C_{24} serves to equalize the impedance at the bases of T_{1b} and T_{3b} with that at the inputs of T_{1a} and T_{3a}. This arrangement improves the common-mode behaviour of the amplifier. The network does not affect the feedback.

Protection circuit

The diagram of the protection circuit is shown in Fig. 4. When the power is switched on, capacitor C_3 is charged slowly via R_4. It takes, therefore, a few seconds before darlington T_7-T_8 is switched on, whereupon the LEDs in the optocouplers (connected to B1 and B2) begin to light. When the potential across C_3 has risen to 1.7–1.8 V, the LEDs light at maximum brightness. The darlington then operates as a constant-current source, since D_5 holds the voltage across R_{15} and that across the base-emitter junction of T_7 and T_8 stable.

Since T_1 is connected to the secondary of the mains transformer via diodes D_1 and D_2, it is switched on every half period as long as the mains voltage is on. Transistor T_2, and consequently T_3, is then off. When there is no voltage across the secondary, for instance, when the power is switched off, T_2, and, consequently T_3, is switched on after half a period. This results in Schmitt trigger T_4–T_6–D_4 changing state, whereupon T_7 and T_8, and thus the optocouplers, are switched off. This is indicated by the lighting of D_{11}.

Current monitoring transistor T_{22} is connected to terminal A. When the load current gets too large, T_{22} begins to conduct, so that T_3 is switched on and the optocouplers are switched off. Darlington T_{11} switches on triacs Tri_1 and Tri_2 via D_8, whereupon the supply lines are short-circuited to ground. If this option is not required, that is, the switching off of the optocouplers is deemed sufficient, D_8 may be omitted.

Protection against high temperatures is provided by T_{12} (connected as diode) and IC_{1a}. Through the transistor, which is mounted on the common heat sink for the power transistors, flows a direct current via R_{18} and R_{19}. The voltage across T_{12} is applied to the inverting (–) input of IC_{1a}, which operates as a comparator with hysteresis (provided by

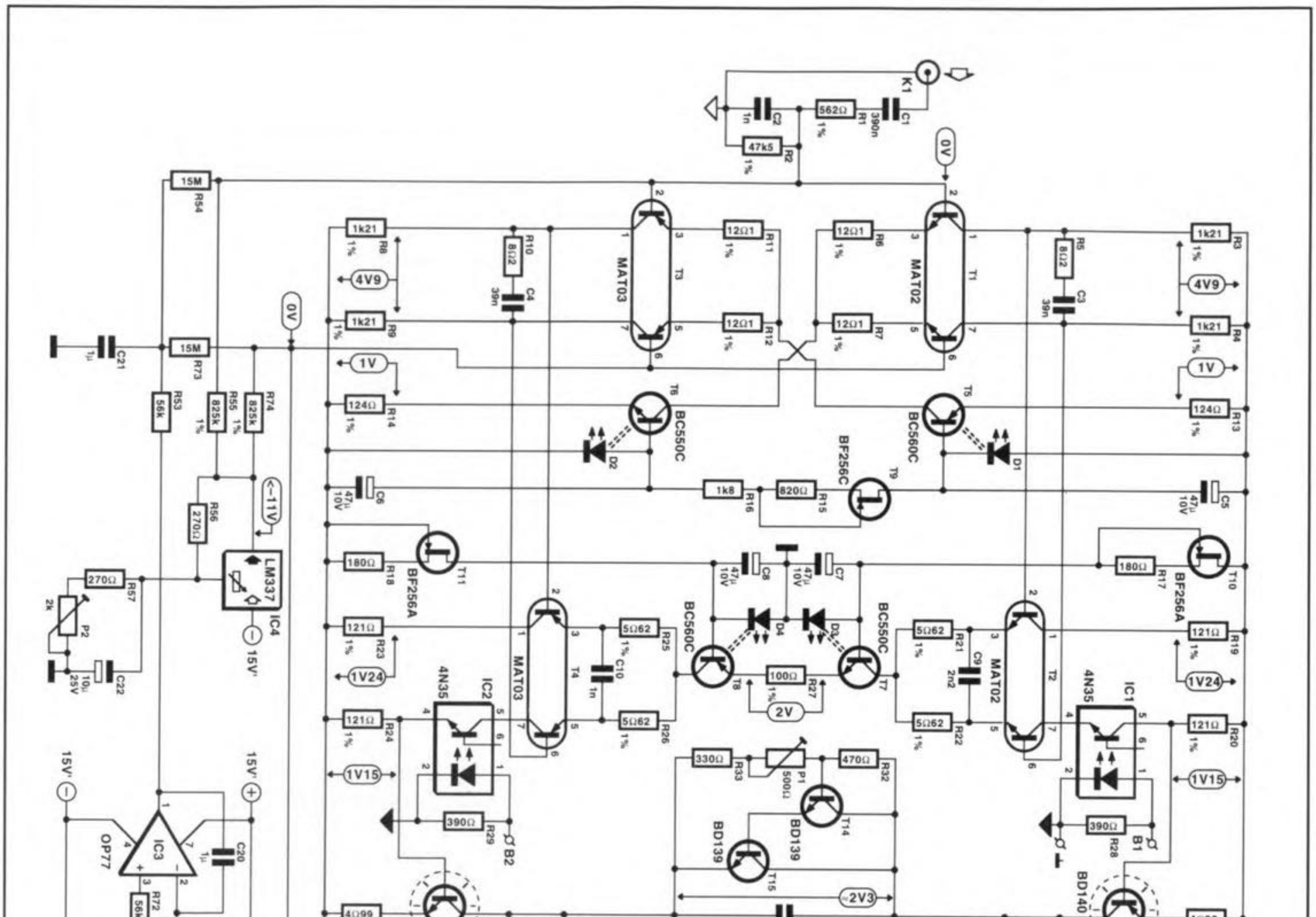


Fig. 3. Circuit diagram of the amplifier.

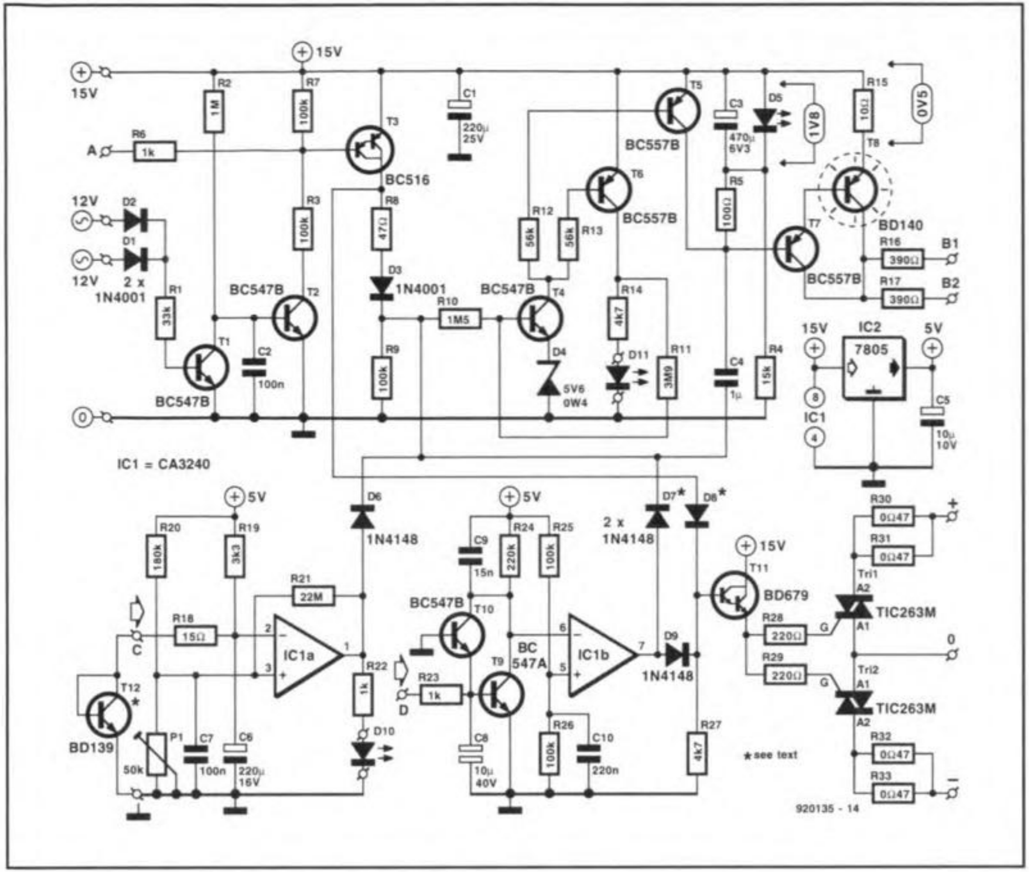


Fig. 4. Diagram of the protection circuit.

R_{21}). That voltage is compared with a reference potential provided by R_{20}-P_1. If it drops below the reference potential, the output of IC_{1a} changes state, whereupon the optocouplers are switched off via D_6. After the temperature has dropped some degrees, the amplifier is switched on again. The temperature at which the protection circuit becomes active is set with P_1.

Any direct voltage at the output of the amplifier is detected by low-pass filter R_{23}-C_8. If the direct voltage exceeds ±0.6 V, transistor T_9 (positive) or T_{10} (negative) is switched on. The inverting input of IC_{1b} goes low and its output goes high, whereupon triacs Tri_1 and Tri_2 are switched on via D_9 and T_{11}. At the same instant, the optocouplers are switched off via D_7. Options here are to omit D_9, so that only the optocouplers are switched off, or to fit D_9, but omit D_7, so that only the supply lines are short-circuited. ■

The construction of the amplifier will be described in next month's instalment.

DIFFERENTIAL THERMOMETER

Design by J. Ruiters

Temperature is a physical property of a body that determines the direction of heat flow when the body is brought into contact with another. Heat always flows from a region of higher temperature to one of lower temperature. A standard thermometer measures the temperature of a body with respect to an arbitrary point—usually 0 °C (or, in the USA, 32 °F) which is the temperature at which pure water freezes, or 0 K, that is, absolute zero or –273.15 °C. It is, however, not always convenient to measure the temperature with respect to these arbitrary points; many measurements are required to indicate the difference in temperature between two regions or bodies. This may be done with a differential thermometer such as the one described here.

Basically, the differential thermometer consists of two sensors that convert temperature into potential, a differential amplifier that magnifies the difference between the two sensor output voltages, a display which indicates that difference, and two switching outputs that may actuate a circuit or circuits if the difference exceeds a predetermined level.

Differential amplifier

The simplest differential amplifier is one designed around one opamp and a number of resistors. This is often expanded by two buffer opamps to obtain a higher input impedance, resulting in the familiar three-opamp differential amplifier. However, the present design is based on a two-opamp differential amplifier—see Fig. 1.

The input signals are applied to the non-inverting (–) inputs of the opamps to ensure a high circuit input impedance. The potential at the inverting (+) input of the first opamp is $U_{cm}-U_d/2$, while that at the inverting input of the second opamp is $U_{cm}+U_d/2$, where U_{cm} is the common-mode voltage and U_d is the difference between the two sensor output voltages. The output voltage, U_o, is calculated from:

$$U_o=\frac{R_4}{R_3}\left[1+\frac{1}{2}\left(\frac{R_2}{R_1}+\frac{R_3}{R_4}\right)+\frac{R_2+R_3}{R_0}\right]U_d$$

$$+\frac{R_4}{R_3}\left(\frac{R_3}{R_4}-\frac{R_2}{R_1}\right)U_{cm}$$

From this it is evident that suppression of the common mode signal is an optimum if $R_2/R_1=R_3/R_4$. Anu deviations are amplified by a factor R_4/R_3. To obviate this, R_1 may consist of a fixed and a variable resistor so that the common mode rejection can be set to maximum. However, if matters such as the dynamic range of the amplifier and the temperature coefficient of the resistors are taken into account, it is better to make resistors R_1–R_4 equal. The term R_4/R_3 is then 1 and, since all resistors change equally with temperature, the balance between R_2/R_1 and R_3/R_4 is retained.

The amplification of the difference signal may be adjusted with the value of R_0. It is clear from the foregoing formula that R_0 affects only the difference signal and not the common mode signal. This makes adjusting the amplification, if needed, simpler.

An incidental advantage of making the values of the resistors equal is that the formula for U_o simplifies to

$$U_o=2(1+R_n/R_0)U_d,$$

where $R_n=R_1=R_2=R_3=R_4$.

A drawback of this type of differential amplifier, in contrast to the one-opamp and three-opamp types, is that the first opamp magnifies not only the signal, but also the common-mode voltage. Assuming thet R_1–R_4 are equal, the common-mode signal in the output, U_1, of the first opamp is amplified by a factor of ×2. The level of U_1 is given by

$$U_1=-(1+R_n/R_0)U_d+2U_{cm}.$$

The maximum drive to the second opamp must, of course, also be borne in mind. Suppose that the differential amplifier has an amplification of ×10 for a maximum differential voltage of ±1 V. The ratio R_n/R_0 is then 4 and the maximum output voltage is ±10 V. Potential U_1 is ±5 V+$2U_{cm}$. If the maximum output voltage is equal to the maximum drive level (that is, ≈ supply voltage), the level of the common-mode voltage must not exceed ±2.5 V to prevent the first opamp being overdriven.

Supply/reference voltages

The power supply for the thermometer, shown in Fig. 2, is fairly unusual in that the reference voltage regulator is integrated in the display driver, although for clarity's sake it is shown separate.

The unregulated 8–15 V supply voltage is stabilized by the reference voltage source, which is preset with the aid of R_{18} and R_{19} to give an output of 6.3 V. Since the differential amplifier requires a symmetrical supply, an articificial 'earth' is concocted with the aid of opamp IC_{2a} and resistors R_{15}–R_{17}, R_{20} and R_{21}. This does not, of course, result in a true

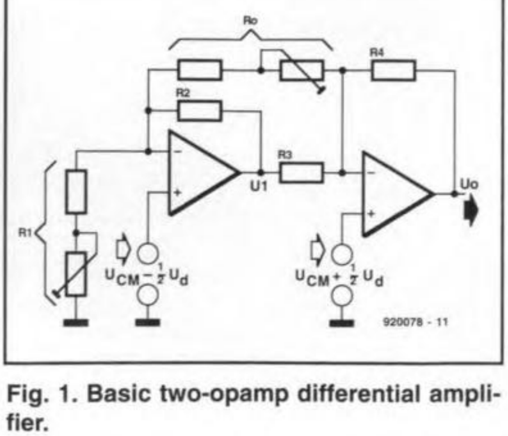


Fig. 1. Basic two-opamp differential amplifier.

TECHNICAL PARAMETERS

Sensors	Silicon diodes (e.g., 1N4148) with maximum junction temperature of 200 °C.
Switching outputs	Open-collector type (BC517: I_c max. 400 mA; T_j max 150 °C; P_{tot} max 6.25 mW; $R_{th\text{-}j\text{-}a}$ 200 K/W
Supply voltage	8–15 V, unregulated
Display	LED bar (10 LEDs)
Sensitivity	Preset (standard 0.25 °C per LED)

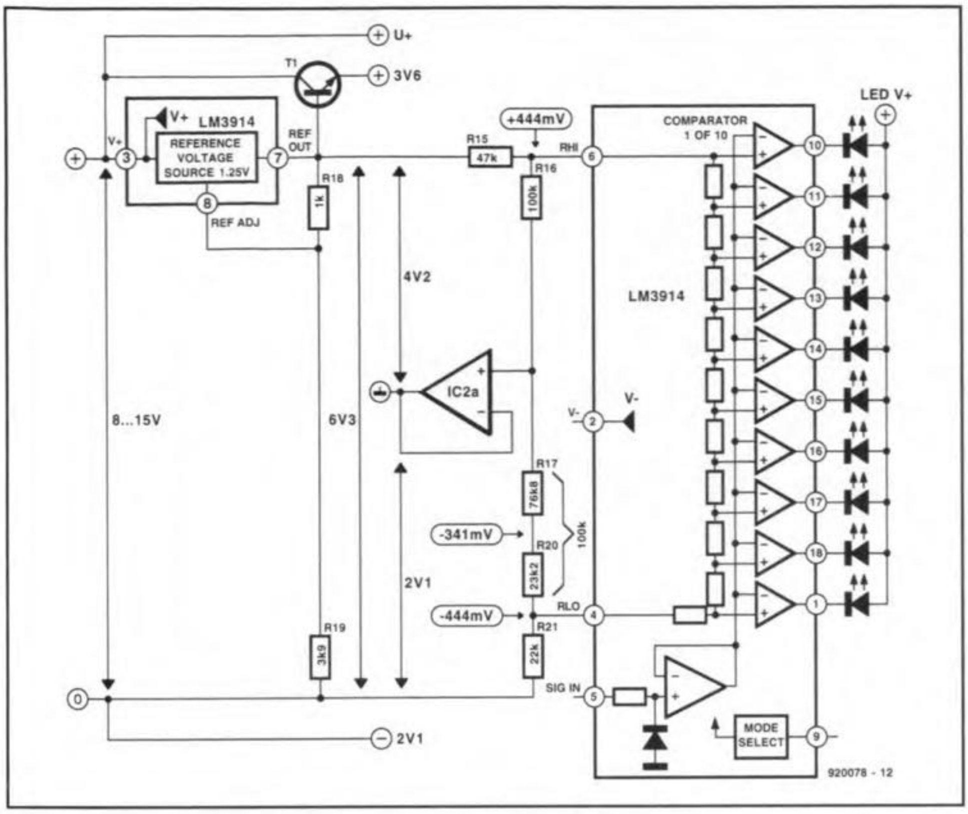


Fig. 2. The internal voltage regulator of the display driver is the source of all required supply voltages.

symmetrical supply: the 'earth' potential is 2.1 V above true earth and 4.2 V below the output level of the regulator. Raising the level of the positive voltage more than that of the negative voltage with respect to true earth increases the drive capability of the differential amplifier.

The supply voltage so created still cannot be used, however. This is because the output current of the regulator determines the current through the display LEDs. Since the current through each LED is about ten times as large as the output current of the regulator, the latter must not be too large and, moreover, must not vary much. For this reason, the regulator action is 'enhanced' by transistor T_1. However, since the output voltage of the regulator is also used as reference for the display, T_1 is not in the feedback circuit. The transistor, therefore, cannot influence the quality of the regulator. It means, however, that the positive supply voltage for the differential amplifier is 3.6 V instead of 4.2 V it is no longer so well regulated, but this is of no consequence here.

The reference voltage for the regulator is derived from potential divider R_{18}–R_{19}. To ensure that the display indicates the same magntitude irrespective of whether the temperature difference is positive or negative, the voltage across the resistive divider in the display driver (about 12 kΩ) must be symmetrical with respect to earth. This is arranged by using 100 kΩ resistors, R_{16} and R_{17}–R_{20} respectively, between earth and reference inputs R_{HI} and R_{LO} of the display driver (note that the +input of IC_{2a} is at ground potential). The reason for using two resistors, R_{17} and R_{20} instead of a single 100 kΩ will be discussed later on.

Circuit description

The temperature sensors in the prototype are Type 1N4148 diodes, D_1 and D_2 in Fig. 3. Silicon diodes are used because their threshold voltage has a temperature coefficient of about 2 mV K^{-1}. The diodes are connected in a bridge circuit that, when their temperature is the same, is balanced by P_1.

The signals from the sensors are applied to differential amplifiers IC_{3a} and IC_{3b} via low-pass filters R_3–C_4 and R_{14}–C_6 respectively.

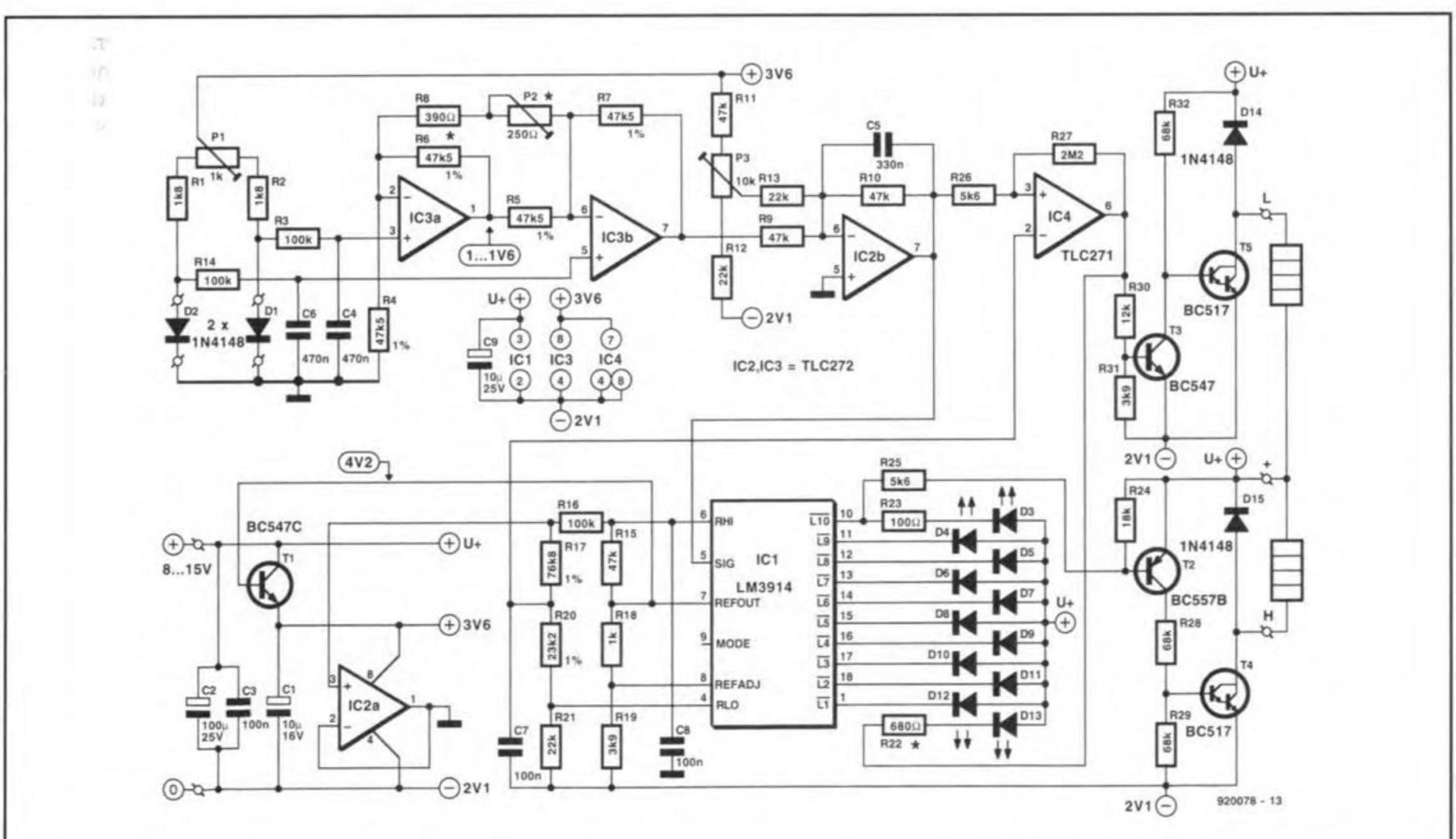


Fig. 3. Circuit diagram of the differential thermometer.

The output of the amplifier is fed to IC_{2b} which, with the aid of P_3, corrects the offset of the amplifier. The signal at the output of IC_{2b} is then suitable as input for display driver IC_1.

The driver has two switching outputs, of which one operates when the positive peak is reached, and the other when the negative maximum is about to be exceeded.

In the case of positive levels, as soon as D_3 has been switched on by the driver, T_2 will also be on. This transistor in turn switches on T_4, resulting in the load (relay) being switched on. In the case of negative levels, the input voltage to IC_1 is compared with the potential at junction R_{17}–R_{20} at which D_{12} just goes out. When the measured temperature is sufficiently negative, the output of IC_4 goes low, whereupon D_{13} lights, T_3 is switched off, and T_5 is switched on, so that the associated load (relay)is switched on.

The relays are shunted by free-wheeling diodes D_{14} and D_{15}. If relays are not required, terminals L and H may be interlinked to form a wired-OR connection.

The circuit without relays draws a current of about 30 mA from an 8–15 V supply; when either of the relays is switched on, the current increases to well over 400 mA. If the thermometer is not used constantly, a 9 V PP3 battery may be used as supply.

Construction and calibration

The thermometer is best constructed on the printed-circuit board shown in Fig. 4. Sensors D_1 and D_2 may be linked to it via a cable up to 1 m (3 ft) long. The diodes may be replaced by transistors, for instance, Types BC107 and BC547, whose base and collector are linked together: the base–emitter diode serves as the sensor.

The brightness of D_{13} may be somewhat less than that of the other LEDs; this may be rectified by varying the value of R_{22} by trial and error.

Before the circuit can be calibrated, both sensors must be at the same temperature and all potentiometers set to the centre of their travel.

Connect a high-impedance voltmeter between the anodes of D_1 and D_2, and adjust P_1 for zero reading (no LED lights). Next, adjust P_3 until the centre LED (D_8) just lights. The magnification of the differential amplifier is then ×185 (gain=45 dB). Assuming a temperature coefficient of 2 mV °C^{-1} and an input sensitivity of the display of 88.8 mV per LED, the overall sensitivity is about 0.25 °C per LED (88.8/2×185).

If greater precision or a different scale is required, the two sensors should be kept at the desired temperature difference and P_2 adjusted until D_{13} just lights. Another method is to multiply the maximum temperature difference by 2 and take the result as a voltage in mV. With a voltmeter between the anodes of D_1 and D_2, adjust P_1 until the meter indicates that voltage. Next, adjust P_2 until D_{13} just lights and readjust P_1 for zero reading of the meter. ■

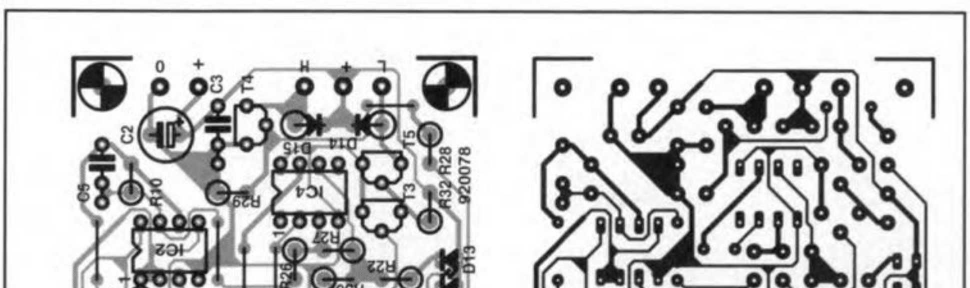


Fig. 4. Printed circuit board for the differential thermometer.

PARTS LIST

Resistors:
R1, R2 = 1.8 kΩ
R3, R14, R16 = 100 kΩ
R4–R7 = 47.5 kΩ
R8 = 390 Ω
R9–R11, R15 = 47 kΩ
R12, R13, R21 = 22 kΩ
R17 = 76.8 kΩ
R18 = 1 kΩ
R19, R31 = 3.9 kΩ
R20 = 23.2 kΩ
R22 = 680 Ω
R23 = 100 Ω
R24 = 18 kΩ
R25, R26 = 5.6 kΩ
R27 = 2.2 MΩ
R28, R29, R32 = 68 kΩ
R30 = 12 kΩ
P1 = 1 kΩ preset, horizontal
P2 = 250 Ω preset, horizontal
P3 = 10 kΩ preset, horizontal

Capacitors:
C1 = 10 µF, 16 V, radial
C2 = 100 µF, 16 V, radial
C3, C7, C8 = 100 nF
C4, C6 = 470 nF
C5 = 330 nF
C9 = 10 µF, 25 V, radial

Semiconductors:
D1, D2, D14, D15 = 1N4148
D3, D4, D12, D13 = LED, 3 mm, red
D5, D6, D10, D11 = LED, 3 mm, yellow
D7–D9 = LED, 3 mm, green
T1, T3 = BC547C
T2 = BC557B
T4, T5 = BC517
IC1 = LM3914
IC2, IC3 = TLC272
IC4 = TLC271

Miscellaneous:
Enclosure 57×142×23.5 mm ($2^1/_4$×$5^9/_{16}$×$^{15}/_{16}$ in)
PCB Type 920078 (see page 70)

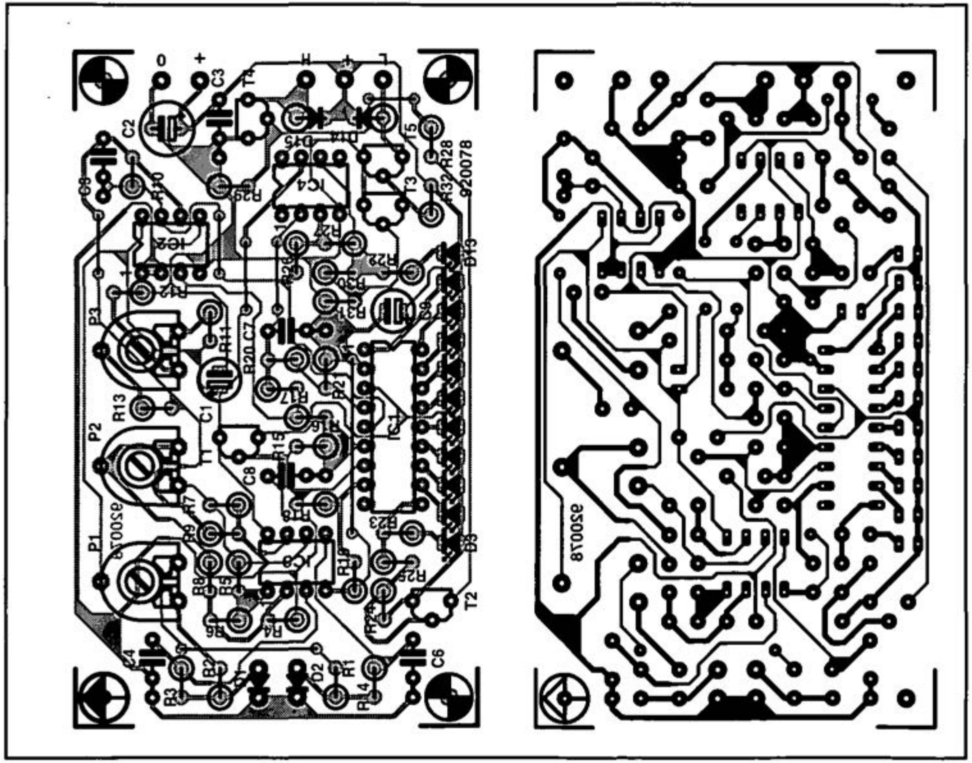


Fig. 4. Printed circuit board for the differential thermometer.

R22 = 680 Ω
R23 = 100 Ω
R24 = 18 kΩ
R25, R26 = 5.6 kΩ
R27 = 2.2 MΩ
R28, R29, R32 = 68 kΩ
R30 = 12 kΩ
P1 = 1 kΩ preset, horizontal
P2 = 250 Ω preset, horizontal
P3 = 10 kΩ preset, horizontal

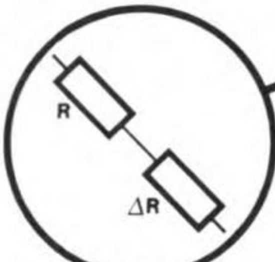
Capacitors:
C1 = 10 µF, 16 V, radial
C2 = 100 µF, 16 V, radial
C3, C7, C8 = 100 nF
C4, C6 = 470 nF
C5 = 330 nF
C9 = 10 µF, 25 V, radial

Semiconductors:
D1, D2, D14, D15 = 1N4148
D3, D4, D12, D13 = LED, 3 mm, red
D5, D6, D10, D11 = LED, 3 mm, yellow
D7–D9 = LED, 3 mm, green
T1, T3 = BC547C
T2 = BC557B
T4, T5 = BC517
IC1 = LM3914
IC2, IC3 = TLC272
IC4 = TLC271

Miscellaneous:
Enclosure 57×142×23.5 mm (2¼×5⁹⁄₁₆×¹⁵⁄₁₆ in)
PCB Type 920078 (see page 70)

THE WHEATSTONE BRIDGE

Any time a device produces a resistance (or resistance change) as the transducible property for a measurement, we can use the Wheatstone bridge to make the measurement easier. The bridge is probably the most common form of resistive sensor circuit.



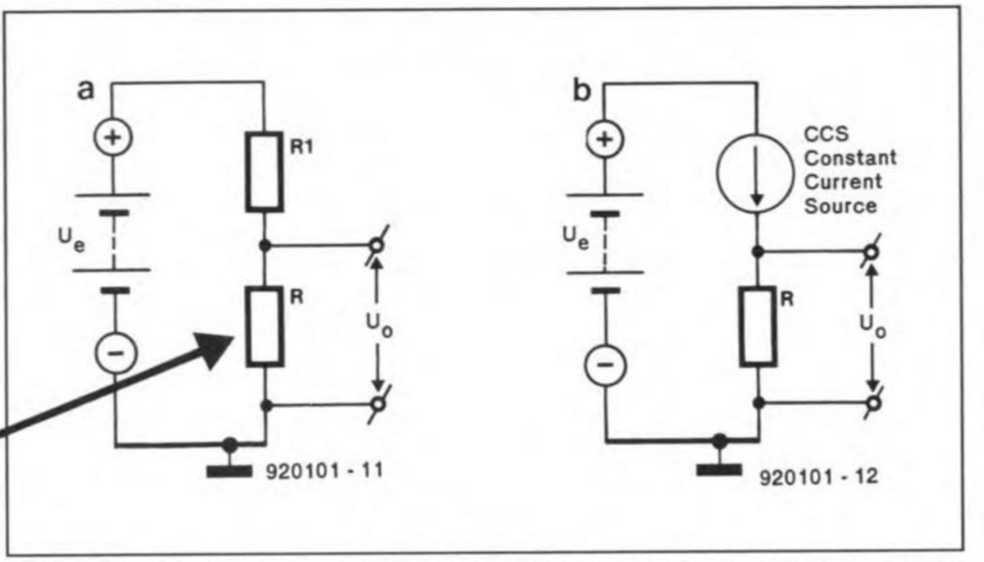


Fig. 1. (a) Basic half-bridge circuit; (b) half-bridge circuit based on a constant current source (CCS).

By Joseph J. Carr

MANY sensors used in electronic instruments use electrical resistance as the transducible property. For example, a thermistor produces a resistance that is a function of the applied temperature. Strain gauges are wire or semiconductor elements that change resistance when deformed in either tension or compression; this phenomenon is called piezoresistivity, and forms the basis for a wide range of pressure sensors and other instruments. Photoresistors produce a resistance that is inversely proportional to the applied light level. All these resistive sensors can be accurately measured with the aid of the Wheatstone bridge.

Bridge circuits

Before any resistive sensor can be useful, it must be connected into a circuit that will convert its resistance changes into a current or voltage output; most applications are voltage output circuits. Figure 1 shows several popular forms of circuit. The circuit in Fig. 1a is both the simplest and least useful (although not useless); it is sometimes called the 'half-bridge' circuit, or 'voltage divider' circuit. The sensor element of resistance R is placed in series with a fixed resistor, R1, across a stable d.c. voltage, U_e. The output voltage, U_o is found from the standard voltage divider equation:

$$U_o = \frac{U_e R}{R + \text{R1}} \tag{1}$$

Equation (1) describes the output voltage U_o when the sensor is at rest (i.e., nothing is stimulating the resistive element). When the element is stimulated, however, its resistance changes a small amount, ΔR. The output voltage in that case is:

$$U_o = \frac{U_e(R \pm \Delta R)}{(R \pm \Delta R) + \text{R1}} \tag{2}$$

Another form of half-bridge circuit is shown in Fig. 1b, but in this case the sensor element is connected in series with a constant current source (CCS), which will maintain current I at a constant level regardless of changes in the strain gauge resistance. In this case, $U_o = I(R \pm \Delta R)$. The LM334 device is an example of a commercial CCS.

Both of the half-bridge circuits suffer from a serious defect: output voltage U_o will always be present regardless of the value of the force applied to the sensor. Ideally in any sensor system, the output voltage should be zero when the applied stimulus is zero. For example, when a gas pressure sensor is open to atmosphere, the gauge pressure is zero so the output voltage should also be zero. Secondly, the output voltage should be proportional to the value of the stimulus when the stimulus is not zero. A *Wheatstone bridge* circuit has these properties. We can use resistive sensors for all of the elements of the Wheatstone bridge, or just one.

Figure 2a shows the basic circuit for the Wheatstone bridge: the circuits to follow are but variations on this theme. The bridge consists of four resistive arms (R1 through R4), and an *excitation voltage* source, U_e. As can be seen in the redrawn circuit of Fig. 2b, the Wheatstone bridge is basically two resistor voltage dividers in parallel with each other. Voltage divider R1/R2 produces an output voltage U_1:

$$U_1 = \frac{U_e \text{R2}}{\text{R1} + \text{R2}} \quad , \tag{3}$$

while voltage divider R3/R4 produces voltage U_2:

$$U_2 = \frac{U_e \text{R4}}{\text{R3} + \text{R4}} \quad . \tag{4}$$

Each of these voltages is single-ended, i.e., it is unbalanced with respect to common or ground. Output voltage U_o is *balanced* with respect to common, and is the difference between each half-bridge voltage:

$$U_o = U_1 - U_2 = U_e \left(\frac{\text{R2}}{\text{R1} + \text{R2}} - \frac{\text{R4}}{\text{R3} + \text{R4}} \right). \tag{5}$$

When $U_1 = U_2$, and $U_o = 0$, the bridge is balanced, and is said to be in the *null condition*. This state occurs when:

$$\frac{\text{R1}}{\text{R2}} = \frac{\text{R3}}{\text{R4}} \quad . \tag{6}$$

Please note that the resistances need not be equal, only the *ratio* of the resistances in the two arms need be equal to establish the null condition.

One also might notice that knowledge of three resistance values (say, R1, R2 and R3) implies knowledge of the fourth by calculation when the null condition is present. It is common practice to use fixed precision resistors for two elements (e.g., R1 and R3), and a calibrated variable resistor for the third resistor (e.g., R2), and then an unknown for the four-resistance branch. Such a system for measuring unknown resistances is shown in Fig. 2c.

If R2 is adjusted for $U_o = 0$, with unknown Rx connected in place of R4, the value of Rx is inferred from:

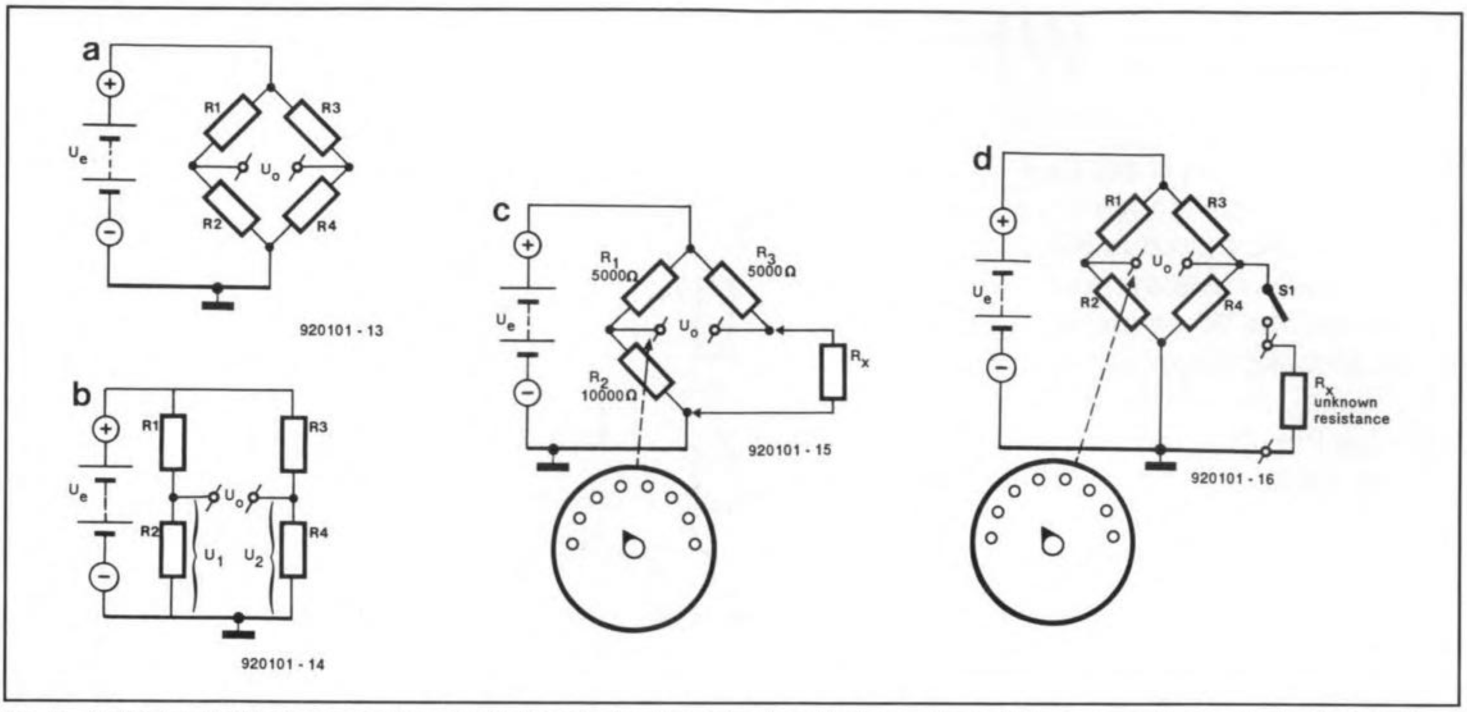


Fig. 2. (a) Standard Wheatstone bridge circuit; (b) circuit redrawn to show the two voltage dividers more clearly; (c) circuit for using a Wheatstone bridge to measure an unknown resistance; (d) alternate circuit for measuring unknown resistances.

$$R_x = \frac{R_2 R_3}{R_1} \qquad (7)$$

or, where $R_1 = R_3$ (not a necessary condition, but certainly convenient), $R_x = R_2$.

Another operating condition is shown in Fig. 2d. This method uses a *departure from null* to indicate R_x. With switch S_1 open, resistor R_2 is adjusted to null (i.e., $U_o = 0$). Switch S_1 is then closed, causing R_x to shunt R_4 to produce a new (lower) resistance for this arm of the bridge, and forcing $U_o \neq 0$. The value of U_o is an indication of unknown R_x.

Alternatively, switch S_1 can be an SPDT type that replaces R_4 with R_x, rather than simply shunting ($R_4 \parallel R_x$). This 'departure from null' is the basis for many sensor based instruments.

Figure 3a shows a Wheatstone bridge circuit in which two resistive sensors (SG_1 and SG_2) are used in two arms of the bridge, with fixed resistors R1 and R_2 forming the alternate arms of the bridge. It is usually the case that SG_1 and SG_2 are configured so that their actions oppose each other; that is, under stimulus, SG_1 will have resistance R+ΔR, and SG_2 will have resistance R–ΔR, or vice versa.

One of the most linear forms of sensor bridge is the circuit of Fig. 3b in which all four bridge arms contain resistive elements. In most such sensors, all four strain gauge elements have the same resistance (R), which will usually be a value between 50 Ω and 1000 Ω.

The output from a Wheatstone bridge is the difference between the voltages across the two half-bridges. We can calculate the output voltage for any of the standard configurations from the equations given below (assuming all four bridges have nominally the same resistance, R.

One active element:

$$U_o = \frac{U_e \Delta R}{4R} \qquad (8)$$

(accurate to ±5% if $h < 0.1$)

Two active elements:

$$U_o = \frac{U_e \Delta R}{2R} \qquad (9)$$

Four active elements:

$$U_o = \frac{U_e \Delta R}{R} \qquad (10)$$

Where:
U_o is the output potential in volts (V);
U_e is the excitation potential in volts (V);
R is the resistance of all bridge arms;
ΔR is the change in resistance in response to the applied stimulus.

Sensor sensitivity

The sensitivity factor (Φ) of a Wheatstone bridge sensor circuit relates the output voltage (U_o) to the applied stimulus value (Q) and excitation voltage. In most cases, the sensor maker will specify a number of microvolts (or millivolts) *output potential per volt of excitation potential per unit of applied stimulus*:

$$\Phi = U_o / U_e / Q_0 \qquad (11)$$

or, written another way:

$$\Phi = \frac{U_o}{U_e Q_0} \qquad (12)$$

Where:
Φ is the sensor sensitivity (μV/U_e/Q);
U_o is the output potential (V);
U_e is the excitation potential (V);
Q is one unit of applied stimulus.

If we know the sensitivity factor, we can calculate the output potential as follows:

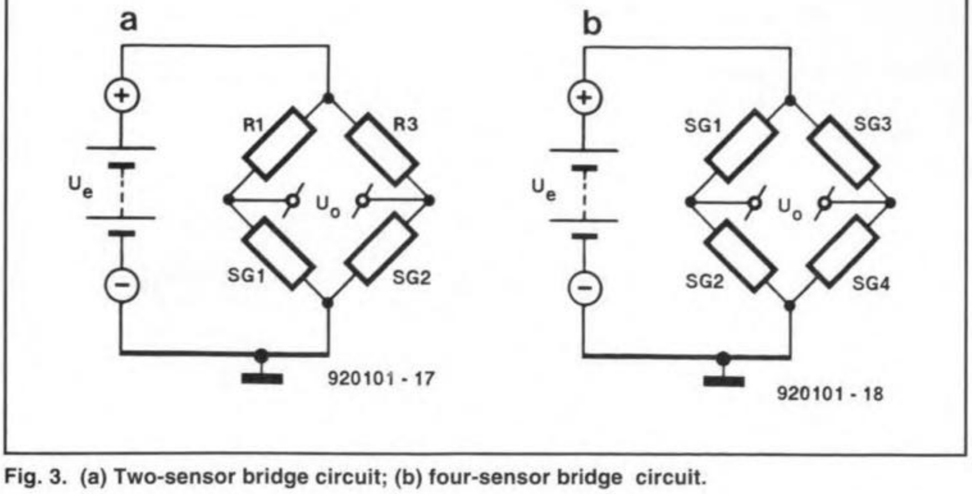


Fig. 3. (a) Two-sensor bridge circuit; (b) four-sensor bridge circuit.

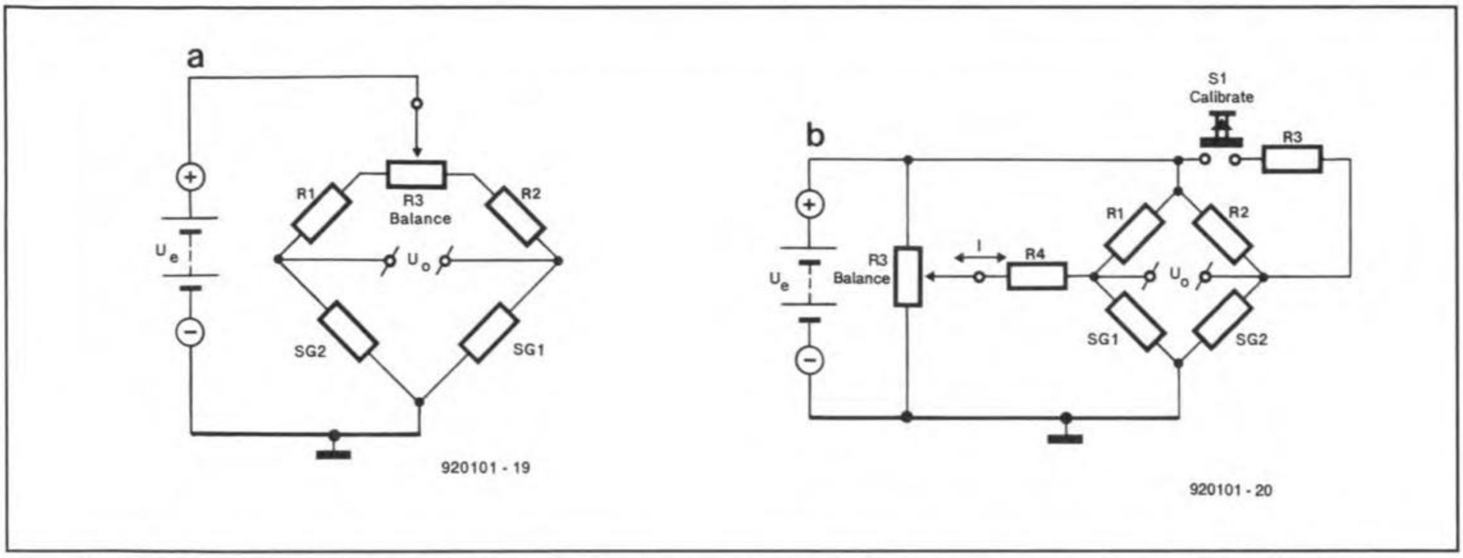


Fig. 4. (a) Bridge balance potentiometer (R3) to compensate for circuit tolerances; (b) injection current method for balancing the bridge.

$$U_o = \Phi U_e Q_0 \tag{13}$$

Equation (13) is the one that is most often used in circuit design.

Example

A certain fluid pressure sensor has a sensitivity (P) of 5 μV/U_e/T, which means that 5 microvolts output potential is generated per volt of excitation potential per Torr of pressure[1]. Find the output potential when the excitation potential (U_e) is +7.5 V, and the applied pressure is 400 Torr.

$$U_o = \Phi U_e Q$$

$$U_o = \left(\frac{5\mu V}{U_e T}\right) \times 7.5V \times 400\text{Torr}$$

$$U_o = (5 \times 7.5 \times 400)\mu V = 15{,}000\mu V$$

(which is 0.015 V, or 15 mV).

Balancing and calibrating a bridge sensor

Few, if any, Wheatstone bridge sensors meet the ideal condition in which all four bridge arms have exactly equal resistances at rest. In fact, the bridge resistance specified by the manufacturer is only a nominal value, and the actual value may vary quite a bit from the specified value. There will inevitably be an offset voltage (i.e., U_o is not zero when Q is zero). Figure 4 shows two circuits that will balance the bridge when the stimulus is zero.

In Fig. 4a the balancing potentiometer is placed between the excitation potential and one of the excitation nodes. The resistance balance of the potentiometer is varied between the two legs of the bridge, nullifying any differences between them. The potentiometer is usually a precision type with five to fifteen turns to cover the entire range.

The purpose of the potentiometer in Fig. 4b is to inject a balancing current (I) into the bridge circuit at one of its nodes. R1 is adjusted, with the stimulus at zero, for zero output voltage.

Another application for this type of circuit is injecting an intentional offset potential. For example, on an electronic scale, one that uses a strain gauge to measure weight, such a circuit is used to adjust for the 'tare weight' of the scale, which is the sum of the platform and all other weights acting on the sensor when nobody is standing on the scale. This is also sometimes called 'empty weight compensation'.

Calibration of a bridge sensor

Calibration can be accomplished either the hard way, or the easy (and less accurate) way. The hard way is to set the sensor up in a system and apply the stimulus. The stimulus is measured and the result is compared with the sensor output. For example, if you are testing a pressure sensor, connect a manometer (pressure measuring device containing a column of mercury), pressurize the system, and then measure the pressure directly. The result is compared with the sensor output. Similarly, temperature sensors can be exposed to a known temperature, and the bridge output noted. All sensors should be tested in this manner initially when placed in service and then periodically thereafter.

The easy (and less accurate) way is to connect a calibrating resistor in parallel with one leg of the bridge (R3 in Fig. 4b) to create an offset that is equal to some standard stimulus. A 'CAL' switch (S1) will insert the resistor in the circuit, unbalancing the bridge an amount R, whenever a quick calibration or test is needed.

Output display devices

The output of the Wheatstone bridge is a differential voltage, U_o, that is proportional to the unbalance of the bridge. This

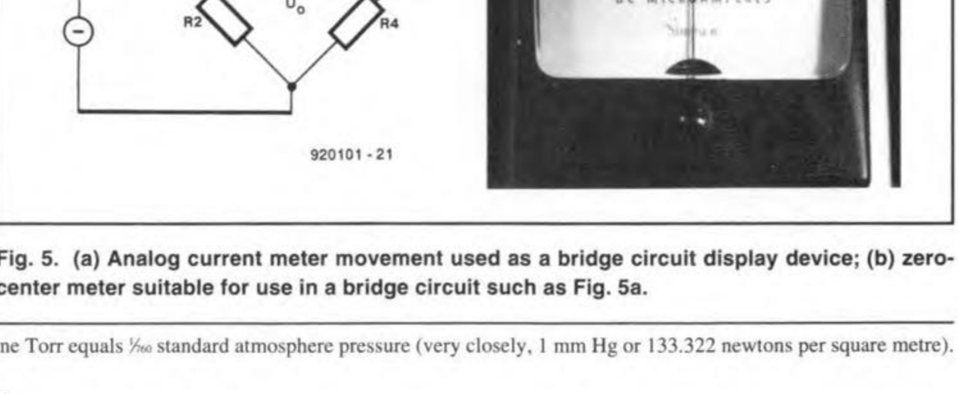


Fig. 5. (a) Analog current meter movement used as a bridge circuit display device; (b) zero-center meter suitable for use in a bridge circuit such as Fig. 5a.

[1] **torr**. A unit of presssure used in vacuum technology. One Torr equals 1/760 standard atmosphere pressure (very closely, 1 mm Hg or 133.322 newtons per square metre).

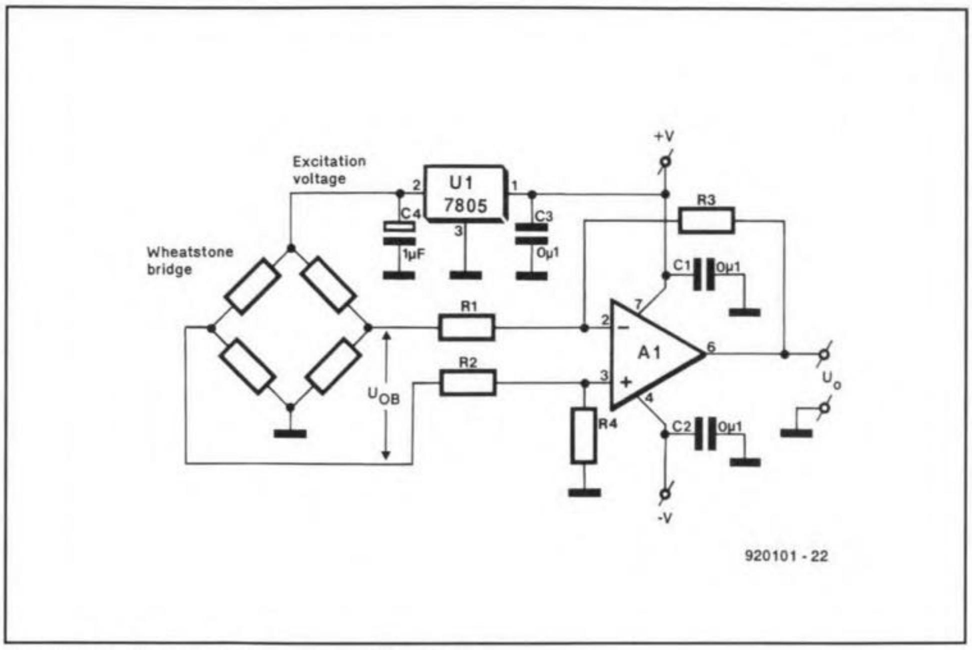


Fig. 6. DC differential bridge amplifier circuit.

voltage can be either positive or negative, depending on the direction of unbalance. In many cases, the output of the bridge will be displayed on an analogue or digital voltmeter, an oscilloscope or a strip-chart recorder.

It is also possible to use a current meter for the output display, as shown in Fig. 5a. The meter, M1, is connected between the output nodes across which U_o appears. This meter is usually a milliammeter or microammeter (Fig. 5b), depending on the best sensitivity required.

It is not strictly necessary to insert the sensitivity control (R5) in series with the meter, but it is highly recommended if the unbalance is large and the meter has a low current range. Large displacements of the bridge could generate sufficient current to damage the meter. It is common practice to initially set R5 to maximum, or near maximum, resistance, and then reduce its resistance as the bridge nears the null condition. A few commercial resistance measuring bridges place a switch in shunt with R5 in order to remove it from the circuit when the bridge is close to null.

Bridge amplifier circuit

The output potential of most bridges (U_{ob} in Fig. 6a) is a very small voltage that, for many applications, must be amplified for practical use. The Wheatstone bridge is a balanced device, so a differential amplifier is needed to amplify U_o. The amplifier circuit uses an operational amplifier (A1) in the d.c. differential amplifier configuration. In this type of circuit, R1 = R2 and R3 = R4, in order to maintain balance, and the voltage gain is:

$$A_v = \frac{R3}{R1} \qquad (14)$$

The input resistors, R1 and R2, should be at least ten times the source resistance of the bridge. If all arms of the bridge are equal, then the source resistance is the value of any one arm of the bridge.

The excitation voltage in Fig. 6a is supplied by an IC voltage regulator. Separate regulation is needed because variations in the power supply voltage are transmitted to the bridge, and reflected as changes in the output voltage. In the case shown, the voltage for the bridge is +5 V, so a 7805 regulator is used. In general, the excitation voltage for typical bridges is low in order to prevent self-heating of the sensors, so a 7805 is a reasonable general selection.

In many cases, the output of the bridge is so small that it is difficult to transmit for any length in a wire or cable. In those cases, it is sometimes prudent to install a preamplifier on the body of the sensor. I constructed such a preamp for the user of a Grass Type FT-3 gram-force transducer, which is based on the Wheatstone bridge circuit that uses strain gauge elements as the arms. The output signal tends to be 100 µV, or so, at full scale. In order to overcome interfering hum from the 60 Hz power mains, I built a gain-of-100 d.c. differential amplifier (making the output voltage 10 mV rather than 100 µV) inside a small metal box that interfaced with the mating connector.

Applications of bridges: circuits that you can build

The Wheatstone bridge can be used in a wide variety of applications circuits, only a few of which can be covered here. The purpose of the circuits below is to stimulate thinking into these and other applications for which the same principles hold.

Differential Thermometer

A differential thermometer produces an output voltage that is proportional to the *difference* between two temperatures. Uses for such thermometers include investigations of thermal insulation effectiveness; control of heating/cooling equipment based on temperature differences; simple curiosity as you gaze through an iced window pane; and so forth. Figure 7 shows the circuit for such a thermometer based on thermistor sensors.

The thermistor is a device that produces a resistance value that is a function

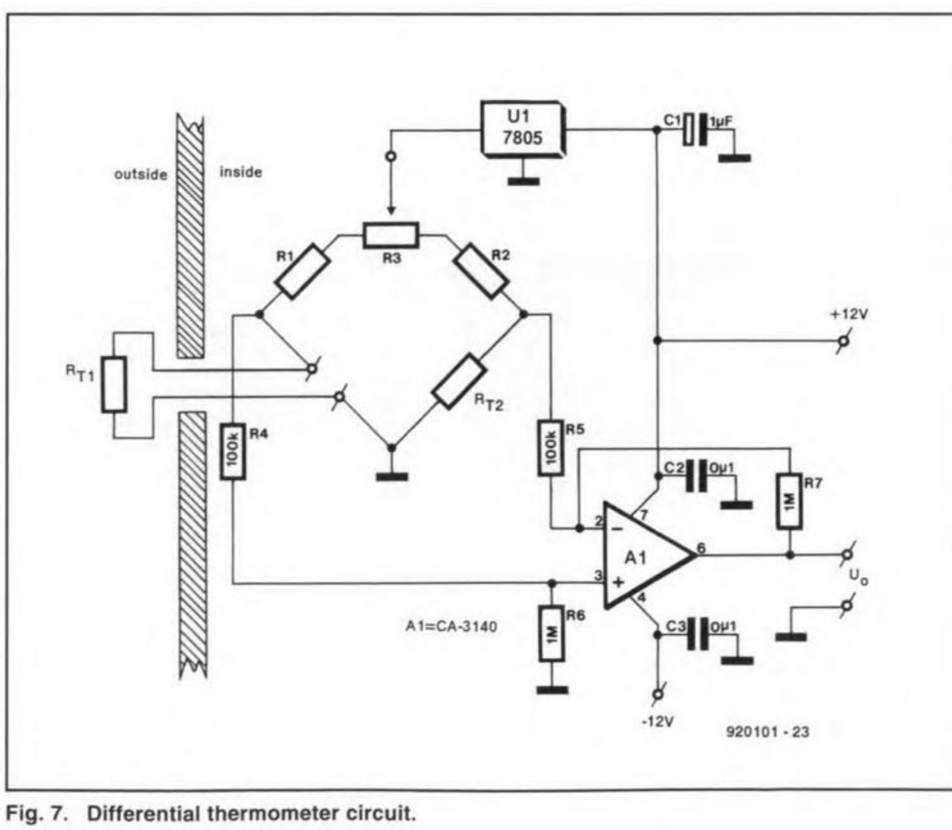


Fig. 7. Differential thermometer circuit.

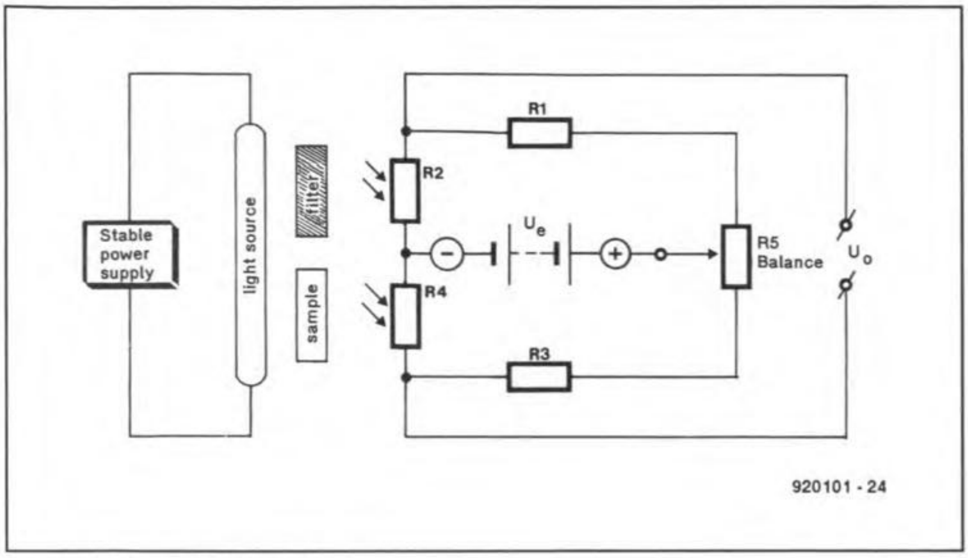


Fig. 8. Photocolorimeter circuit.

of temperature. Devices RT1 and RT2 in Fig. 7 are identical thermistors, and are used in two opposing arms of a Wheatstone bridge circuit. Resistors R1 and R2 form the other two arms of the bridge. The values for R1 and R2 are not given because the convenient values depend on the specific thermistors being used. A rule-of-thumb is to make R1 and R2 equal to each other, with a value approximately the value of RT1 and RT2 at a mid-range temperature. Balancing potentiometer R3 should have a value of 10 to 20 percent of the value of R1 and R2.

As in the previous case, the bridge excitation source is a 7805 IC voltage regulator, which produces a regulated +5 V from the +12 V power supply.

The input resistors to A1, the differential amplifier, should be at least ten times the 'looking back' resistance of the bridge. Examination of thermistor catalogues reveals that 10 kΩ at 30 °C is a common value, so I set these resistors at ten times that value, or 100 kΩ. The gain of ten was set for convenience, and requires 1 MΩ resistors for R6 and R7. Depending on the thermistors used, and the output voltage required, it may be necessary to increase the gain of the amplifier (remember, R1 = R2, R6 = R7, and A_v = R7/R5 = R6/R4).

Photocolorimetry

One of the most basic forms of instrument circuit is also both the oldest and most commonly used: *photocolorimeters*. These devices are used for such applications as measuring the oxygen content in blood, CO_2 content of air, water vapour content in a gas, blood electrolyte (Na and K) levels, and a host of other similar measurements.

Photocolorimetry is basically a comparison measurement technique in which light (or IR and UV depending on the purpose of the instrument) transmission over two paths is compared. Figure 8 shows the basic circuit of the most elementary form of colorimeter. Although the circuit is very basic, this is the actual circuit used in a once widely-used medical blood oxygen meter.

The basic circuit is the Wheatstone bridge, and it uses a pair of photoresistor cells (R2 and R4) as the light sensors. Potentiometer R5 in Fig. 8 is used as a bridge balance control, and it is adjusted for zero output (U_o = 0) when the same light shines on both photoresistors. The output voltage from the bridge (U_o) will be zero when the two legs of the bridge are balanced. In other words, U_o is zero when R1/R2 = R3/R4. It is not necessary for the resistor elements to be equal (although that is often the case), only that their resistance ratios be equal. Thus, a 500 kΩ/50 kΩ ratio for R1/R2 will produce zero output voltage when R3/R4 = 100 kΩ/10 kΩ.

The photoresistors are arranged such that light from a calibrated source illuminates both equally and fully, except when an intervening filter or sample is present in one or both pathways. Thus, the bridge can be nulled to zero using potentiometer R5 under this zero condition. In most instruments that are based on this principle, a translucent sample is placed between the light source and one of the photocells. The amount of transmission to light allowed by the sample is a measure of its optical density, and is thus a transducible property. Let us look at a couple of different types of instrument to see how this principle is applied.

(1). Blood O_2 Level. A once widely used method for measuring blood oxygen level is based on the basic colorimeter of Fig. 8. It works because the 'redness' of human blood is a measure of its oxygenation. This instrument is nulled with neither standard filter cell nor blood in the light path; i.e., when white or red light shines on both cells. A standard colour 800 nanometer[2] filter is introduced between the light source and R2, and a blood sample is placed in a standardized tube between the light source and R4. The degree of blood O_2 saturation in the sample is thus reflected by the difference in the bridge reading between the sample path and filter path. On one model oxygen meter, a separate resistor across the R1/R2 arm is used to bring the bridge back into null condition, and the dial for that resistor is calibrated in percent-O_2. More modern instruments based on digital computer techniques provide the measurement in a more automatic manner.

(2). Respiratory CO_2 Level. The exhaled air from humans is roughly 2 to 5 percent carbon dioxide (CO_2), while the percentage of CO_2 in normal room air is negligible. A popular form of 'End Tidal CO_2 Meter' is based on the fact that CO_2 absorbs infrared (IR) waves at three discrete wavelengths. The 'light source' in that type of photocolorimeter is actually either an IR LED or a Cal-Rod device (identical to the one that heats an electric coffee pot!); the photocells are selected for good IR response. In this type of instrument, room air is passed through a glass cuvette placed between R2 and the heat source, while patient expiratory air is passed through the same type of cuvette placed between the heat source and R4. The difference in IR transmission across the two paths is a function of the percentage of CO_2 in the sample circuit.

The associated electronics (not shown) will allow zero and maximum span (i.e., gain) adjustment. The zero point is adjusted with room air in both cuvettes, while the maximum scale (usually 5% CO_2) is adjusted with the sample cuvette purged of room air and replaced with a calibration gas (usually 5% CO_2, 95% nitrogen). This calibration gas must be obtained from a local supplier, and be specified as a calibration gas. Otherwise, the quantities may be only approximate. Also, be sure of the type of measurement: calibration gases are available by either weight or volume.

The uses of colorimeters do not end with the medical laboratory. The clue to looking for a transducible event is detection of either a density change, or an absorption differential to one or two wavelengths, that is a transducible function of the parameter being measured; for example, IR is absorbed by CO_2, and a certain O_2 saturation level passes light at 800 nm wavelength.

Conclusion

The Wheatstone bridge is simple to understand, simple to build, well behaved, and can form the basis for a very large variety of simple physical instruments that you can build. ■

[2] 800 nm is the *isobestic* point wavelength at which oxygenated arterial blood and deoxygenated veinous blood have the same transmittivity.

DIGITAL AUDIO-VISUAL SYSTEM

PART 1 (OF 4): SYSTEM OUTLINE AND DISSOLVE UNIT

This is the first instalment of an article that describes a high-end slide control system based on a Centronics-driven dissolve unit for four slide projectors. The system allows up to 16 projectors to be controlled automatically or by hand. Music or comment to accompany the slides can be synchronized with the aid of an advanced pulse or timecode registration unit. The timecode option enables you to record all control actions in a complete slide show, whereby all relevant data are safely stored, along with the parallel sound track.

Design by A. Rietjens

FRONT COVER PROJECT

ABOUT four years ago we published a computer-controlled slide fader for four projectors (Ref. 1). Together with a Centronics interface published a little later (Ref. 2), this fader allowed photography enthusiasts to put a computer in control of up to 16 slide projectors. The software written for this system was an MSX BASIC program with limited features. The designer of the slide fader, Albert Rietjens, a keen photographer and slide maker himself, has used the intervening years since this 'early' publication to elaborate the basic system into what is presented here. The result is, we feel, definitely up to scratch: a DiAV (for Digital Audio-Visual) system that competes on all fronts with far more expensive commercial equipment (which appears to be few and far between). In fact, the DiAV will cost you only about one fifth of any commercially available product with an equal set of features.

The DiAV system

The drawing in Fig. 1 presents an overview of the complete system to be described. The central block is formed by the DiAV main unit, which is based on the multi-purpose Z80 card (Ref. 3). The main unit is capable of controlling up to four dissolve units (slide control units, each suitable for controlling up to four projectors). This is achieved by connecting the individual units in series.

A tape recorder may be connected up into this system to add a music channel to the slide series. The tape recorder used for this purpose must have the possibility to record pulses that, on being played back, are converted into control signals for the projectors. This is the simple option. The more advanced is the timecode interface (Ref. 4), which is capable of reading from, and writing to, tape either one of two formats: a timecode signal or a 'special code' called Special Data Language, SDL. The SDL is recorded 'in parallel' with the sound track (music channel) to ensure absolute synchronicity. In addition to information about the course of the slide series, the SDL also contains all information on the current positions of the slide carriers in the projectors. This synchronization works so well that the system is capable of moving the carriers in all projectors to the desired positions (i.e., slide) when the tape is started at any point in the series. Once running, the whole system is perfectly synchronized, and the slides appear in the programmed order from the new start point onwards.

The main unit puts the user in general control over all sub-systems, and has a large number of options for its control. Those of you who have followed the articles on the multi-purpose Z80 card know that this sports interfaces for a liquid crystal display (LCD), a PC-XT keyboard and an infra-red (IR) remote control receiver module. The keyboard and the IR link are the primary control elements of the main unit. The remote control is particularly useful for 'quick and dirty' control of the main unit, i.e., if you want to show a couple of slides without bothering too much about special effects. Although the IR remote control can be used to enter all data, the PC-XT keyboard will be preferred whenever a 'real' series is to be programmed.

Owners of an IBM PC or compatible may also control the main unit via the RS232 serial interface, or convey control programs written with a word processor from the PC to the DiAV, and vice versa.

The main unit has a 32-kByte RAM disk (with battery backup) to hold the program that describes the slide series. This program can also be read back for editing on the PC. The RAM allows up to 32 series to be stored, or fewer if the series are relatively large (the average series will comprise something like 100 slides, and consume a RAM space of about 1 kByte).

For emergency cases, the main unit has a small keyboard that allows you to select those basic functions that 'save' you when you have forgotten the remote control, or when the batteries are flat.

DiAV: a slide control system with professional features

Dissolve unit
- Microcontroller-driven
- No special ICs except microcontroller
- Interface compatible with slide controller (earlier publication)
- Transistor drivers for carrier solenoids
- No modifications inside projectors
- Simple to connect; only connecting cable depends on projector
- Also usable as a stand-alone unit (with limited functions)

Main unit
- Controlled by multi-purpose Z80 card
- Stand-alone system; independent of computer type
- Operated via infra-red remote control or via PX-XT keyboard
- Battery back-up
- Memory for up to 32 slide series
- RS232 interface for PC control and program exchange
- Direct synchronization by pulse control (connects straight to ITT recorder for slide control)

Main unit in combination with timecode interface
- Full tape synchronization possible
- Uses timecode for synchronization
- Slide series program editing using timecode
- Perfectly timed slide changes (accuracy: 10 ms)

Overall performance comparable to £1250+ systems.

The electronics

The complete DiAV is a combination of a number of building blocks published earlier in *Elektor Electronics* (see references). However, since the original slide control unit goes back four years, we thought it fit to design a new interface for it, taking into account everything we have learned in the mean time about its practical use. Fortunately, this does not mean that constructors of the 'old' interface have another piece of equipment to forfeit. The 'new' interface is compatible with the 'old' one, provided the latter is controlled via the Centronics interface developed for it. Those of you who have a fully-fledged slide control plus Centronics interface may, therefore, skip the following sections on function and construction. Note, however, that the 'new' interface has a number of extras and improvements. Also, its 'package' is stylish, neat and attractive looking — see the introductory photograph.

The dissolve unit

The block diagram of the new dissolve unit is given in Fig. 2. The most conspicuous feature of this unit is that it is controlled by a microprocessor rather than by discrete electronics. Here, using a microcontroller allows us to cut down drastically on external components. The circuit may be controlled via a Centronics interface, which is available on most, if not all, PCs. Note, however, that the computer is required only if you do not use the Z80 main unit, or if you wish to write your own system software.

The control signals supplied by the PC are passed to another dissolve unit (if used) via a Centronics connector. In addition to a Centronics input, the interface also has an I^{2}C connection. This is reserved for future applications, and not implemented in the current control software.

To enable the processor to control the brightness of the projector lamps directly, it must know when the zero crossing of the mains voltage occurs. This information is supplied by a zero-crossing detector incorporated in the power supply. The zero-crossing detector is common to all projector lamps, which means that the dissolve unit and all projectors must be powered from the same mains outlet (via an approved distribution block). Note that this is not essential in the UK because in a ring circuit all outlets have the zero crossing simultaneously. The processor uses the zero-crossing information and the commands received via the inputs to arrange the brightness of the individual projector lamps, and the changing between projectors. It can do so via the 'projector control' blocks shown in Fig. 2.

In principle, the functions described so far would suffice for the target system, because they allow us to do all we want: control lamp brightness, and change slides on any of the connected projectors. The processor, however, also allows us to control a display that indicates the slide positions in the carriers, the lamp brightness, and the 'slide change' function. These functions are controlled via the count display block and the lamp indicator block, respectively.

About the projectors

Before discussing the electrical schematic, we have a look inside a typical slide projector. The crucial part is shown in Fig. 3. Broadly speaking, projectors can be divided into two classes: types with one-button control, and types with two-button

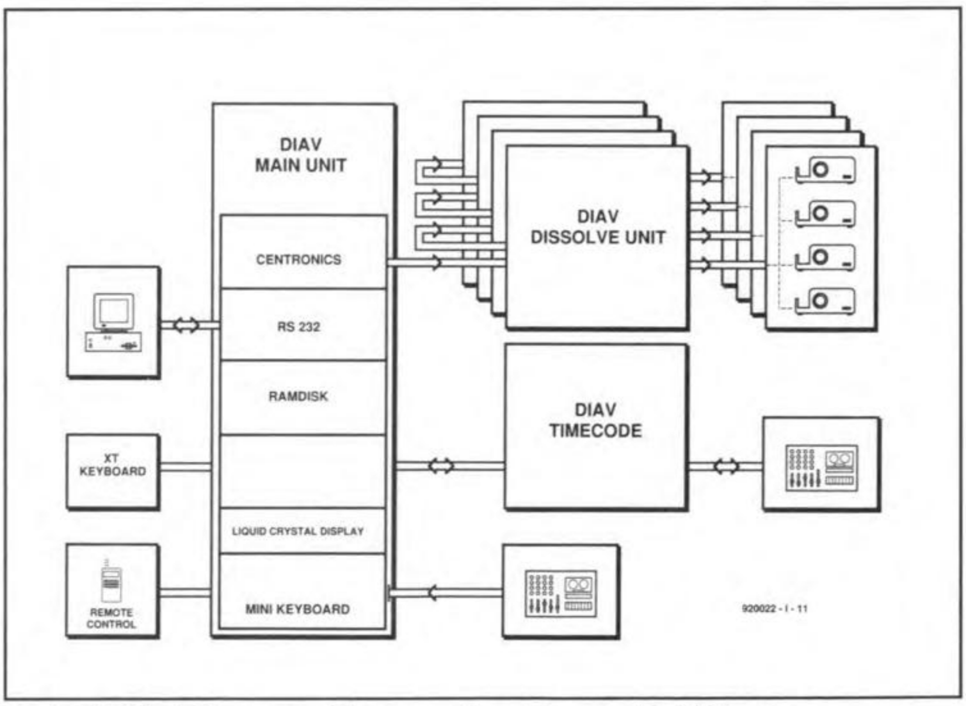


Fig. 1. This block diagram provides an overview of the complete DiAV system.

control. With one-button projectors, the forward of reverse direction of the slide carrier is determined by the time the button is pressed. By contrast, the two-button type has one button for each direction. The buttons cause electromagnets (solenoids) to be energized that, in turn, cause the slide carrier to move forward or reverse (or turn accordingly in the case of a carousel carrier). The electromagnets are powered by a direct voltage which is derived from the secondary of the mains transformer fitted in the projector.

The electromagnets are usually shunted by back-e.m.f. suppressor diodes. In some older projectors, these diodes are not present, and must be retro-fitted to enable the proposed projector control to function properly.

Figure 3 also shows the triac as it is wired in projectors with a straight slide carrier. By contrast, the triac is connected externally to most professional 'carousel carrier' projectors we have seen so far.

Dissolve unit electronics

The central parts in the circuit diagram of the dissolve unit (Fig. 4) are a microcontroller (IC3), an address latch (IC4) and an EPROM (IC5) that contains the necessary software. The microcontroller is a 16-MHz 80C32. Apart from the EPROM, the controller addresses a number of buffers with specific functions: IC7 to read the Centronics input; IC8 to set the slide carrier control; and IC9-IC10 to control the display functions. All these ICs are addressed via IC15a.

The Centronics input is formed by connector K1, which is 'looped through' to the Centronics output, K2, via IC12 and IC6. This means that all series-connected units receive the same data. Each new databyte is latched in IC6 at the end of the strobe pulse, whereupon it can be read via IC7. At the same time, bistable IC13a is set, which produces a high signal on the BUSY line of K1. IC12d passes the busy signal(s) from any further unit(s). This enables all units to evaluate the received data. The Q\ output of IC13a (pin 6) triggers the INT1 interrupt input of the processor, so that the received data can be processed immediately. Switches 1 and 2 of S1 determine which bank of four projectors is controlled (see Table 1).

As already mentioned, the I²C interface is not supported by the current software version. It is, however, used for a simple manual control that allows two, three or four projectors to be controlled, with a variable overflow time between 0 s and 10 s, in steps of 1 s (see also Table 1).

Power supply

The circuit is powered from an alternating voltage source to enable the zero-crossings of the mains voltage to be detected (this is necessary for the lamp dimmers). Figure 5 shows the timing relevant to the triac gate triggering. The signal numbers refer to the test points in the circuit diagram of the dissolve unit, Fig. 4.

The alternating voltage applied to J1 is rectified by D5-D8. The smoothing, however, does not take place until 'behind' D9. The anode of D9 carries signal '1', which enables components R26, R28, D34, T13 and IC12a to detect the zero-crossings (signal '2'). When the voltage drops below the threshold voltage of D34 plus the voltage across the base-emitter diode of T13, this transistor will stop conducting, so that the collector voltage swings high. This high level is fed to the processor via buffer

Fig. 3. Block diagram of the dissolve unit.

IC12a. To enable a minimum brightness level to be set, this signal is also applied to IC11b, a monostable multivibrator (MMV). The negative (falling) edge at pin 9 triggers the MMV, which responds by generating a pulse that starts at the end of the zero-crossing, and lasts until just before the next zero-crossing. A preset, P1, determines how far the end of the pulse is removed from the new zero-crossing. The processor will fire the triac from the end of the pulse to the next zero-crossing, which sets up a minimum brightness level (signal 4a). This setting ensures that the lamp filament can never go 'cold' between two successive overflow actions. This enables the lamp to light up quickly from 'off' to the desired brightness. Signals 4b and 4c in Fig. 5 show the gate control with a partly dimmed lamp, and one that lights at full intensity, respectively.

Next, let us have a look at the four identical projector control circuits. The functions of the previously mentioned push-buttons on the projector controls are taken over by combinations of an optocoupler and a transistor. The operation of this interface can be explained by reverting for a moment to the internal diagram of the projector. The common connection of the forward/reverse buttons is connected to the highest direct voltage in the projector. When, for instance, R1 is connected to ground, optocoupler IC1a sends base current into T1, and so causes the relevant electromagnet in the projector to be energized. The need for a suppressor diode across the electromagnet coil is evident: without it, the back-e.m.f. produced when a coil is switched off would very likely destroy the relevant driver transistor.

If jumper JP1 is closed (fitted) at power-on, the interface will control the projectors as if they were 'one-button' types, and control the relevant transistor connected to pin 2 of K9-K12 such that the slide carrier moves in the desired direction. This setting may be changed, via the control, while the unit is in use.

The second function to be controlled in each projector is the lamp intensity, or, in other words, the triac. This is achieved with the aid of T3 (T6, T9 and T12 have identical functions). When the circuit is connected to the projectors, the anode terminal, A1, of the triac is connected to ground, while resistor R5 is connected to the gate terminal. By making T3 conduct, a gate current is established for the triac, which fires. When the gate current is interrupted, the triac stops conducting. In this way, the lamp brightness is controlled by means of the phase angle, as already illustrated in Fig. 5. The gate driver transistors are controlled directly by the microprocessor. This is achieved by resetting an internal counter at the end of every zero-crossing, and then enabling the counter again. Next, the contents are compared with a predetermined value, which depends on the desired brightness. When the counter state exceeds the preset value, a pulse train is sent to the triac gate. This train lasts until the next zero-crossing occurs. A simple filter, R3-C1, is fitted to prevent excessive 'pollution' of the dissolve unit power supply voltage. The projector connections of all four projectors are gathered on K7, from where a length of flatcable takes them to K13. This connector, in turn, is wired to DIN connectors for the four individual projectors.

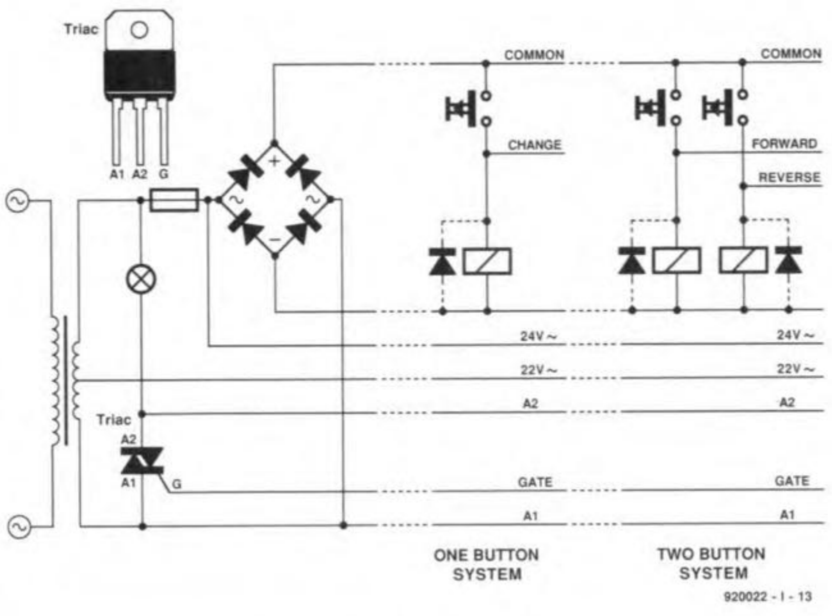


Fig. 3. Typical lamp/solenoid circuit in one-button and two-button slide projectors. Mind you: the triac is not fitted in all projectors!

S1-1	S1-2	S1-3	S1-4	Function
on	on	X	X	Bank 1: projector 1-4
off	on	X	X	Bank 2: projector 5-8
off	off	X	X	Bank 3: projector 9-12
on	off	X	X	Bank 4: projector 13-16
X	X	on	on	2 projectors in manual mode
X	X	off	on	2 projectors in manual mode
X	X	on	off	3 projectors in manual mode
X	X	off	off	4 projectors in manual mode

Table 1. Switches S1-1 and S1-2 set the dissolve unit bank selection, while switches S1-3 and S1-4 set the number of projectors when manual control is used.

The display

The display consists of two parts: a counter display (eight 7-segment displays) and the lamp display (24 LEDs). Both displays are multiplexed in a simple way by software that varies the data applied to IC9 and IC10. In both cases, the addressed display section is determined by a part of the latched dataword (the two highest bits on IC9, and bits D4, D5 and D6 on IC10). A decoder IC is used to produce numbers on the display. The decoder converts a 4-bit number into a 7-segment code. The remaining bit, D7, is used to drive the decimal point.

LEDs D15, D21, D27 and D33 indicate the slide changing operations, while the remaining LEDs indicate the set lamp brightness.

A switch, S3, on the main board allows the display to be switched to a lower intensity in case the light it emits is distracting (in the dark, during a slide show).

The control protocol

Those of you who wish to build the complete DiAV system can make use of the extensive control software developed for it. Alternatively, you may wish to have a go at producing your own control software, for which it is, of course, necessary to know the programming details of the

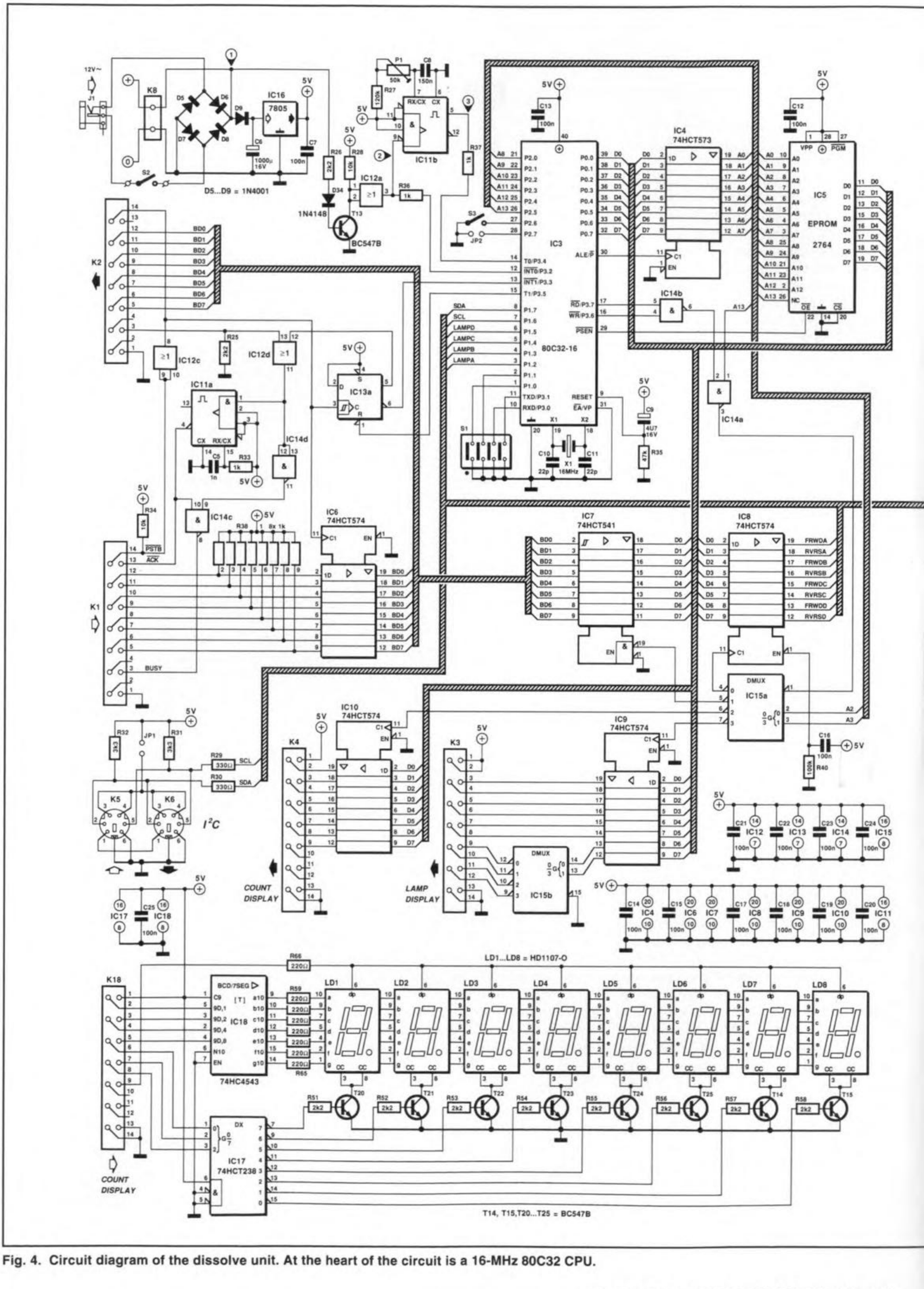
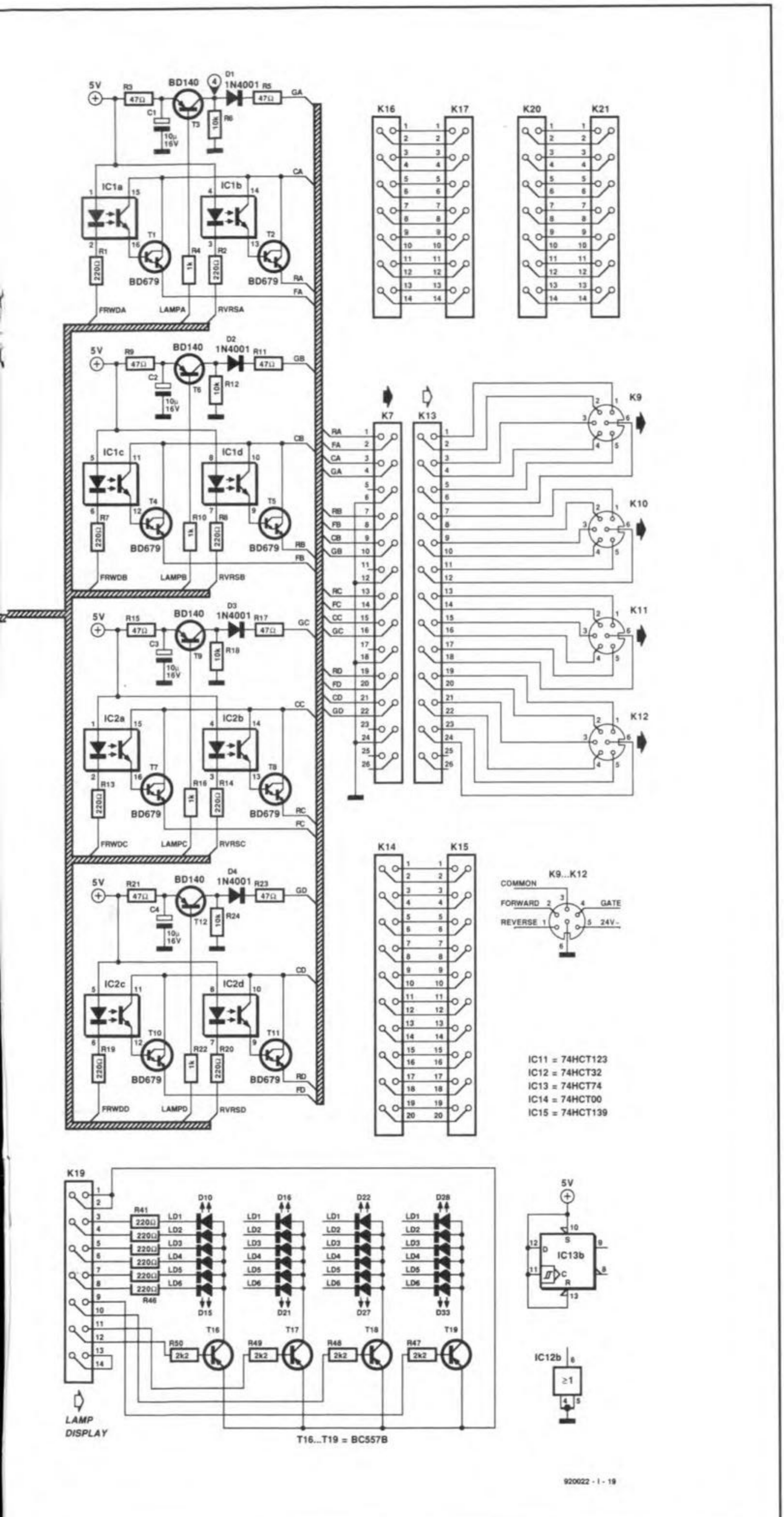


Fig. 4. Circuit diagram of the dissolve unit. At the heart of the circuit is a 16-MHz 80C32 CPU.



Centronics interface or the manual control.

As already mentioned, the present dissolve unit uses the same protocol as the Centronics interface described in Ref. 2. A control cycle consists, in principle, of two databytes sent one after another: the projector control byte and the databyte proper. The first selects the desired projectors and the associated bank of four projectors, while the databyte determines the way the selected projectors are controlled. The functions of the bits in the projector control byte and the projector databyte are given in Tables 2 and 3.

A projector control byte always has two 'ones' in the two highest bit positions. In the databyte, these positions form separate indicators for the carrier forward/reverse control. The remaining six bits in the databyte determine the lamp brightness in the selected projector. The bank selection bits in the projector control byte must match the settings of switches S1 and S2 for the selected unit to be addressed. In principle, it is possible to select all four projectors in a control byte, after which only one databyte is required to issue the same command to all four projectors. This can be done without problems when the 'old' Centronics interface is used. The present interface, however, responds differently: on receiving a 4-projector selection word (control byte 1100 00xx), it switches the dissolve unit to its set-up (initialization) mode. If the command is followed by a databyte '0', the four projectors will not only have their lamps dimmed completely, but the display is reset also. Next, a number of settings can be selected. The set-up mode is left on receipt of a carriage return (0DH) or a line feed (0AH) command. Table 4 shows an overview of the set-up options.

D7	1	control word ID
D6	1	
D5	P4	0 selects projector 4
D4	P3	0 selects projector 3
D3	P2	0 selects projector 2
D2	P1	0 selects projector 1
D1	X	bank selection
D0	X	

Table 2. Bit functions in the projector control byte.

D7	1 = change forward
D6	1 = change reverse
D0-D5	lamp intensity

Table 3. Bit functions in the projector databyte.

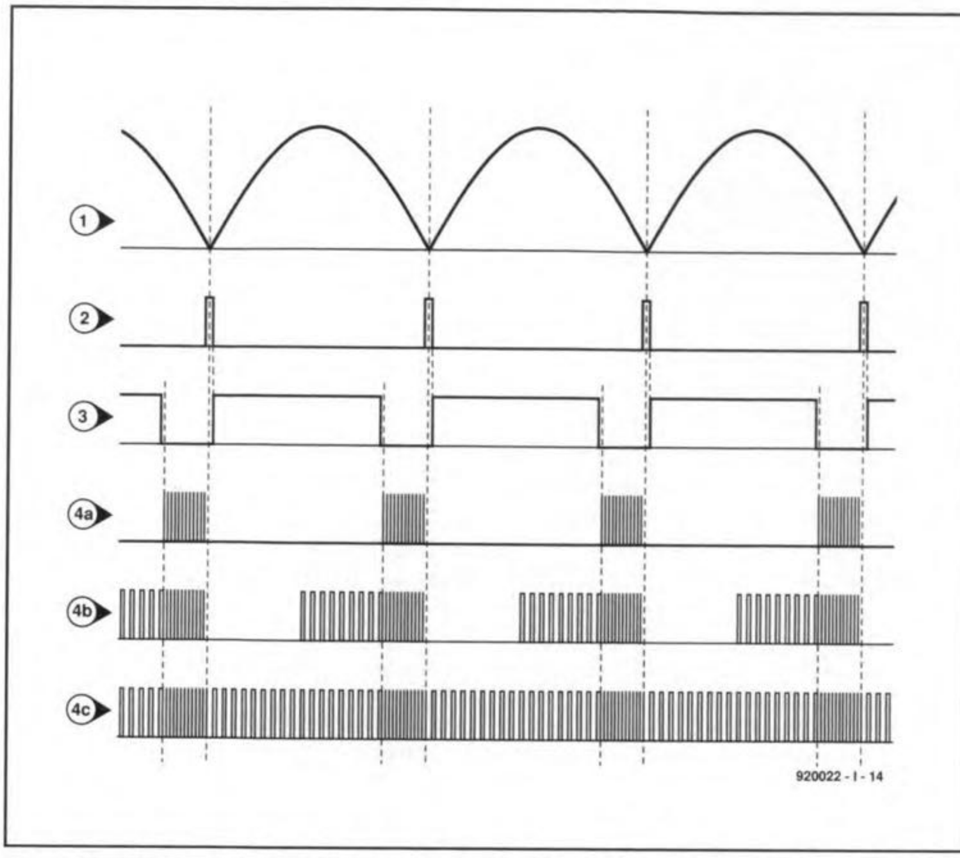


Fig. 5. Timing diagrams to illustrate the relation between the zero-crossings and the gate control signal.

The listing in Fig. 6 is an example of a simple BASIC program containing LPRINT statements to control the dissolve unit. Note the use of the semicolon (;) after each control byte. If you forget this character, the CR/LF sequence that follows it is taken to be a databyte. The semicolon is not required after databytes, because the projector selection is reset after each databyte. Just for the sake of completeness, Fig. 7 shows the wiring of the Centronics cable between the PC and the dissolve unit.

The manual control is connected to one of the I²C inputs as shown in Fig. 14. Switches S4 and S5 select between forward or reverse overflow respectively, or, after pressing S6, between lengthening or shortening the overflow time.

Connecting the projectors

It was already mentioned that some projectors have an internal triac to control the lamp brightness, while others require the triac to be connected as an external part. Those of you who feel less confident about modifying the electrics of the slide projector are best off with an 'internal triac' type of projector. In case such a projector is not available, there is no other option than to

```
10 ' Automatic dissolve program for DiAV SLIDE CONTROLLER
20 ' A$ can be equal to '123456789ABCDEFG'
30 ' or part of it, each defining one projector
40 CLS : LOCATE 5,10
50 A$="1234": PRINT "The projectors selected are ";A$
60 LOCATE 8,10: PRINT "[ SPACE ] for next projector"
70 LOCATE 9,10: PRINT "[ ENTER ] or [ R ] for previous projector"
80 LOCATE 11,10: PRINT "[ F ] for fast dissolve"
90 LOCATE 12,8 : PRINT "* [ N ] for normal dissolve"
100 LOCATE 13,10: PRINT "[ L ] for long dissolve"
110 LOCATE 15,10: PRINT "[ Q ] to exit"
120 B$=""
130 IF LEN(A$)>16 OR LEN(A$)=0 THEN GOTO 1040
140 '.................. calculate the projector addresses
150 FOR I=1 TO LEN(A$)
160     B=ASC(MID$(A$,I,1))-1
170     IF B<48 OR B>102 THEN 1040
180     IF B<58 THEN B=B-48: GOTO 230
190     IF B<65 THEN 1040
200     IF B<71 THEN B=B-55: GOTO 230
210     IF B<97 THEN 1040
220     B=B-87
230   B=252-2^(B MOD 4)*4+B\4 +(B\4=3)-(B\4=2)
240   B$=B$+CHR$(B)
250 NEXT
260 '........................ Initialize constants
270 PROJECTOR = 2 '.......... Select double button
280 S3 = 3  ' ............... S3 swithes high/low
290 DISPLAY = 6 ' ........... Display high intensity
300 BAR = 8 '................ Lamp display as centered bar
310 '........................ The next constants have to
320 '........................ be adjusted according to your
330 '........................ system speed
340 F=160:  '................ Forward changing time
350 R=320: '................. Reverse changing time
360 T=400: '................. Total changing time
370 W=100: '................. Wait after dissolve before changing
380 S=1000: '................ Basic dissolve speed
390 '........................ All projectors off
400 '........................ and reset of display
410 '........................ and setup
420 LPRINT CHR$(192);CHR$(193);CHR$(194);CHR$(195);CHR$(0);
430 LPRINT CHR$(PROJECTOR);CHR$(S3);CHR$(DISPLAY);CHR$(BAR)
440  '....................... Main loop
450 X=0: Y=0: L=LEN(A$)-1: D=2*S :FIRST=1
460 C$=" rRfFnNlLQq"+CHR$(13)
470 I$=INKEY$ : IF I$="" THEN 470
480 CHAR=0
490 FOR I=1 TO LEN(C$)
500   IF I$=MID$(C$,I,1) THEN CHAR=1
510 NEXT
520 IF CHAR <>1 THEN 470
530 IF I$=" " THEN GOSUB 630
540   IF I$=CHR$(13) OR I$="r" OR I$="R" THEN GOSUB 730: GOTO 470
550   LOCATE 11,8 : PRINT " "
560   IF I$="f" OR I$="F" THEN D=S :LOCATE 11,8: PRINT "*"
570   LOCATE 12,8 : PRINT " "
580   IF I$="n" OR I$="N" THEN D=2*S :LOCATE 12,8: PRINT "*"
590   LOCATE 13,8 :PRINT " "
600   IF I$="l" OR I$="L" THEN D=3*S :LOCATE 13,8:PRINT "*"
610   IF I$="q" OR I$="Q" THEN CLS : END
620 GOTO 470
630 '........................ Next projector
640 FIRST =0
650 Y=X
660 X=ASC(LEFT$(B$,1))
670 A$=RIGHT$(A$,L)+LEFT$(A$,1)
680 B$=RIGHT$(B$,L)+LEFT$(B$,1)
690 GOSUB 840
700 LOCATE 17,10: PRINT "Projector ";RIGHT$(A$,1);" is on"
710 DA=128: C=F: GOSUB 910
720 RETURN
730 '........................ Previous projector
740 IF FIRST =1 THEN 830
750 Y=ASC(MID$(B$,L,1))
760 DA=64: C=R: GOSUB 910
770 Y=X
780 A$=RIGHT$(A$,1)+LEFT$(A$,L)
790 B$=RIGHT$(B$,1)+LEFT$(B$,L)
800 X=ASC(RIGHT$(B$,1))
810 GOSUB 840
820 LOCATE 17,10: PRINT "Projector ";RIGHT$(A$,1);" is on"
830 RETURN
840 '........................ Dissolve
850 FOR I=0 TO 63
860 LPRINT CHR$(X); CHR$(I-1*(I=9))
870 LPRINT CHR$(Y); CHR$(63-I+(63-I=9))
880 FOR J=0 TO D: NEXT
890 NEXT
900 RETURN
910 '.......................... Change slide
920 FOR I=0 TO 100  ' ..... wait before change
930 FOR J=0 TO W : NEXT
940 NEXT
950 LPRINT CHR$(Y);CHR$(DA)
960 FOR I=0 TO 100
970 FOR J=0 TO C: NEXT: '....... changing time
980 NEXT
990 LPRINT CHR$(Y);CHR$(0)
1000 FOR I=0 TO 100
1010 FOR J=0 TO T-C : NEXT
1020 NEXT: '.. Wait before next dissolve is allowed
1030 RETURN
1040 CLS: LOCATE 9,10: PRINT "Error in line 50 adjust A$"
1050 END
```

Fig. 6. A simple BASIC program to get you started with the dissolve unit. The projectors used (here: 1 to 4) are identified in line 50.

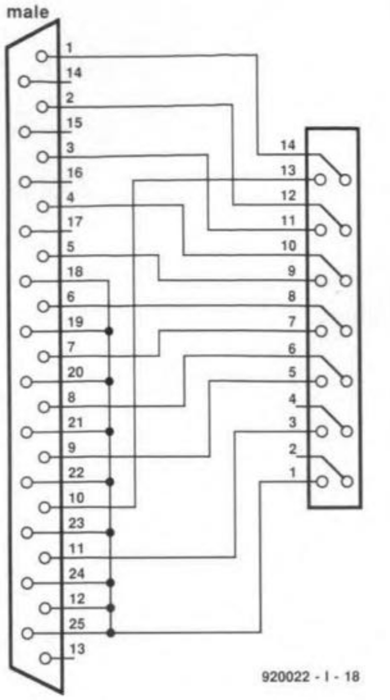


Fig. 7. Overview of connections between the PC's Centronics output and the dissolve unit.

00h	reset display and gate triggering
01h	single button projectors: change on pin 2 of K9-K11
02h	double button projectors: forward change on pin 2 of K9-K11 reverse change on pin 1 of K9-K11
03h	S3 switches display on/off
04h	S3 switches between high and low intensity
05h	set display high intensity
06h	set display low intensity
07h	lamp indicator as linear bar
08h	lamp indicator as centred bar
09h	—
0Ah	setup end
0Dh	setup end

Table 4. These setup comands can be issued to the dissolve unit after sending a setup control byte (1100 00xx).

install the triac yourself as an upgrade to the projector. Here, we show you how to do this — it is not very difficult.

Unfortunately, there is a hardware compatibility problem to begin with: manufacturers of slide projectors use different connectors for the triac control input. Figure 8 shows the three most commonly found connector types. Still other connectors and pin assignments exist, so you are well advised to consult the user manual that came with the projector. The 6-way DIN connector (Fig. 8a) is used for our system. On the projector, the overflow or AV socket is usually marked by two small triangles (see Fig. 9). Figure 10 shows the construction of the connecting cable for the 6-way DIN and the 10-way DIN versions.

Projectors with an RTG22 connector require a separate triac module to be made.

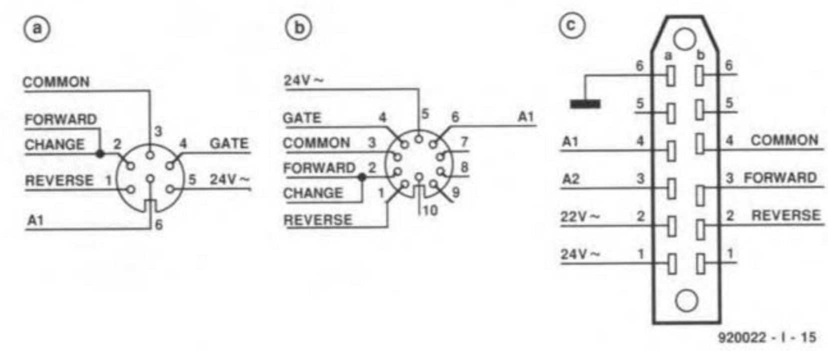


Fig. 8. Overview of the most commonly used slide projector connection systems. Figure 8a shows the 6-way version which is also used for the DiAV. In addition to this connection, you may also come across 10-way DIN (8b) and 12-way RTG22 (8c) versions (the latter nearly always on carousel type projectors).

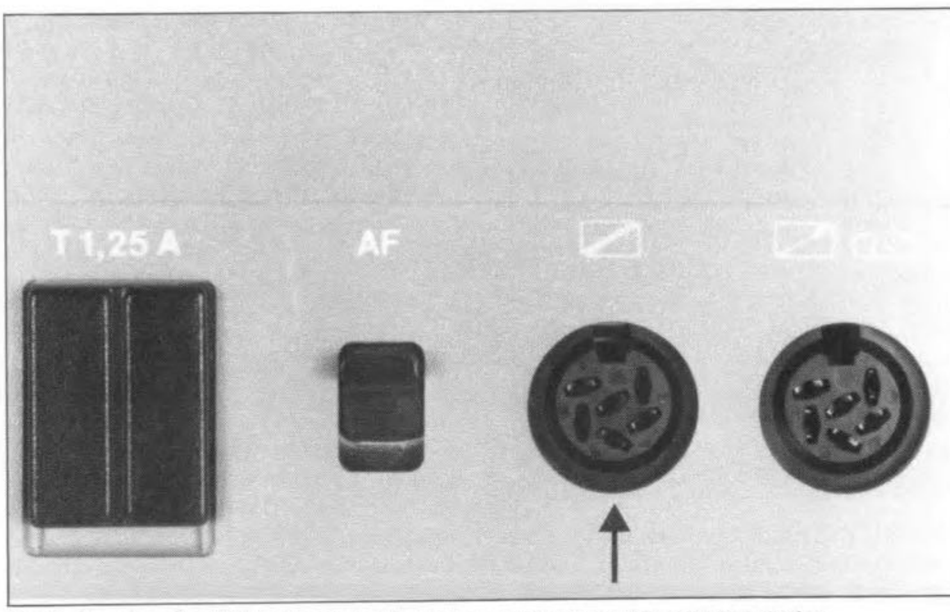


Fig. 9. Showing the AV (audio-visual) legend on projectors with an internal triac.

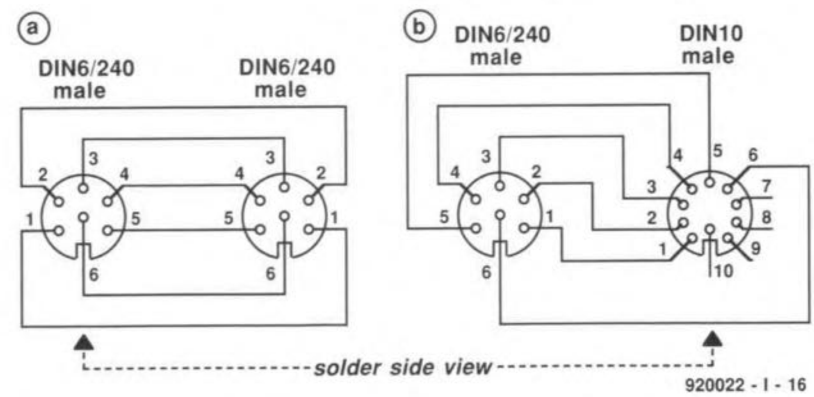


Fig. 10. Construction of the connecting cables.

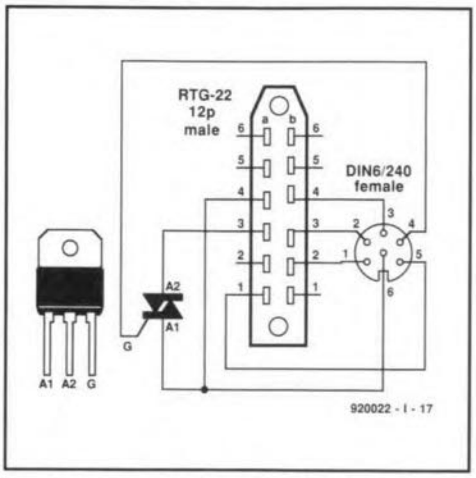


Fig. 11. Those of you who wish to make use of a carousel slide projector will have to connect the triac as an external module. The necessary parts and connections are shown here.

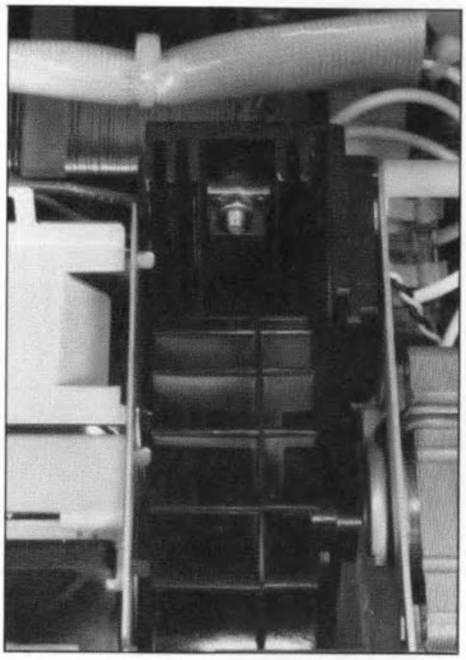


Fig. 12. Illustrating the internal triac upgrade. The triac is fitted as close as possible to the fan to ensure it is adequately cooled.

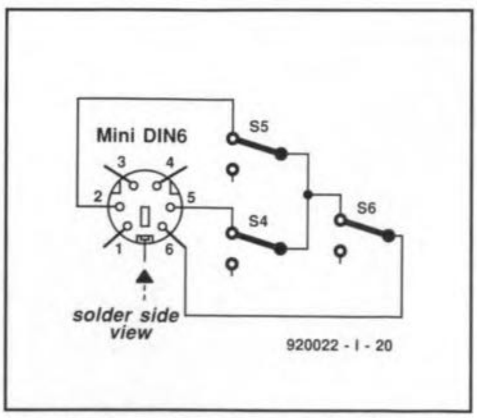


Fig. 13. Construct this simple connecting cable if you wish to use the dissolve unit as an independent control for your slide projector. This is achieved by making use of the I2C interface on the unit.

Fig. 14. This photograph illustrates how the triac module is constructed. Do not forget to fit the triac with a thermal insulation set.

This module is connected via a 6-to-6-way cable as illustrated in Fig. 11. The module is a small diecast aluminium case drilled to accept the connectors, the triac and a heat-sink. Its construction is illustrated in Fig. 14. In view of the high currents (up to 10 A), the A1 and A2 terminals of the triac should be connected with short lengths of fairly thick wires (1.5 mm² or SWG17). Bend the anode terminals around the wire ends before soldering, so that the junction can never come loose even when very high temperatures are reached.

So far, we have assumed that the triac is contained in the projector. However, this is not usually the case with inexpensive projectors, which must be upgraded. If you do so, stick to one of the connection diagrams shown in Fig. 8, preferably 8a or 8b. The reason is obvious: compatibility! Mount the triac on a small heat-sink, close by the fan (see Fig. 12). Do not forget to use an insulating washer and mounting bush. For 150-W projectors, use a TIC236 triac, or a TIC263 for 250-W types. The triac may be tested by connecting its gate terminal to the 24-V a.c. source via a 1-kΩ resistor, whereupon the lamp should light.

To be continued...

This is the first of four instalments. The next instalment will discuss the construction and testing of the dissolve unit. Also, details will be given on the use of the multi-purpose Z80 card as the main unit in the DiAV system. For this purpose, some components on the Z80 card need to be changed with respect to the original design.

Although the DiAV is a modular system, some of you may want to built it as a self-contained, compact unit. Part 3 of this article series will, therefore, show how the timecode interface, the main unit and one dissolve unit may be fitted into a single enclosure.

The last part of the article will describe the software and the user options created in the system. ❑

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2. 'Centronics interface for slide fader'. *Elektor Electronics* December 1988.
3. 'Multi-purpose Z80 card'. *Elektor Electronics* May and June 1992.
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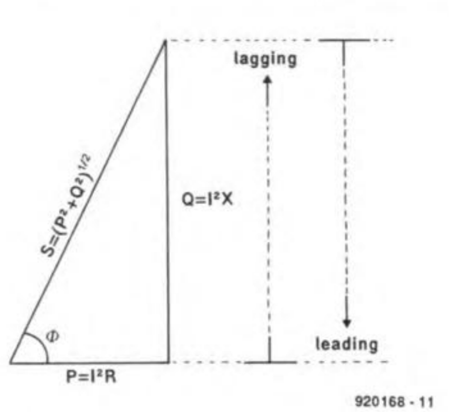
SCIENCE & TECHNOLOGY

UNDERSTANDING POWER FACTOR COMPENSATION

By Dr K. A. Nigim

The high consumption of electrical energy, prompting fears of exhausting traditional fuels used by power generating plants, has paved the way for new strategies in improving the quality and efficiency of existing generating stations. One of the successfully adopted strategies is power factor compensation.

1



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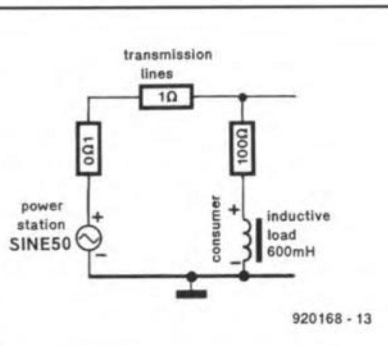

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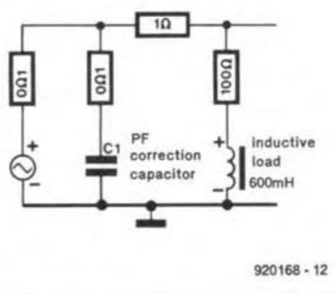
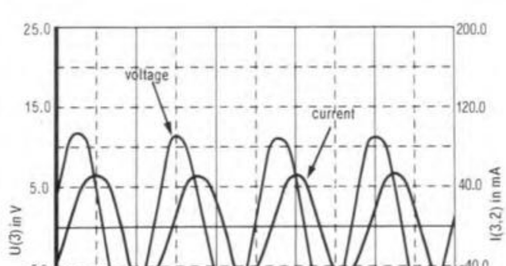
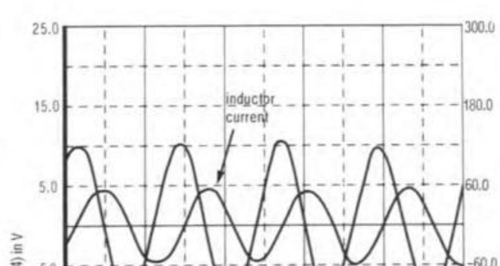


4a



4b



What does power factor mean?

Consider the case of two houses located in Energy Lane. Each of them consumes 1000 W of useful power from the mains supply.

The first house, owned by Mr and Mrs W, consumes 4.17 A at 240 V. The useful or active power, *P*, delivered to their total load is

P = voltage × current × power factor,

where the power factor is cosine ϕ, in which ϕ is the angle between the voltage and current waveforms across the load—see Fig. 1. Clearly, the W family is consuming power at unity power factor (ϕ=0). Electrically speaking, their home is nonreactive. Electrical engineers give the term nonreactive to a load in which the phase difference between the voltage and current is 0. If an angle ϕ exists between these quantities in either a positive or negative direction, the load is termed capacitive (leading power factor) or inductive (lagging power factor) respectively.

The second house, owned by Mr and Mrs VAR, consumes 8.33 A at 240 V, giving a power factor of 0.5 (ϕ=45°). Electrically speaking, their house is of a reactive nature.

This comparison between the two houses shows that a low power factor means that there is a higher current flowing into the VAR house, which causes an increase in copper losses and a greater likelihood of blown fuses (overload).

Generating companies are committed to supplying both reactive and nonreactive loads. They are, therefore, faced with the following practical problems caused by the low power factor in the VAR's load.

- Reduced plant capacity and efficiency owing to overloaded cables and transformers.
- Increased transmission cable losses.
- A lower voltage level owing to the high losses; this in turn affects almost all types of load, particularly electric motors (lower efficiency).

If the generating companies function with low power factors, the plant generators and distribution lines are overloaded unnecessarily by all families VAR, and this causes high fuel consumption and requires larger generators, transformers, switch gear and heavier transmission lines.

Supply authorities do all they can to improve the power factor of their loads, either by the installation of capacitors or special machines, or by the use of tariffs that encourage consumers to do so.

What causes a low power factor?

Inductive loads, such as motors, transformers, induction furnaces, motor speed controllers, welding equipment and fluorescent lights require for their operation two kinds of current.

- A magnetizing current to establish the necessary magnetic medium (flux). Without the flux, electric energy cannot be transferred through the core of transformers or across the air gap of motors. Industrial motors and transformers draw the magnetic energy from the power lines, thereby causing a delay between current and voltage owing to their inductive nature. The power delivered to the load is known as *reactive power*, *Q*, which is expressed in Volt-Ampere reactive (VAr).
- A power producing current, known as active, working or usable, which is converted into useful work. It causes a fan to rotate in motors, heaters to produce heat and pumps to pump liquid or gas. Here, there is no delay between current and voltage. The power delivered to the load is known as *active power*, *P*, which is expressed in watt (W).

The power in an a.c. circuit is termed the apparent power, *S*, which is expressed in volt-ampere (VA). It is equal to the root of the sum of the squares of the reactive power and the active power:

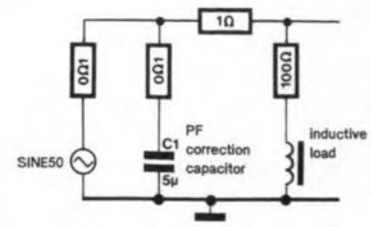
$S=(P^2+Q^2)^{1/2}$ (see Fig. 1).

The apparent power is a practical measure of the capacity of a.c. equipment. For instance, the size of a transformer required to supply a given industrial load is determined by its VA (or kVA) rating.

The ratio of the active to the apparent power is the *power factor* (PF) of the load, that is:

$PF=P/S$.

Since, as stated before, PF=cosϕ, the power factor can be expressed either by the ratio of active and apparent power or by the cosine of the angle between voltage and current.



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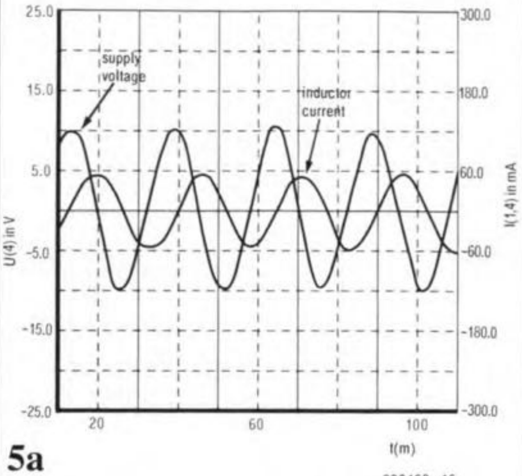

5a

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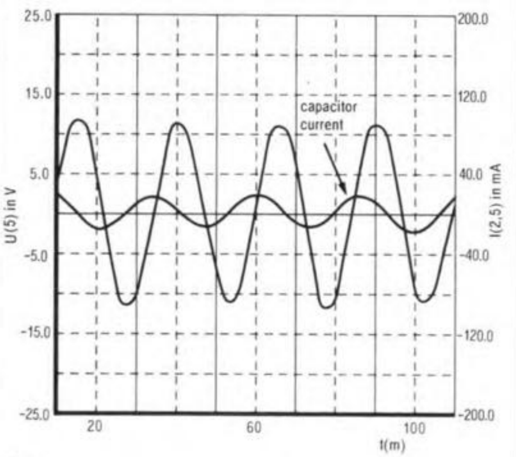

5b

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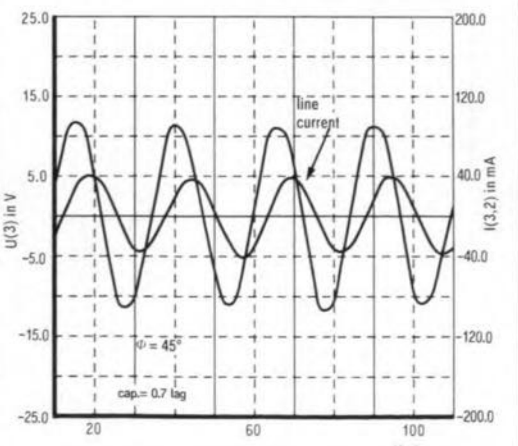

5c

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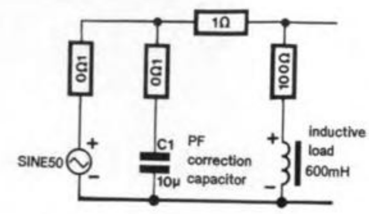

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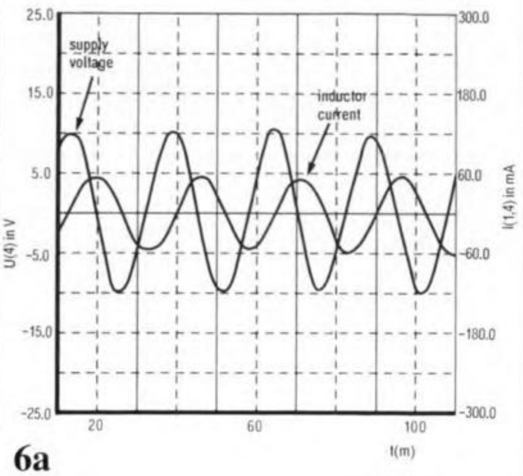

6a

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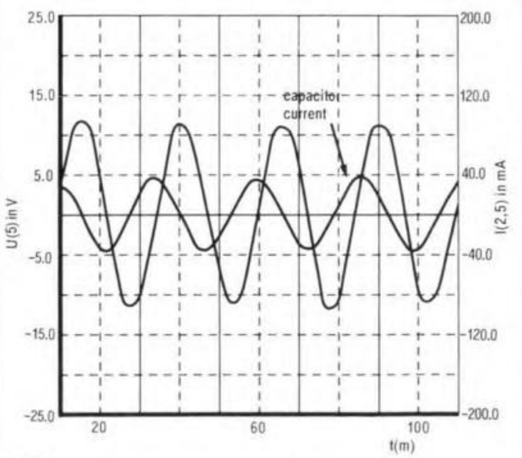

6b

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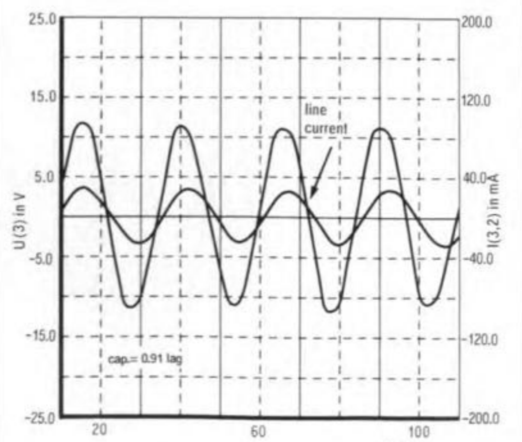

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6c

How to compensate a low power factor

From what has been said so far, it would seem that a certain value of capacitive load connected across an inductive load would return the overall power factor to unity (or at least nearly so). And, indeed, this can be proved to be so with the aid of Computer Aided Engineering (CAE) software or by a more traditional method.

CAE method. The mains voltage is represented by an a.c. source of fixed voltage level and frequency and the transmission lines by a resistance in series—see Fig. 2. Across this is the inductive consumer load, R+j2X_l. The voltage and current waveforms computed with the aid of Micro Cap III software are shown in Fig. 4. Figure 4a shows the voltage and current drawn from the mains. The overall power has a value of 0.47, which is below the regulations of most supply authorities.

The power factor can be improved by connecting a suitable capacitor across the load as shown in Fig. 3. The correction capacitor is given a value of 5 µF as in Fig. 5 and of 10 µF as in Fig. 6. The resulting waveforms are plotted in Fig. 5a, b, c and in Fig. 6a, b, c. It is clear from Figs 5c and 6c that the power factor has increased considerably compared with that in Fig. 4a.

This time-saving method of analysis provides enough information to prove the point. However, not everyone is fortunate enough to have a CAE package at his/her disposal and in that case a traditional method with the use of a hand-held calculator must be employed.

Traditional method. Again with reference to Fig. 2, the complex current, I_l, flowing through the load is given by

$$I_l=U\angle 0°/(R+jX_l)$$

$$=240\angle 0°/213.8\angle 62°=$$

$$=1.12\angle -62° \text{ A}.$$

This gives an active power of

$$P=I^2R=125.4 \text{ W},$$

a reactive power of

$$Q=(I^2X_l)=-236.5 \text{ VAr},$$

and an apparent power of

$$S=(P^2+Q^2)^{1/2}=267.6 \text{ VA}.$$

From this, the power factor is

$$\text{PF}=P/S=\cos\phi=0.468,$$

so that ϕ=62° lag.

When a 10 µF capacitor is connected across the load as in Fig. 6, the following results will ensue.

Current, I_i, in the inductive element is

$$I_i=U\angle 0°/(R+jX_i)$$

$$=240\angle 0°/213.8\angle 62°$$

$$=1.12\angle -62° \text{ A}.$$

Current, I_c, in the capacitive element is

$$I_c=U\angle 0°/(r-jX_c)$$

$$=240\angle 0°/318.3\angle -89.9°$$

$$=0.754\angle 89.8° \text{ A}.$$

Active power is

$$P=(I_i^2R+I_c^2)=126 \text{ W}.$$

Reactive power in theinductive element is

$$Q_i=I^2X_i=-236.5 \text{ VAr}.$$

Reactive power in the capacitive element is

$$Q_c=I^2X_c=+181 \text{ VAr}.$$

Total reactive power is

$$Q=-55.5 \text{ VAr}.$$

Apparent power is

$$S=(P^2+Q^2)^{1/2}=138 \text{ VA}.$$

Overall power factor, cosϕ, is

$$\text{PF}=P/S=0.913,$$

from which ϕ=24°.

It is evident that connecting a capacitance across the load improves the power factor.

State of the art

Connecting a capacitance across an inductive load is not the best practical remedy for a low power factor, since variations of the load will necessitate different values of capacitance to counter consequent changes in the power factor. In such cases, a combination of binary switched capacitors could be considered.

Where large reactive powers are consumed a so-called synchronous condenser provides a more practical approach.Such a condenser is a 3-phase a.c. synchronous motor whose magnetic energy is controlled so as to provide a variable source of leading or lagging power factors.

With the advance of power electronic devices in combination with microprocessor-based software and hardware, static VAr compensators (SVC) have been developed that nowadays replace capacitors or synchronous condensers in medium to large networks.

Static VAr compensators

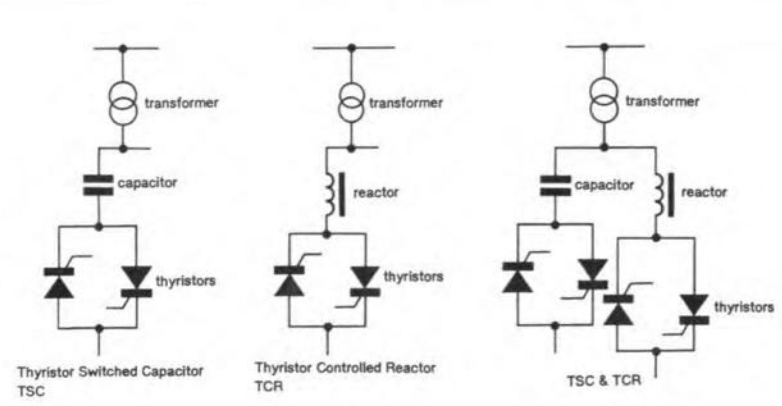
Reactive power absorption for consumers with lagging power factors, or reactive power generation for consumers with leading power factors, can be provided by means of power electronic devices in combination with inductors or capacitors. Such power electronic devices, thyristors, triacs and MOSFETs, are used to control the instant at which current begins to flow in the circuit.

There are various arrangements of thyristor-controlled elements in practical use:

- thyristor switched capacitor, TSC;
- thyristor-controlled reactor, TCR;
- combination of TSC and TCR.

The TSC may be considered as a variable capacitive reactance (Fig. 7a), and the TCR as a variable inductive reactance (Fig. 7b). A combination of the two is shown in Fig. 7c.

The advantages of employing these compensators for improving the power factor are enormous. The reactive power is continuously variable from a full leading to a full lagging power factor. There are no moving parts that will wear out or contacts that will erode. The cost of installation is roughly half that of a synchronous condenser, coupled with low losses and small maintenance requirements. A drawback is, however, the generation of high harmonic levels on the network lines. ■



7

8051/8032 ASSEMBLER COURSE

PART 8 (FINAL): LCD AND KEYBOARD INTERFACING

By Dr. M. Ohsmann

In this last instalment of the course we first deal with an ever popular subject: how to connect a liquid crystal display (LCD) to the 80C32 single-board computer. LCD modules with one or two text lines are available at relatively low cost these days, and are simple to drive from the 80C32 SBC, as will be shown below.

LC displays

Many stand-alone microcontroller applications require an output device to display texts, numbers and measurement data. An LCD module is ideal for this purpose. For instance, it allows a sequence of user entries to be given a menu-like structure which uses only a couple of keys as the hardware.

To keep the connection of an LCD as simple as possible, a special interface is provided on the 80C32 extension board.

Connections

The electrical connections between the extension board and the LCD are established by a 14-way flatcable. It is assumed here that the LCD has a Hitachi Type HD44780 controller, or a direct equivalent. Unfortunately, the pinning of the connectors on the LCDs that can be used is not standard, so you are well advised to ask for a datasheet when purchasing a display. Suitable types include the H2570 (Hitachi), LM016L and LM1612A (Sharp), and VK2116L (Vikay). The pinning of LCD connector K1 (on the 80C32 extension board) is given in Fig. 50. This information must be used to make the cable to the connector on the LCD. The LCD enable signal is generated after a read (RD=1) or write (WR=1) operation to address 0C009H or 0C001 respectively. The level of address line IOA3 then determines whether the read/write operation concerns display data (RS=IOA3=0; address 0C009H), or a display command (RS=IOA3=0; address 0C001H). The R/W\ terminal of the LC display is connected directly to the RD output of the 80C32 SBC.

Commands and data are exchanged via the bidirectional databus. The display itself can work in 4-bit mode (bits 0-3) or 8-bit mode (bits 0-7). Since we are working with an 8-bit microcontroller, and the display is wired to the databus, it is self-evident that the LCD is programmed to operate in 8-bit transfer mode. However, if you wish to interface the LCD to, say, a PORT, it may be wiser to use 4-bit transfer mode, since this reduces the number of PORT lines used.

Voltage V0 on K1 terminal 3 serves to set the LCD contrast. The setting can be adjusted depending on the ambient light intensity and the viewing angle. Before connecting the LCD, make sure that it is properly connected — when in doubt, consult the datasheets.

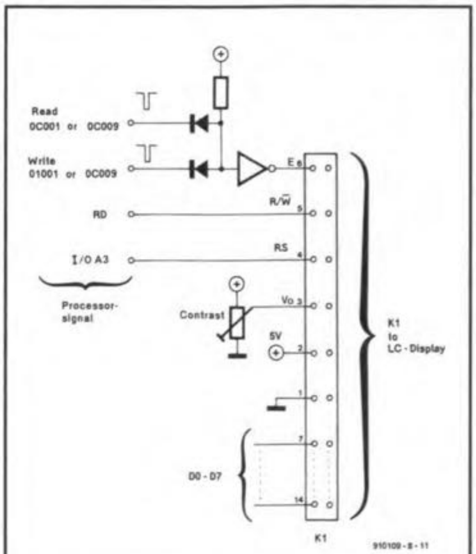


Fig. 50. Connecting the LCD to the 80C32 SBC extension card.

Instruction	Code										Description	Execution Time (when f_{cp} or f_{osc} is 250KHz)
	RS	R/W̄	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0		
Clear Display	0	0	0	0	0	0	0	0	0	1	Clears all display and returns the cursor to the home position (Address 0)	82 μs ~ 1.64ms
Return Home	0	0	0	0	0	0	0	0	1	*	Returns the cursor to the home position (Address 0). Also returns the display being shifted to the original position. DD RAM contents remain unchanged.	40 μs ~ 1.6ms
Entry Mode Set	0	0	0	0	0	0	0	1	I/D	S	Sets the cursor move direction and specifies or not to shift the display. These operations are performed during data write and read	40 μs
Display ON/OFF Control	0	0	0	0	0	0	1	D	C	B	Sets ON/OFF of all display (D), Cursor ON/OFF (C), and blink of cursor position character (B).	40 μs
Cursor or Display Shift	0	0	0	0	0	1	S/C	R/L	*	*	Moves the cursor and shifts the display without changing DD RM contents	40 μs
Function Set	0	0	0	0	1	DL	N	F	*	*	Sets interface data length (DL), number of display lines (L), and character font (F)	40 μs
Set CG RAM Address	0	0	0	1	A_{CG}						Sets the CG RAM address. CG RAM data is sent and received after this setting	40 μs
Set DD RAM Address	0	0	1	A_{DD}							Sets the DD RAM address. DD RAM data is sent and received after this setting.	40 μs
Read Busy Flag & Address	0	1	BF	AC							Reads Busy flag (BF) indicating internal operation is being performed and reads address counter contents	1 μs
Write Data to CG or DD RAM	1	0	Write Data								Writes data into DD RAM or CG RAM	40 μs
Read Data to CG or DD RAM	1	1	Read Data								Reads data from DD RAM or CG RAM	40 μs
	I/D = 1: Increment I/D = 0: Decrement S = 1: Accompanies display shift S/C = 1: Display shift S/C = 0: Cursor move R/L = 1: Shift to the right R/L = 0: Shift to the left DL = 1: 8 bits DL = 0: 4 bits N = 1: 2 lines N = 0: 1 line F = 1: 5 x 10 dots F = 0: 5 x 7 dots BF = 1: Internally operating BF = 0: Can accept instruction										DD RAM: Display data RAM CG RAM: Character generator RAM A_{CG}: CG RAM address A_{DD}: DD RAM address Corresponds to cursor address. AC: Address counter used for both of DD and CG RAM address.	Execution time changes when frequency changes (Example) When f_{cp} or f_{osc} is 270 KHz: $40\mu s \times \frac{250}{270} = 37\mu s$

*Don't care

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Fig. 51. LCD controller command set.

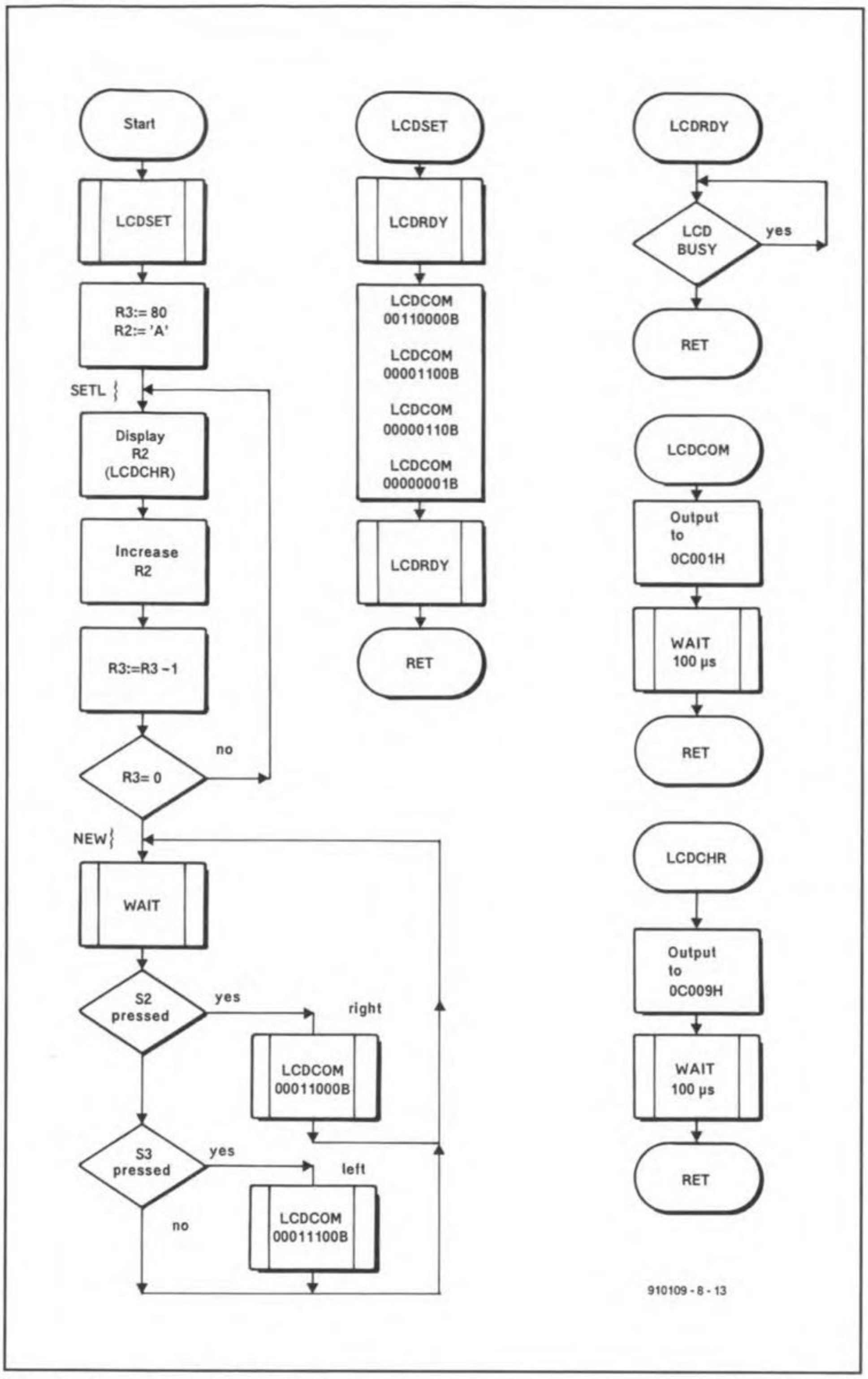


Fig. 52. Flowchart of the LCD driver program.

MCS-51 PROGRAMMING

A COURSE IN 8 INSTALMENTS

Hardware/software requirements:

- **a 8032/8052AH-BASIC single board computer as described in Elektor Electronics May 1991. The preferred CPU is a 8051 or 80C32. Alternatively, any other MCS51-based microcontroller system (but read part 1 of the course);**
- **a course diskette (IBM: order code ESS 1661; Atari: order code ESS 1681) containing programming examples, hex file conversion utilities, and an assembler;**
- **a monitor EPROM (order code ESS 6091);**
- **an IBM PC or compatible operating under MS-DOS, or an Atari ST with a monochrome display.**

Overview of publications:

Part 1: Introduction (February 1992)
Part 2: First 8051 instructions (March 1992)
Part 3: Hardware extensions for 80C32 SBC (April 1992)
Part 4: Flags, bit addressing, PSW, conditional jumps, logic operators (June 1992)
Part 5: Arithmetic instructions (July 1992)
Part 6: Analogue signal processing and stack management (September 1992)
Part 7: Serial interface programming (October 1992)
Part 8: LCD and keyboard interfacing (November 1992).

LCD commands

The Hitachi LCD controller databook devotes some 30 pages to a full description of all possibilities offered by the controller-plus-LCD combination. Hence, we are forced to limit ourselves to the most important commands, in the knowledge that more extensive information is available from the manufacturer.

Many LCDs capable of displaying the ASCII character set have the same LCD controller IC, and thus the same command set. The one listed in Fig. 51 is valid for the popular LCD modules Type H2570, LM016L and LM1612A.

To begin with, a few words about the basic operation of these displays with integrated controller. The display has an internal buffer with a capacity of 80 characters. This is the Display Data RAM, DD-RAM, at addresses 000H to 04FH. A display with one line of 16 characters displays the characters contained between 00H to 0FH, starting at the left side of the screen. In this way, a kind of window is created, which can be shifted by the Display Shift command. This works in a simple manner: while the characters remain stored at the same address in the DD-RAM, the window in the DD-RAM is given a different start address.

With a two-line display such as the LM16255, the top line displays the characters starting at 000H, and the second line displays the characters starting at 040H. This is what makes two-line LCDs a little more difficult to program than one-line types.

Then there is the cursor, which determines the position (in the DD-RAM) of the next character. This position is called the address counter in the following description. The cursor may be visible or invisible, depending on the way it is programmed. It may also flash, if desired. By appropriate programming, you can select between a display shift and a cursor movement when a character is transferred to the LCD. This enables a horizontally scrolling text to be displayed relatively easily.

Finally, the LCD has an on-board character RAM, designated CG-RAM, in which you can store the pixel outlines of ASCII codes 0 to 7. The exact organization of the CG-RAM is given in the datasheets. This RAM allows you to define your own characters.

Commands are sent to the LCD by outputting the desired code to address 0C00H (i.e., RS is low, and R/W\ also).

After this brief introduction follows a short description of the various LCD commands. The asterisk in the examples below stands for 'bit level irrelevant'.

Clear Display
0 0 0 0 0 0 0 1

This command causes all DD-RAM locations to be filled with 20H (= ASCII 'space'). The cursor is set to position 0, as is the display window, which negates the effect of any previously given Display Shift command.

Return Home
0 0 0 0 0 0 1 *

Resets the cursor to position 0, and resets any previously given Display Shift. The contents of the DD-RAM are not changed.

Entry Mode Set
0 0 0 0 0 1 I/D S

This command serves to determine what happens after a databyte has been transferred to the display. The increase/decrease (I/D) bit determines whether the internal DD-RAM is automatically increased (I/D=1) or decreased(I/D=0) when a character is read or written. The value of this address is stored in the address counter, AC.

The shift bit, S, indicates if a display shift is to occur automatically in the direction set by the I/D bit. This shift occurs when S=1, and does not occur when S=0. During the shift, the cursor retains its position inside the display window.

Display ON/OFF Control
0 0 0 0 1 D C B

This command enables us to switch the display and the cursor on and off without changing the contents of the DD-RAM. The display is switched on and off by programming D=1 and D=0 respectively. Similarly, C=1 and C=0 switch the cursor on and off, and the same goes for the 'blink' (B) bit.

Cursor or Display Shift
0 0 0 1 S/C R/L * *

This command is used to move the cursor or shift the display. It is essential if you want to program a horizontally scrolling text. The options are:

S/C	R/L	
0	0	Cursor left
0	1	Cursor right
1	0	Display left, cursor follows display
1	1	Display right, cursor follows display

Function Set
0 0 1 DL N F * *

DL=1: 8-bit interface
DL=0: 4-bit interface
N=0: one line
N=1: two lines

Only on some types:
F=0: 5×7 dot matrix
F=1: 5×10 dot matrix

This command sets the display's mode of operation after the reset at switch-on. We will be using the LCD in 8-bit mode with one line.

Set CG RAM Address
0 1 a5 a4 a3 a2 a1 a0

This command prepares the LCD for a data transfer to the character RAM by fixing the CG address for the next byte to be conveyed. Bits a0 and a5 form the address to be loaded into the address counter, AC.

Set DD RAM address
1 a6 a5 a4 a3 a2 a1 a0

This command prepares the LCD for a data transfer to the display data RAM (DD-RAM) by fixing the DD-RAM address for the next byte to be conveyed. Bits a0 to a6 form the address to be loaded into the address counter, AC.

Read Busy Flag
Read back:
BF a6 a5 a4 a3 a2 a1 a0
(where R/W\=1)

When BF=1, the display is busy processing the previous command, and can not accept a new command or data. When BF=0, the display is ready to accept a new command, or new data. At the same time, the value of the AC is read.

Write DATA to CG or DD-RAM
Data:
d7 d6 d5 d4 d3 d2 d1 d0
(where R/W\=0; RS=1)

Depending on whether a CG-RAM address or a DD-RAM address was sent, this command takes a byte into the respective memory area. The mode defined with the aid of the Entry Mode command determines whether the AC is increased or decreased after the byte has been conveyed.

Read DATA from CG or DD-RAM
Data:
d7 d6 d5 d4 d3 d2 d1 d0
(where R/W\=1; RS=1)

This command allows bytes to be read from the CG-RAM or the DD-RAM. Before this command, the address must have been conveyed by SET CG ADDRESS or SET DD ADDRESS.

Display test

The flowchart and assembly listing of a simple LCD test program are given in Figs. 52 and 53 respectively. The function of the program is simple: first, a text is written to the display. Next, the display contents can be shifted to the left or to the right by pressing a key.

The example program on your course disk (XAMPLE12.A51) contains a number of subroutines which you may use in your own programs. The operation of each of these routines will be discussed below.

LCD subroutines

Subroutine **RCOM** fetches the state of the LCD into the accumulator. This is achieved by setting Port P2 to the high byte of the display address, 0C01H. The lower address byte is loaded into register R0. Next, a MOVX instruction is used to read out the LCD's BUSY flag, which appears in accumulator bit position 7. As mentioned earlier in this course, Port P2 is used as the high address byte with indirect addressing of the external memory.

Subroutine **LCDRDY** waits until the LCD BUSY flag is at 0. RCOM is used for this function. LCDRDY is used during the relatively 'slow' LCD initialization commands, to make sure that the LCD has actually accepted the command conveyed.

Subroutine **WT1** waits 100 µs. Since most LCDs have a display command execution time shorter than 100 µs, this subroutine may be used to wait for a display command to finish.

Subroutine **LCDCOM** conveys a command (RS=0) to the display. The addressing method is the same as that used with the MOVX instruction in the RCOM subroutine. The command is followed by a 100-µs delay.

Subroutine **LCDCHR** sends a character to the character RAM (DD-RAM) of the display (RS=1), and then waits 100 µs. Before calling LCDCHR, it may be neces-

```
****** LISTING of EASM51 (XAMPLE12) ******
LINE LOC  OBJ         T          SOURCE
   1 0000                ; ****** FILE XAMPLE12.A51 *************************************
   2 0000                P2      EQU   0A0H  ; for higher address
   3 0000                ACC     EQU   0E0H
   4 0000                Addrhi  EQU   0C0H  ;  MSB of LCD address C001H or C009H
   5 0000                addrRS0 EQU   001H  ;  LCD LS byte of address with RS=0
   6 0000                addrRS1 EQU   009H  ;  LCD LS byte of address with RS=1
   7 0000                ;
   8 0000                        ORG 4100H
   9 4100 31 2F     [2] START   ACALL LCDSET         ; initialize LCD
  10 4102 7B 50     [1]         MOV   R3,#80         ; 80 characters
  11 4104 7A 41     [1]         MOV   R2,#'A'        ; starting with A
  12 4106 EA        [1] SETL    MOV   A,R2
  13 4107 31 4F     [2]         ACALL LCDCHR         ; display on LCD
  14 4109 0A        [1]         INC   R2             ; next character
  15 410A DB FA     [2]         DJNZ  R3,SETL        ; repeat
  16 410C 31 24     [2] NEW     ACALL WAIT           ; wait
  17 410E 90 C0 00  [2]         MOV   DPTR,#0C000H ; read keys
  18 4111 E0        [2]         MOVX  A,@DPTR
  19 4112 30 E7 05  [2]         JNB   ACC.7,RIGHT  ; test bits 7 and 6
  20 4115 30 E6 08  [2]         JNB   ACC.6,LEFT
  21 4118 80 F2     [2]         SJMP  NEW            ; nothing to do
  22 411A 74 18     [1] RIGHT   MOV   A,#00011000B ; shift display S/C=1 R/L=0
  23 411C 31 47     [2] OUT     ACALL LCDCOM         ; send as LCD command
  24 411E 80 EC     [2]         SJMP  NEW
  25 4120 74 1C     [1] LEFT    MOV   A,#00011100B ; shift display S/C=1 R/L=1
  26 4122 80 F8     [2]         SJMP  OUT
  27 4124                ;
  28 4124 78 FF     [1] WAIT    MOV   R0,#255        ; wait a while
  29 4126 79 FF     [1] WAIT1   MOV   R1,#255
  30 4128 00        [1] WAIT2   NOP                  ; 255*4 microsec
  31 4129 00        [1]         NOP
  32 412A D9 FC     [2]         DJNZ  R1,WAIT2
  33 412C D8 F8     [2]         DJNZ  R0,WAIT1       ; * 255
  34 412E 22        [2]         RET                  ; approx. 65500*4 microsecs
  35 412F                ;                           ; LCD driver routines
  36 412F 31 41     [2] LCDSET ACALL  LCDRDY         ; wait for last command to complete
  37 4131 74 30     [1]        MOV    A,#00110000B ; DL=1 N=0 F=0 : 8 bit , one line , 5*7 dots
  38 4133 31 47     [2]        ACALL  LCDCOM         ; as command
  39 4135 74 0C     [1]        MOV    A,#00001100B ; D=1 C=0 B=0, display on, cursor/flash off
  40 4137 31 47     [2]        ACALL  LCDCOM
  41 4139 74 06     [1]        MOV    A,#00000110B ; I/D=1 S=0 : increment w. display shift
  42 413B 31 47     [2]        ACALL  LCDCOM
  43 413D 74 01     [1]        MOV    A,#00000001B    ; reset Display
  44 413F 31 47     [2]        ACALL  LCDCOM
  45 4141 31 5A     [2] LCDRDY ACALL  RCOM              ; wait until LCD ready
  46 4143 20 E7 FB  [2]        JB     ACC.7,LCDRDY      ; bit 7 = BUSY-Flag
  47 4146 22        [2]        RET
  48 4147                ;
  49 4147 75 A0 C0  [2] LCDCOM MOV    P2,#Addrhi        ; send command to LCD
  50 414A 78 01     [1]        MOV    R0,#addrRS0       ; RS=low <=> command
  51 414C F2        [2]        MOVX   @R0,A             ; output at address P2,R0
  52 414D 80 06     [2]        SJMP   WT1               ; wait
  53 414F                ;
  54 414F                LCDCHR EQU $                   ; output character via LCD
  55 414F 75 A0 C0  [2]        MOV    P2,#Addrhi        ; MS address
  56 4152 78 09     [1]        MOV    R0,#addrRS1       ; RS=high <=> data
  57 4154 F2        [2]        MOVX   @R0,A             ; output at address P2,R0
  58 4155 78 32     [1] WT1    MOV    R0,#50            ; 100 microseconds
  59 4157 D8 FE     [2] WT2    DJNZ   R0,WT2            ; wait
  60 4159 22        [2]        RET
  61 415A                ;
  62 415A 75 A0 C0  [2] RCOM   MOV   P2,#Addrhi     ; read LCD status
  63 415D 78 01     [1]        MOV   R0,#addrRS0    ; RS=low
  64 415F E2        [2]        MOVX  A,@R0          ; fetch
  65 4160 22        [2]        RET
  66 4161                      END
********** SYMBOLTABLE (21 symbols) **********
       P2 :00A0       ACC :00E0    Addrhi :00C0   addrRS0 :0001
  addrRS1 :0009     START :4100      SETL :4106       NEW :410C
    RIGHT :411A       OUT :411C      LEFT :4120      WAIT :4124
    WAIT1 :4126     WAIT2 :4128    LCDSET :412F    LCDRDY :4141
   LCDCOM :4147    LCDCHR :414F       WT1 :4155       WT2 :4157
     RCOM :415A
```

Fig. 53. Assembly code listing of the LCD driver.

sary to set the new RAM address with the aid of SET DD-RAM ADDRESS.

Subroutine **LCDSET** arranges the basic settings of the LCD. First, it calls LCDRDY to make sure that all previous commands have been processed. Next, the LCD mode is set to: 8-bit; one line; 5×7 dots. This is done with the aid of LCDCOM. After the mode setting operation, the display and the cursor are switched off (lines 39 and 40), and the Shift mode is set (lines 41 and 42). Next, the display is cleared. Since this command may take up to 1.6 ms, it is followed by subroutine LCDRDY. Those of you who have studied the listing carefully will have noted a useful programming trick. When 'subroutine1' ends with the instruction sequence

```
LCALL subroutine2
RET
```

this can be replaced with a single line instruction

```
LJMP subroutine2
```

and so make use of the RET command of 'subroutine2' (line 52 in the listing). Although this trick saves a few lines of assembly code, it should not be used too often since it easily causes confusion. Here, it is only shown in the interest of the example.

The main program

The main LCD driver program starts by calling LCDSET to set up the display. Next, it writes 80 ASCII characters *ABCDEFG....* into the display RAM before entering an endless loop starting at NEW. In this loop the state of keys S2 and S3 is tested. When one of these is pressed, a left or right Display Shift command is sent to the LCD via LCDCOM. To make sure that the display contents scrolls slowly, subroutine WAIT is called in every loop iteration. WAIT simply idles 0.26 s (255×255×4 µs).

Assignment: road diversion

The last assignment in the course is to write a program that displays text and numbers (decimal and hexadecimal) on the LCD. To get started, have a look at the character output routine (V24 serial interface driver) in the system monitor, EMON51, and work on routeing the characters to the LCD.

Further outlook

This brings us to the end of the 8051/8032 Assembler Course, which has covered the most important programming aspects of the MCS-51 family of microcontrollers. The knowledge gathered during the course should enable you to start your own projects based on one of the processors in the family, or any of the follow-up types that are currently available.

To avoid awkward problems arising later, microcontroller-based projects should have a fairly long planning phase. Always give a good deal of thought to questions such as: which part of the project is realized by software, and which by hardware? How are the necessary hardware extensions connected (ports or bus)? Is battery backup required? Does the processor used have enough speed and computing power to handle the desired task? Are interrupts required to deal with 'fast' events? What are the sub-problems into which the overall program and project can be divided?

Answering the above questions requires quite some experience, which, as we all know, can only be acquired 'the hard way', i.e., by practice. In not a few cases, an apparently simple task may prove quite tangled when looked back upon, or will eventually appear to be over your head. In general, a good start can be made with simple hardware projects that can be built from a couple of TTL ICs: a die, a digital clock, a morse code generator, and so on. The functions of such devices lend themselves very well to software implementations that yield a lot of practical experience.

Keyboard interfaces

Most hardware projects you may come up with will require some kind of data input device. To offer you some insight into the problems that may crop up, we will briefly discuss six ways of interrogating the state of a keyswitch, i.e., determine whether it is pressed or not. As will become evident, the proposed circuits differ in regard of hardware as well as software.

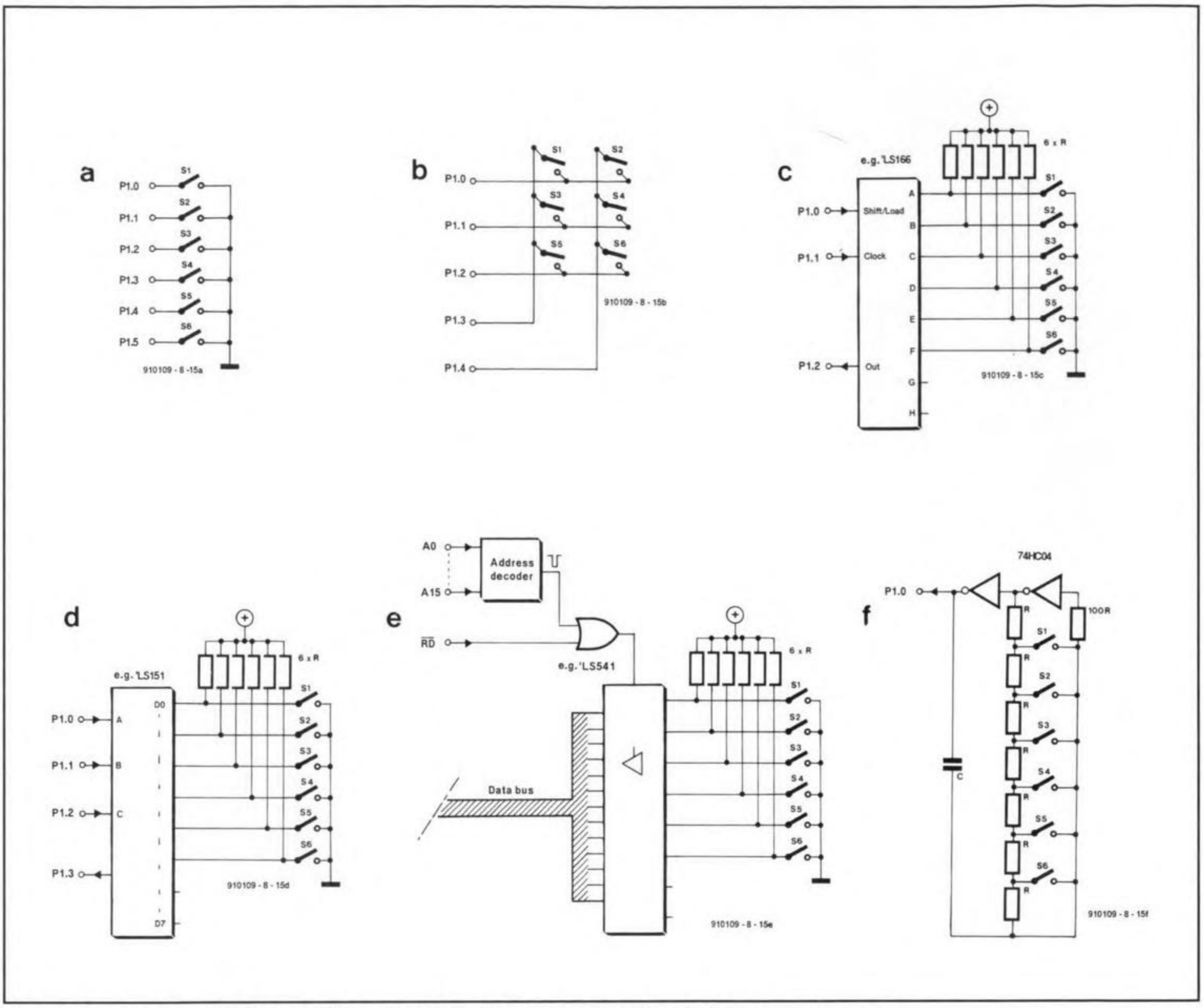


Fig. 54. Six possible ways of connecting switches or a keyboard to the 80C32 single-board computer.

Also, each circuit has its own advantages and disadvantages.

a. Direct port connection

The connection shown in Fig. 54a is the simplest of all: each key pressed takes a port line to ground. Current limiting is not even required because the 8051 contains pull-up resistors. The software is simple, too: each switch can be interrogated by a bit test instruction (JB or JNB). The disadvantage of this circuit lies in the number of port lines used. This makes it difficult to implement, say, an ASCII keyboard interface, since there some 60 keys (= port lines) are involved.

b. Matrix port connection

In this circuit (Fig. 54b), the keys are arranged in rows and columns that form a matrix. The state of any individual key in the matrix can be interrogated by putting a 'wandering low' on to the row lines. The position of the pressed key is then easily found by scanning the rows. The advantage of the matrix circuit is that a large number of keys can be read using relatively few lines: only 16 to read 64 keys. There is also a disadvantage: keys may not be pressed simultaneously. However, this may be overcome by fitting decoupling diodes at the matrix crosspoints. Unfortunately, the software for the matrix keyboard is fairly complex.

c. Shift register connection

The circuit option given in Fig. 54c requires remarkably few lines. A load pulse is used to copy the switch state into the shift register. Next, the switch state is shifted into the 8051 by eight clock pulses sent via port line P1.2. Note that only three port lines are required, and that the control software is fairly simple. Where more keys need to be read, shift registers may simply be cascaded (connected in series). Note, however, that this results in a longer 'read' time.

d. Multiplexed connection

The switch circuit in Fig. 5d requires four port lines, of which P1.0, P1.1 and P1.2 select one of keys S1-S6 via an 8-to-1 multiplexer. The state of the selected switch is fed back to the controller via port line P1.3. This circuit can make do with simple control software, and is simple to turn into a cascade to allow more keys to be connected.

e. BUS connection

The circuit drawn in Fig. 5e uses the processor bus to convey switch states. It is particularly useful when there is no free port line available. The keyboard address is selected via an address decoder, and the read signal is used to transfer the state of the keys on to the databus via a three-state buffer. Although the software for this option is relatively simple, the hardware is a bit on the complex side, particularly because we need to connect both the address bus and the databus.

f. Multivibrator interface

The last keyboard input circuit to be discussed here, Fig. 5f, works with only one port line. An oscillator based on two inverters operates at a frequency which changes when one of the keys is pressed. The 'key identity' is then established by the software, which measures the frequency of the rectangular signal on P1.0. Although this circuit requires the fewest port lines of all variants (except, of course, the bus connection), its suffers from two disadvantages: first, it requires fairly complex software and, second, it is not so easy to extend the number of keys since the frequency differences then become too small to be resolved reliably by the processor.

The way ahead

To be able to make the best possible use of the experience gathered from simple programs and projects, teach yourself to write program sections in such a way that they can be used later for other applications. In the course of time, this method of working will yield a collection of items that can be used over and over again to build larger programs. Also, the better your documentation on each subroutine, the easier it becomes to fit one into a larger program.

Contrary to common belief, assembly language programming is not all juggling and applying one trick after another. In the author's opinion, assembly language does allow structured programming just like any other higher language, since the program structure is mainly the result of the programmers's thinking. In this context, it is perhaps useful to advise beginners to read as much as possible about assembly language programming.

In spite of the different sources available for learning purposes, assembly language programming is never easy, and is quite demanding in regard of discipline. Fortunately, life is made a little easier by a number of programming tools, which will be discussed briefly below.

Macro-assembler

During this course we have used a simple assembler which is, none the less, perfectly adequate for the beginner. The professional user with a large budget will, of course, want to use more powerful tools. Well, these are available: a number of commercially available assemblers have 'extra' features such as the ability to handle macros. A macro is a 'shorthand' identifier for a long, frequently used, sequence of instructions or other texts. The assembler recognizes the macro identification, and automatically translates it into the text it represents.

Apart from this possibility, many assemblers allow the separate assembly of chunks of assembly code, which can be 'stitched together' later, along with items from a subroutine library. This is achieved with the aid of a linker. Although working with 'bits and pieces' is most useful when building a fairly large program, the hobbyist will often be able to manage quite well without a linker utility.

Those of you who find assembly language programming too arduous may avail themselves of higher programming languages such as C or Forth, for which a number of 8051 compilers and interpreters are available, albeit at a cost.

8051 emulators

8051 emulator programs are available that allow 8051 software to be tested by quasi-running it on a PC. Some emulators allow the program under test to be executed in single step mode, while the register contents are displayed. As such, emulators are excellent tools to trace and solve software problems and errors. They, are, however, less useful when the problem is caused by incompatibility between software and hardware. The limitations of the emulator are, therefore, often keenly felt when the program is used to 'mimic' a microcontroller connected to hardware extensions (peripherals). Fortunately, emulators come at quite low prices, which makes the decision to buy one, and so extend one's programming tools, a little easier than with an expensive assembler. For the beginner, too, an emulator can be quite useful since the workings of individual instructions can be traced with great accuracy on the PC screen. However, an EPROM emulator will be much more useful when it comes to the real thing, i.e., testing the real program in actual use.

EPROM emulators

During this course, all programs are run under the control of the EMON51 system monitor, and loaded into RAM. In many cases, however, it is desirable, from a point of view of cost, to omit a RAM, and run the program from an EPROM. To complicate things even further, such a system may not even have a serial interface. The absence of a RAM and a serial interface would appear to limit the possibilities of testing the software under realistic circumstances, as no data can be downloaded to, or called back from, the system under test. In these cases, an EPROM emulator can be great help, since it allows the most up to date version of the program (in object code) to be downloaded into the system. An excellent design for an EPROM emulator is described in Ref. 1.

In-circuit emulators

An even more difficult situation arises when an 8051 with internal ROM is to be used in a project of which the software is as yet under development. Obviously, an EPROM emulator is useless here, simply because there is no EPROM. In-circuit emulators such as the one described in Ref. 2 simulate the operation of the 8051 CPU running a program selected by the user. An in-circuit emulator is also a fine tool to track down hardware errors caused by, for instance, timing problems.

Follow-up processors: 80535 etc.

Although this course may have been your first acquaintance with the 8051 family of microcontrollers, remember that these devices are relatively old already. Their success, however, is mainly due to their having been endowed with the status of 'industry standard'. Whatever that may mean, these processors are found in countless applications. However, when deciding to develop a microcontroller application, do not forget to have a serious look at some of the derivates of the 8051, which include some very interesting processors like Siemens' SAB80C535 and SAB80C537, OKI's MSM80C154, and Philips Components' PCB83C552. These processors are basically upwards compatible devices, which means that they can do everything a 8051 can, when the same software is used.

The follow-up processors have extended features such as additional timers, on-chip A-D converters, an on-chip watchdog timer, more ports and enhanced (faster) arithmetic units. Our course assembler supports these new features because they are accessible via additional SFRs. An 80C535 controller board will be published in a forthcoming issue of *Elektor Electronics*.

Finale: small hardware projects

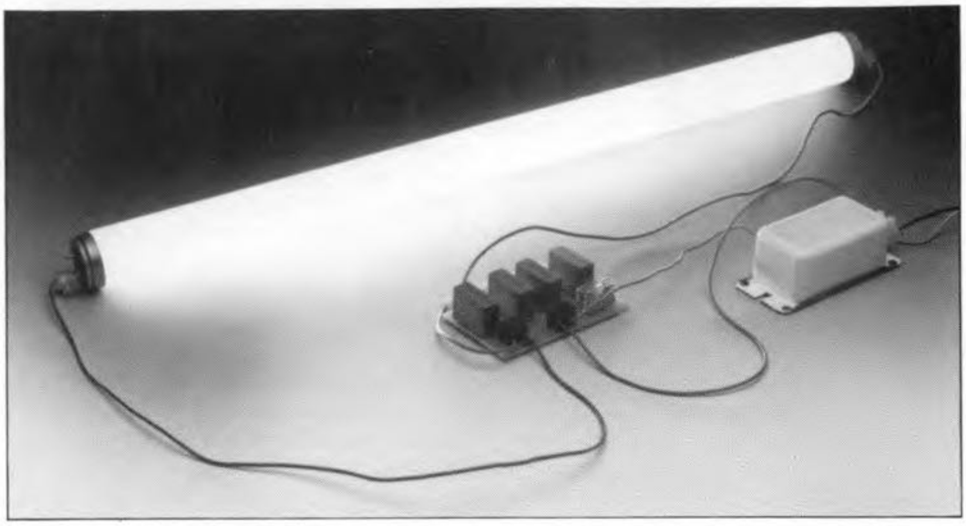
Although this course is now finished, it is really open-ended since there is no limit to what you can program on an 8051. We have up our sleeve a number of small projects that serve to show you the diversity of the possible applications. The projects themselves will be small, and based on very simple hardware. The idea is not so much to elaborate on the project itself, but rather to demonstrate the wide variety of applications you can develop once the basics of assembly language have been acquired. If you have ideas, let us know! ■

References:

1. 'EPROM emulator Mark-2'. *Elektor Electronics* September 1992.
2. '8751 emulator'. *Elektor Electronics* March 1992.

ELECTRONIC STARTER FOR FLUORESCENT TUBES

Design by L. Pijpers



Fluorescent tubes blink and flicker for a few seconds before they light properly. This deficiency is caused invariably by the traditional starter. The circuit described here may be used to replace the starter to obviate the blinking and flickering.

Low-pressure fluorescent tube lighting is justifiably popular because (1) it is 4–6 times as efficient as metal-filament lamps, (2) the life of a fluorescent lamp is about seven times that of a metal-filament lamp, (3) its light is spread much more evenly, and (4) it produces hardly any glare.

A low-pressure fluorescent lamp consists usually of a glass tube, 38 mm in diameter and from 600 mm to 2400 mm long. The tube is filled with an inert gas at a pressure of about $^1/_{250}$ of atmospheric pressure, and also with a drop of liquid mercury. The interior surface of the tube is coated with fluorescent material that converts the ultraviolet radiation from the mercury vapour into light of an acceptable colour.

There is an electrode at each end of the tube that serves as both cathode and anode, since the tube is invariably used in an a.c. circuit. The cathode, which is secured by nickel support wires, consists of a coiled filament coated with a barium-oxide thermionic emitter. The anode if formed by a metal strip attached to the support wires.

The cathodes are heated by passing a current through each filament. If the applied voltage is high enough, a glow discharge is set up through the gas, which excites or ionizes the mercury atoms throughout the tube and results in a mercury-arc discharge. As the arc current increases, the potential drop across the choke also increases, so that the voltage across the tube decreases, until a balance is reached.

Fluorescent tubes require some external components for satisfactory operation: a ballast, usually a choke, to limit the current through the tube, a starter for preheating the filaments, and a power factor correcting capacitor—see Fig. 1.

The simplest starter is a special switch (normally called the starter), which nowadays is invariably of the glow type (there used to be thermal types, but these have all but disappeared). The contacts of the switch are mounted on bimetallic strips that bend towards each other when they are heated. The switch is normally contained, together with a small radio interference suppression capacitor, in a sealed tubular case that is filled with an inert gas, usually argon or helium.

When the lamp switch is closed, the full mains voltage is applied across the starter, which causes a glow discharge through the gas across the open contacts. This discharge heats the bimetallic strips, whereupon the contacts close. As soon as this happens, current flows through the choke and the two series-connected filaments, whereupon the cathodes are heated. When the cathodes reach a certain temperature (called the 'emission temperature'), ionization begins and the ends of the tube start to glow. The voltage across the starter then decreases and the bimetallic strips begin to cool down. After a predetermined time, the contacts open quickly. This causes a high-voltage surge to be induced across the choke, which is applied to the tube, causing it to strike.

The choke causes a power factor (lag) that may be as low as 0.6, which is clearly very inefficient. To improve the power factor to a value closer to 1.0 (in practice 0.8–0.9), a suitably rated power factor compensating capacitor* is connected across the mains input terminals.

The reason for the blinking and flickering of the fluorescent tube is simply that the contacts of the starter switch open at any given moment. Invariably, the value of the current at that time is too low to induce a high enough voltage across the choke to make the tube strike. At the same time, the cathodes of the tubes often have not been sufficiently heated.

Electronic starter

There are several ways of using electronics to improve the striking of fluorescent tubes. The first is by simply replacing the starter by a thyristor circuit.

The second is using an h.f. amplifier and transformer to increase the frequency and the level of the operating voltage. This method, however, is feasible for low power (5–9 W) tubes only; the costs for higher power tubes are fairly high.

The third, proposed here, is based on the circuit in Fig. 2.

The choke is retained for limiting the current, but is no longer needed for inducing a high voltage.

At the instant the mains switch is closed, the fluorescent tube presents a high impedance and the four capacitors are not charged. For

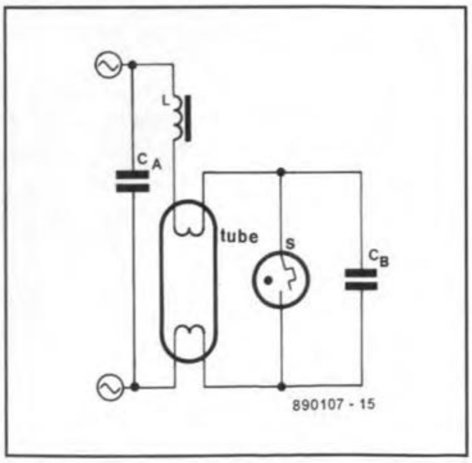


Fig. 1. Standard configuration of a fluorescent lamp circuit.

Table 1. Component values in Fig. 2. for various tube ratings.

	TUBE RATING		
	20 W	40 W	60 W
C_1	0.47 µF/1000 V	0.47 µF/1000 V	1 µF/1000 V
C_2	0.47 µF/1000 V	0.47 µF/1000 V	1 µF/1000 V
C_3	0.47 µF/1000 V	0.47 µF/1000 V	1 µF/1000 V
C_4	0.47 µF/1000 V	0.47 µF/1000 V	1 µF/1000 V
D_1	1N4007	1N5408	1N5408
D_2	1N4007	1N5408	1N5408
B_1	280 V/1.5 A	280 V/2.0 A	280 V/3.0 A
F_1	500 mA	1 A	3 A

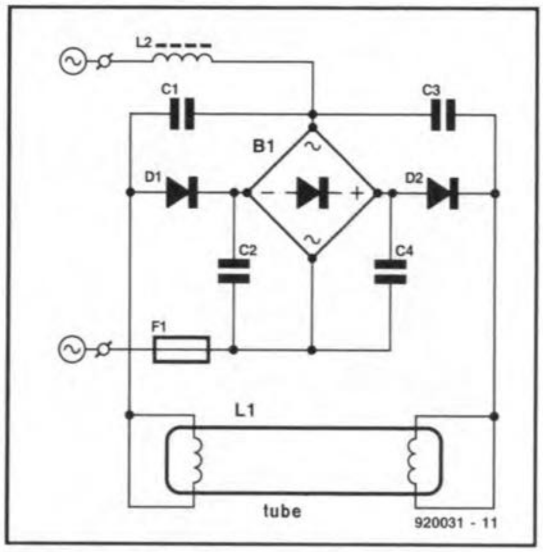


Fig. 2. Circuit of the electronic starter.

simplicity's sake, it will be assumed that the mains is going through a positive half cycle, that is, the voltage is high at L_2 and low at F_1. Capacitor C_1 is then charged via D_1 and the bridge rectifier, and C_4 via one of the diodes of the rectifier. The potential across these capacitors rises to about 340 V, the peak value of the mains. During the negative half cycle, C_2 is charged to about 340 V via the rectifier, and C_3 to just over 500 V via C_4 and D_2. This means that part of the charge on C_4 is transferred to C_3. During the next positive half cycle, part of the charge on C_2 is transferred to C_1 via D_1, while C_4 is recharged to about 340 V. In this way, capacitors C_2 and C_4 increase the voltage across C_1 and C_3 to twice the peak voltage of the mains, that is, 680 V. This means that the voltage at the right-hand side of the fluorescent tube is +680 V and that at the other side is –680 V, both with respect to neutral. That voltage remains across the tube until this strikes.

When the tube strikes, the potential across the capacitors instantly drops to 60–80 V, that is, the normal operating voltage of the tube. The capacitors cannot be recharged: from this moment on they serve no purpose as the tube is operated by the direct voltage produced by the rectifier.

Operating the tube from a direct-voltage source is the most obvious difference with normal practice. Another is that the filaments serve as anode or cathode only and no longer as pre-heating elements.

Although this method has the obvious advantage of the tube lighting immediately the mains is switched on, it also has a drawback. Since the ion current through the tube is now polarized, one of the filaments will become thinner and thinner and the other, thicker. Also, a black deposit may occur on the glass of the tube. These are long-term effects, however, and are no cause for immediate concern. It is nevertheless advisable to reverse the tube in its fitting from time to time, say, once every couple of months.

Construction

Since only seven components are used, the construction of the electronic starter is simplicity itself. Because of the high voltages present (well over 1000 V), good-quality board should be used. Also, keep reasonable distances between the soldering points. Furthermore, first class insulation is needed when the circuit is fitted in a suitable enclosure. Do not omit the (quick-blow) fuse under the impression that the choke will limit any peak currents.

Suitable values of components shown in Fig. 2 are given in Table 1. ■

* See 'Understanding power factor compensation' on page 43.

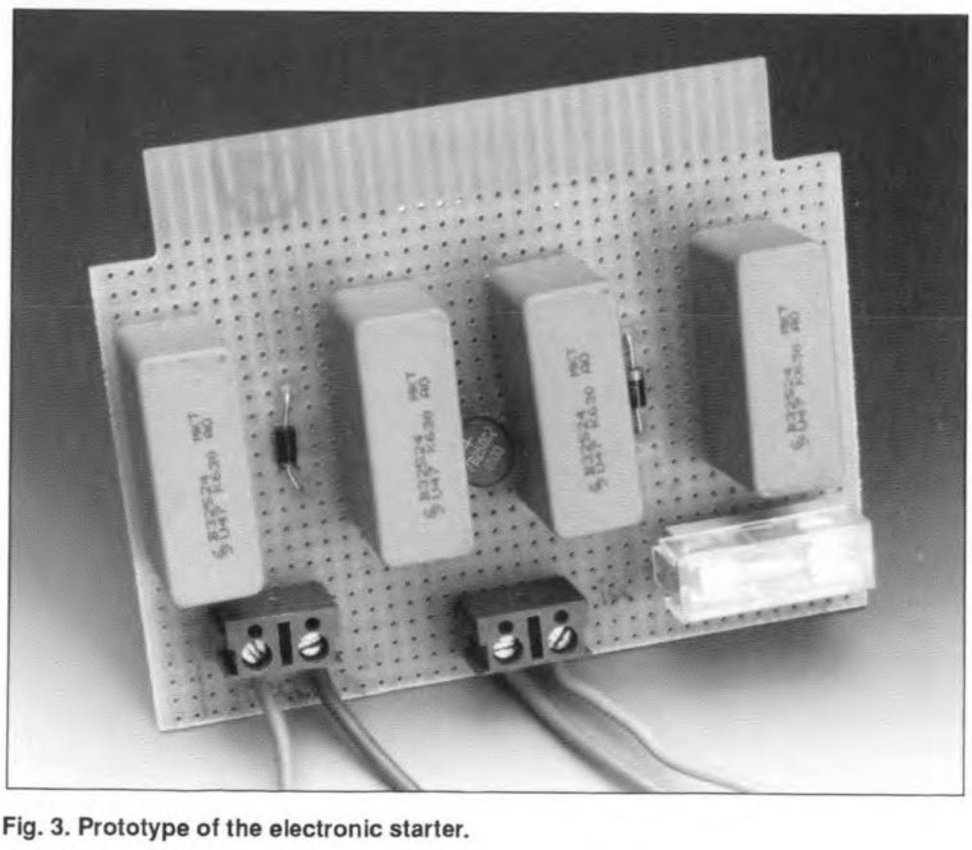


Fig. 3. Prototype of the electronic starter.

SOUND SAMPLER FOR AMIGA

MAIN SPECIFICATIONS

Suitable for:	all Amiga computers
Resolution:	8 bits
Interface:	Centronics printer port
Control:	off-the-shelf software (see overview)
Sample frequency:	adjustable to approx. 25 kHz
Operation:	manually or by software
Sound channel:	mono or stereo

The computers in Commodore's Amiga series are widely praised for their powerful sound and graphics. Not surprisingly, some bulletin boards abound with graphics files and/or tracker modules that have been produced by this popular computer. The sound sampler described in this article gives all Amiga users the possibility to start digitizing sound at a small outlay.

Design by P. Trags

SOUND is only a secondary function on most computers, which appear to be designed to communicate with the user via a screen only. Amiga owners are, however, fortunate to have a computer that is fairly simple to upgrade into a multi-media machine. This is proved by the sound sampler described here, which is purposely kept simple and, therefore, inexpensive.

The circuit proposed here is suitable for all versions of the Amiga, that is, for the A500, A1000, A2000 and the professional A3000. Also, it is designed to be compatible with many of the popular sampler and/or tracker programs Amiga users have come to know. Programs such as Audio Master I, II & III, Record Maker, Perfect Sound, Future Sound and DeLuxe Sound can be used straight away. The sound sampler is capable of digitizing mono as well as stereo signals. The samples generated by the hardware may be reproduced via the sound channels built into the Amiga. By virtue of the four standard channels, a fairly good stereo sound can be produced. The internal resolution of 8 bits forms a seamless link with the resolution of the sampler. Finally, the sampler may be used as a low-voltage, low-frequency oscilloscope, a function which is supported by most sound sampler programs.

Via the printer port

The circuit is fairly simple — see Fig. 1. The sampler is connected to the Amiga via K1, which is hooked up to the computer's printer port. The circuit diagram shows two wire links in the vicinity of K1. These links are required to correct a small hardware flaw in the A1000 computer, which has the +5-V line on the wrong pin of the printer port. This has been put right on later Amiga models.

The remainder of the circuit is pretty straightforward. The two audio signals, left and right, are applied to connectors K2 and K3. Opamps IC3a and IC3b raise the audio signals by a factor of three, and each drive the analogue input of a Type ADC0804 analogue-to-digital converter IC. Since the ADC0804 is reasonably priced, each sound channel has its own A-to-D converter, which results in a fairly large bandwidth. The converter is based on the successive approximation principle. The conversion time is about 100 µs at a clock rate of 640 kHz. One conversion cycle lasts exactly 64 µs, although we must keep in mind that up to eight clock pulses may go by before the conversion is actually started. According to the manufacturer of the ADC0804, National Semiconductor, the clock frequency may lie between 100 kHz and 1.46 MHz. From experience with the chip, it is known that the A-D converter produces more conversion errors as the clock frequency increases. The recommended clock frequency is 640 kHz, which results in a conversion cycle of 100 µs. In the present design, the clock frequency has been made variable, which enables the user to set the optimum frequency for a particular 'recording'. The clock frequency may be set to a value between 0.5 MHz and 1.5 MHz. At the maximum clock frequency specified by the manufacturer, 1.46 MHz, the highest audio frequency that can be digitized is about 10 kHz.

A potentiometer, P2, is provided to compensate the offset of opamps IC3a and IC3b. The signal level may be set with the aid of stereo potentiometer P1. To achieve the best possible sound quality, it is important to ensure signal levels that result in optimum drive for the ADCs. Evidently, P1 and P2 need be adjusted only once if the sampler is used with fairly constant signal ranges, such as, for instance, from a CD player.

The reference voltage for the converters, IC1 and IC2, is generated with the aid of diode D1. In practice, the stability of the forward drop across the diode, about 0.6 V, is sufficient, so that we need not resort to more expensive, specialized, devices for this purpose.

The remainder of the circuit serves to make a selection between sampling the right channel, left channel, or the complete stereo signal. This is achieved with the aid of IC5, a triple two-channel multiplexer. The input signals on pins 14 and 15 are used to select the A-D converters. Both enable signals are furnished by the Amiga computer via pins 12 and 13 on connector K1.

A detection system is provided to make sure that only one ADC is selected at a time (remember, they share a common 8-bit bus). When both ADCs are selected at the same time, IC7c and IC7d have low levels on their inputs. This, in turn, causes the error indicator, D4, to light. Also, the low level at the output of IC7c blocks the signals that pass through gates IC6c, IC6d, IC7a and IC7b. If only one of the outputs goes low (one ADC selected), either D2 or D3 lights, depending on the selected channel. Because the output of IC7c is high in

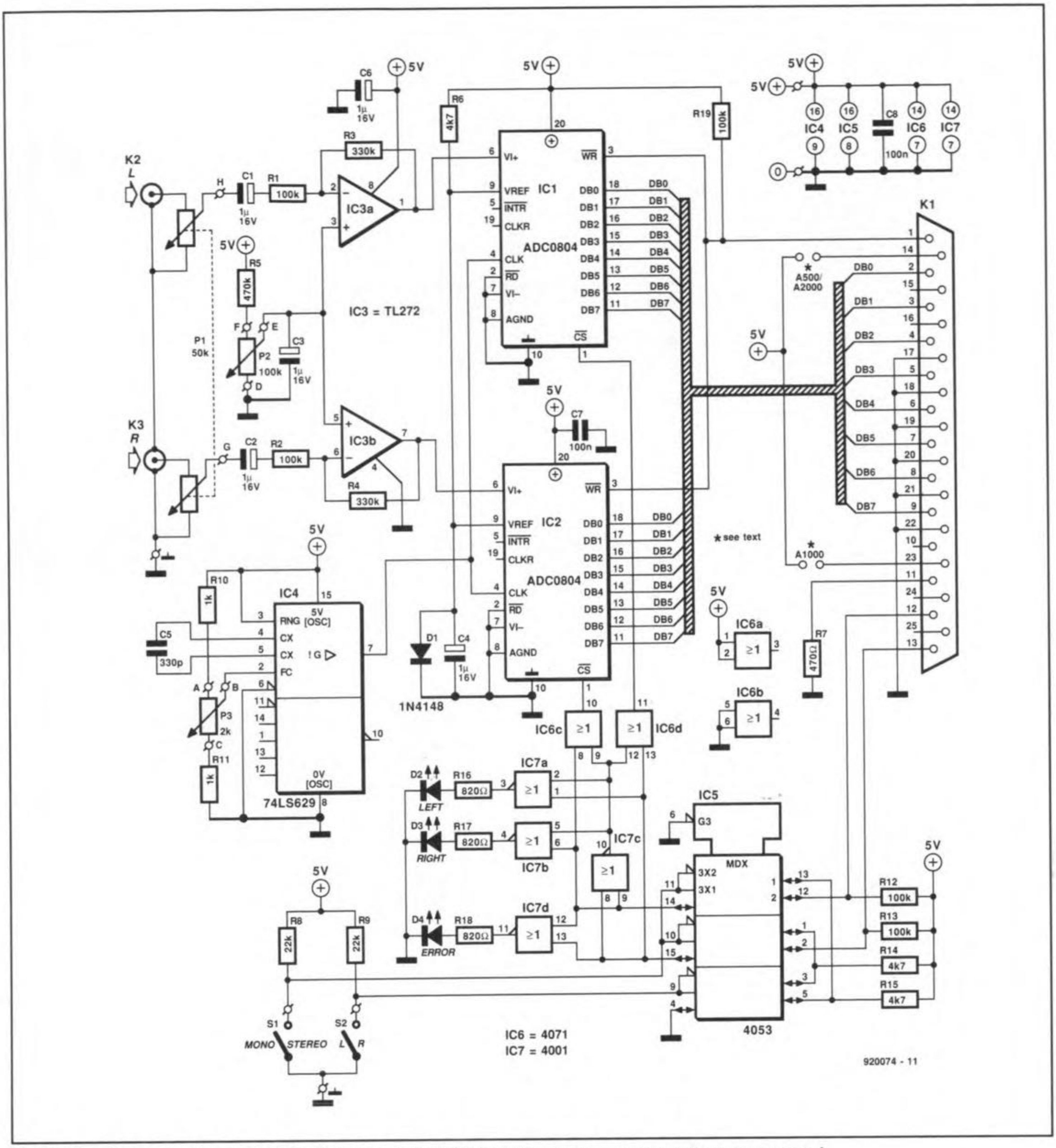


Fig. 1. Circuit diagram of the sound sampler. Note the use of two ADC chips to ensure excellent stereo sound.

that condition, gates IC6c and IC6d pass the enable signals to the relevant A-D converter.

Since the software will switch very quickly between the two channels when stereo mode is used, the two LEDs will light simultaneously. The selection between stereo and mono recordings is made with switch S1. If this switch is set to mono sound, S2 is used to select between left or right. In stereo mode, the Amiga does the switching automatically.

After the Amiga has sent a start-of-conversion (SOC) signal to pin 3 of the ADC0804, the IC starts to compute the digital equivalent of the analogue signal at its input. The digitized value is an 8-bit word, which is applied to the output bus.

Construction and test

The sound sampler is simple to build if the ready-made printed circuit board shown in Fig. 2 is used. Since the components used are inexpensive and not particularly critical in respect of handling, experienced constructors may omit IC sockets. Start the construction by fitting the wire links on the board. Note that two wire links cross, so that insulated wire must be used. Alternatively, the wire link in parallel with IC4 may be run via an arc. Proceed with fitting the resistors, capacitors and connectors. The ICs are fitted last.

The plastic enclosure is drilled and cut to fit the switches, phono sockets, potentiometers and LEDs. Next, fit the completed board into the case, and secure it with the corner screws. The construction is finished by wiring the 'external' parts to the relevant terminals on the board.

Amiga Centronics port connections and functions

Future Sound
(mono only)

pin	name	function
1	STROBE\	start conversion
2-9	D0-D7	data
10	ACK\	no function
11	BUSY	no function
12	PAPER OUT	no function
13	SELECT	no function

Record Maker
(mono only)

pin	name	function
1	STROBE\	start conversion
2-9	D0-D7	data
10	ACK\	no function
11	BUSY	470Ω resistor to ground
12	PAPER OUT	no function
13	SELECT	0 = sample 1 = end of sampling

Audio Master I
(mono only)

pin	name	function
1	STROBE\	start conversion
2-9	D0-D7	data
10	ACK\	no function
11	BUSY	no function
12	PAPER OUT	no function
13	SELECT	0 = sample

Audio Master II/Perfect Sound

pin	name	function
1	STROBE\	start conversion
2-9	D0-D7	data
10	ACK\	no function
11	BUSY	no function
12	PAPER OUT	0 = right
13	SELECT	0 = left

When using Audio Master II, select 'Device Type: Parallel' from options.

Audio Master III
After selecting options Sampler: Hi-speed, and CPU: A, this program works the same as Audio Master II.

DeLuxe Sound
(mono only)

pin	name	function
1	STROBE\	start conversion
2-9	D0-D7	data
10	ACK\	no function
11	BUSY	470Ω resistor to ground
12	PAPER OUT	no function
13	SELECT	0 = sample

Software

As already mentioned, the circuit is compatible with a wide range of popular sampler software available for the Amiga. Our advice is, therefore, simple: go out to your computer shop and buy one of the programs shown in the above box. For the sake of completeness, the box also shows the way the software makes use of the Centronics port. This information may be useful for faultfinding purposes.

As you can see, the sampler is supported by a large number of programs. Apart from these, there are four tracker programs that may be used: Protracker, Soundtracker, Noisetracker and Octalyzer. No shortage of software!

The three potentiometers on the sampler are simple to adjust. Select the oscilloscope function (in the software), and apply an audio channel to the selected input (left or right). Next, turn the volume and off-set controls to mid position, and the clock control fully clockwise. Study the results on the screen, and correct the settings until an optimum signal is obtained. If the sampler is always driven by the same signal source, the offset and clock potentiometers may be replaced by presets. ■

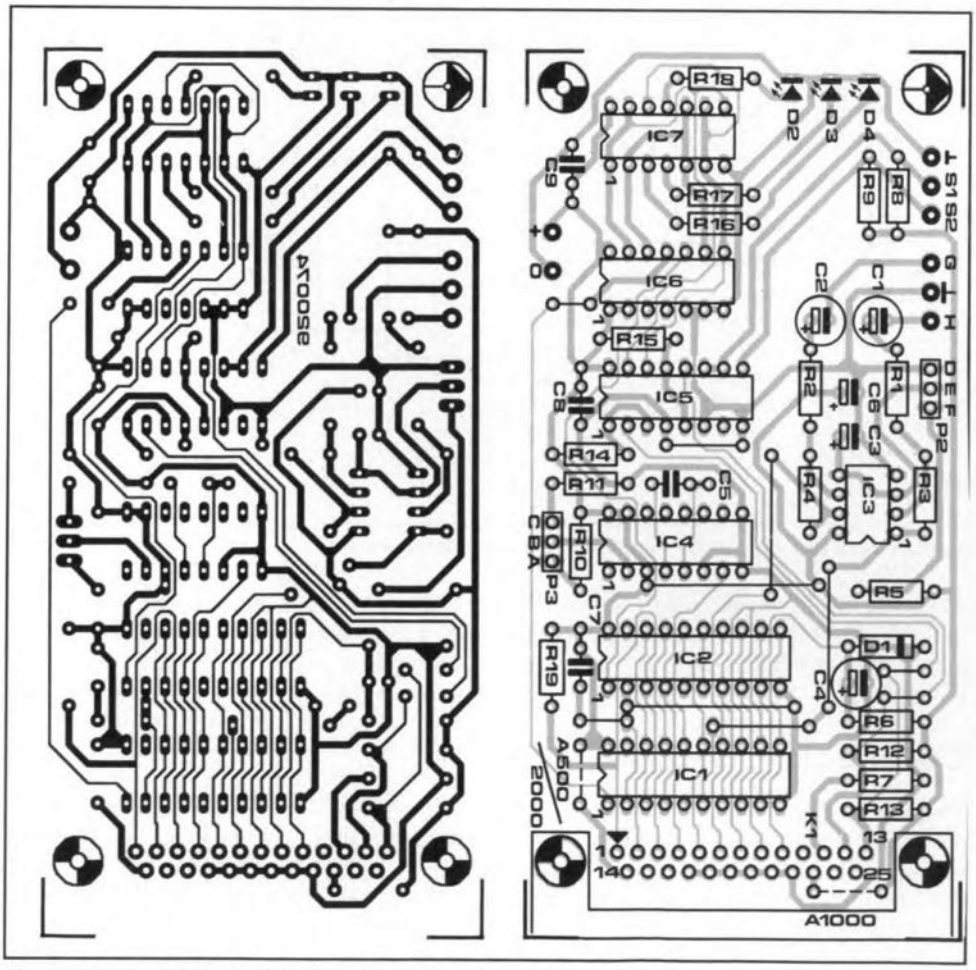


Fig. 2. Single-sided printed circuit board for the sound sampler.

COMPONENTS LIST

Resistors:

5	100kΩ	R1;R2;R12;R13;R19
2	330kΩ	R3;R4
1	470kΩ	R5
3	4kΩ7	R6;R14;R15
1	470Ω	R7
1	12kΩ	R8
1	22kΩ	R9
2	1kΩ	R10;R11
3	820Ω	R16;R17;R18
1	50kΩ log. stereo potentiometer	P1
1	100kΩ lin. potentiometer	P2
1	2kΩ lin. potentiometer	P3

Capacitors:

5	1μF 16V radial	C1;C2;C3;C4;C6
1	330pF	C5
2	100nF	C7;C8

Semiconductors:

1	1N4148	D1
2	green LED	D2;D3
1	red LED	D4
2	ADC0804	IC1;IC2
1	TLC272	IC3
1	74LS629	IC4
1	4053	IC5
1	4071	IC6
1	4001	IC7

Miscellaneous:

1	25-way male sub-D connector	K1
2	phono or RCA socket	K2;K3
2	SPST switch	S1;S2
1	Printed circuit board 920074 (see page 70)	

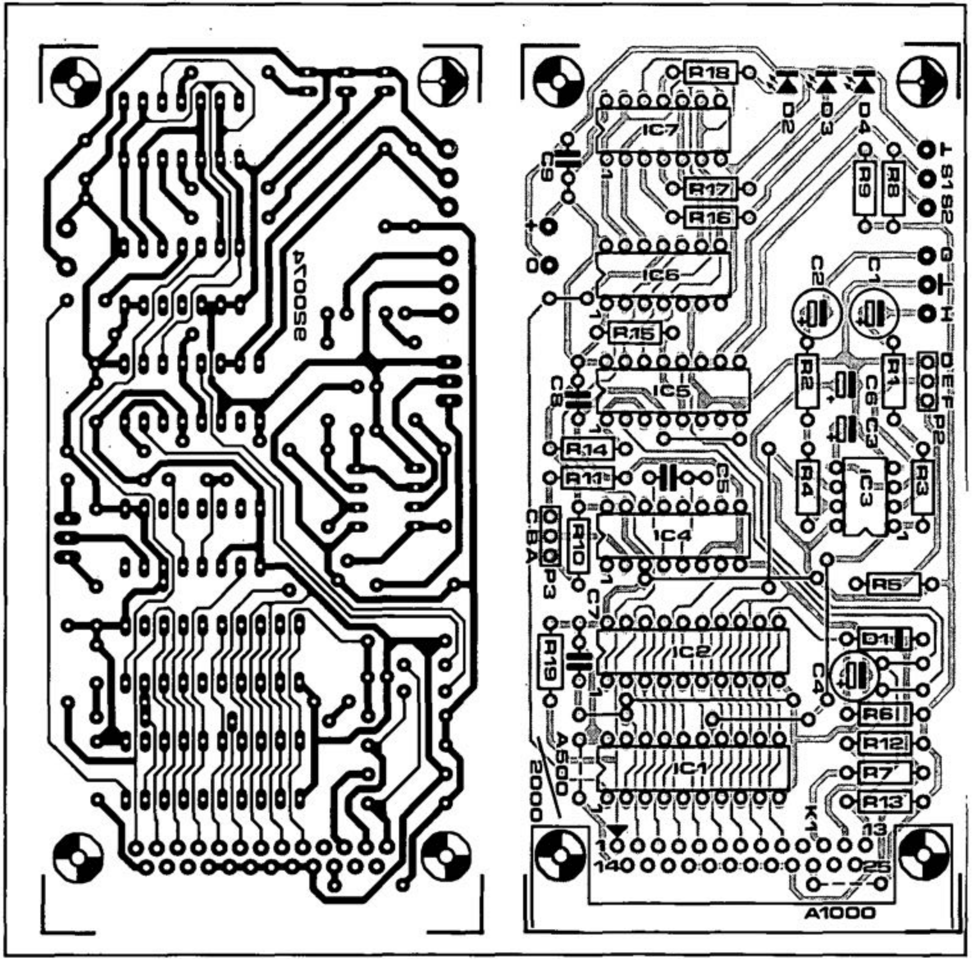


Fig. 2. Single-sided printed circuit board for the sound sampler.

2	1kΩ	R10;R11
3	820Ω	R16;R17;R18
1	50kΩ log. stereo potentiometer	P1
1	100kΩ lin. potentiometer	P2
1	2kΩ lin. potentiometer	P3

Capacitors:

5	1μF 16V radial	C1;C2;C3; C4;C6
1	330pF	C5
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Semiconductors:

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1	TLC272	IC3
1	74LS629	IC4
1	4053	IC5
1	4071	IC6
1	4001	IC7

Miscellaneous:

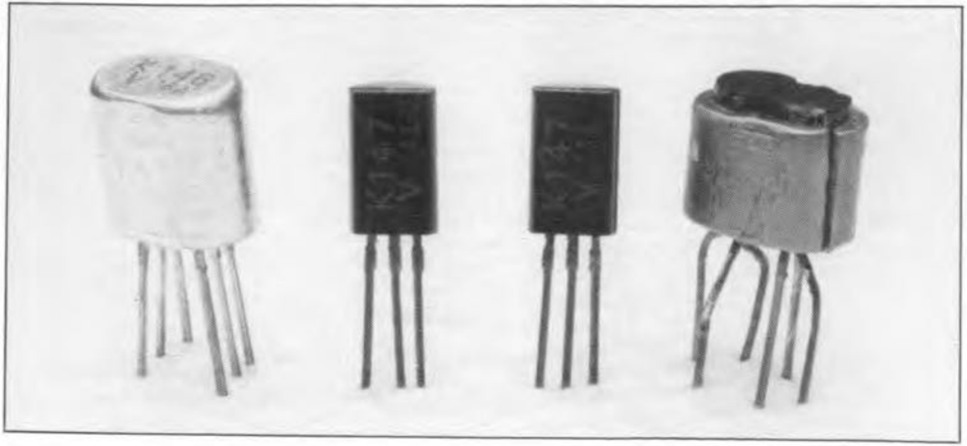
1	25-way male sub-D connector	K1
2	phono or RCA socket	K2;K3
2	SPST switch	S1;S2
1	Printed circuit board 920074 (see page 70)	

CORRECTIONS AND UPDATES

LFA150-A Class-A amplifier

November and December 1991
Replacement for 2SK146V.
We have recently been informed by Toshiba that the dual FET Type 2SK146V used in the LFA150-A design is no longer manufactured. The 2SK146V is not a dual FET in the true sense of the word, i.e., there are no two FETs on a single chip. Rather, it consists of two FETs, each in its own enclosure, which are held together by a metal ring. Such a construction is readily reproduced by clamping two 2SK147V FETs together, using a small piece of metal (e.g., copper or brass).

The photograph illustrates the construction of the replacement dual FET. In practice, the 'imitation' works perfectly. Note, however, that the pin connections of the replacement FET are different from the original 2SK146, which has facing identical pins. By contrast, the dual 2SK147V construction has identical pins in mirrored positions. Fortunately, this is simple to resolve by bending the outer pins (drain and source) of one FET such that the pin positions are swapped. (920163)



Sound sampler for Amiga

November 1991.
Capacitor C9 is mising from the parts list and the circuit diagram. C9 is a 100-nF decoupling capacitor fitted near IC7 (see component overlay).
LEDs D2 and D4 should be transposed, both in the circuit diagram and the parts list. D2 is the ERROR LED, and D4 the LEFT LED. (920074)

LOW-POWER TTL-TO-RS232 INTERFACE

It is not always necessary to resort to special ICs when TTL logic is to be connected to an RS232 interface. Here, a simple adaptor is proposed that can be built from discrete components.

Design by Dipl. Ing. B. C. Zschocke

DESIGNING in TTL (transistor-transistor logic) is straightforward. TTL ICs are inexpensive, available with a plethora of logic functions, and generally well behaved. They are also remarkable for their ability to withstand a lot of rough treatment (electrically, that is). Connecting up one TTL circuit to another rarely poses problems if the distance between boards is not too large. Unfortunately, problems arise when a TTL circuit is to be hooked up to, say, the serial port on a PC. These problems are caused by incompatibility between RS232 and TTL signal levels. Special integrated circuits such as the MAX232 are available to solve the compatibility problem, but their cost is often pretty high. It pays, therefore, to develop an alternative interface based on discrete components. Such a circuit is described here. It consists of an opamp and a handful of diodes and passive parts, all of which you may have lying around in your junk box.

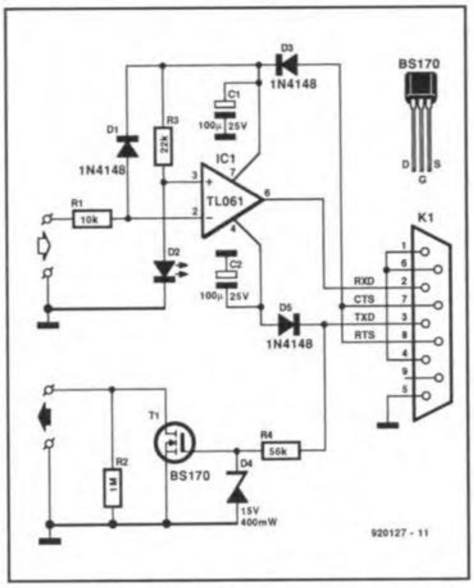


Fig. 1. Circuit diagram of the TTL-to-RS232 interface. Powered by the PC!

About the circuit

The interface shown in Fig. 1 uses the datalines TxD (transmit data) and RxD (receive data), as well as the RTS (request to send) and CTS (clear to send) lines, which are at a positive potential. Ground (pin 5) is, of course, also used. The remaining handshaking lines, DTR (data terminal ready), DSR (data set ready) and DCD (data carrier detect) are wired as a zero-modem, so that the PC switches itself into the 'ready' state.

The communication in the RS232-to-TTL direction is very simple. The TxD line is connected to the gate of a MOSFET Type BS170 via a simple overvoltage protection, R4-D4. When TxD is active (high), the positive voltage turns the transistor on, so that the TTL output is pulled to ground. When TxD is not active, the negative voltage blocks the transistor, so that the output is effectively 'open'. It can be pulled high with the aid of pull-up resistor connected to the power supply of the TTL circuit. Resistor R2 ensures fixed level ratios at the output when this is not connected to a TTL circuit.

The operation of the interface in the TTL-to-RS232 direction is a little more complex, mainly because the two TTL levels, 0 V and +5 V, have to be arranged symmetrically with respect to ground. This is achieved by an opamp set up as a comparator. The reference voltage is produced by R3-D2, which keeps the non-inverting opamp input at about half the TTL supply voltage, or 2.5 V (this equals the drop across a green LED). A high TTL level at the input causes the opamp output to swing to the negative supply level, and a low level, to the postive level. The actual swing of the opamp output voltage depends on the levels used on the RS232 interface. Depending on the RS232 interface card fitted in your PC, this swing can be anything between ±5 V and ±15 V, all of which are handled perfectly by the present interface.

The positive supply voltage for the opamp is obtained from the RTS-CTS terminals on the RS232 interface. The negative supply voltage is obtained from the inactive TxD line. Capacitor C2 functions as a buffer that stores the peak voltage on the line when TxD goes active (low). When that happens, diode D5 prevents C2 being discharged. Components D3 and C1 have a similar function. In addition, D3 prevents a TTL 'high' level being short-circuited via a switched off RS232 interface.

The construction of the interface is entirely straightforward on the printed-circuit board shown in Fig. 2. Nothing can go amiss if you keep a good eye on the position of the polarized components. The TTL input and output are marked by an open and a closed arrow respectively. Finally, do not forget the pull-up resistor at the TTL output — without it, the interface does not operate correctly. ■

COMPONENTS LIST

Resistors:		
1	10kΩ	R1
1	1MΩ	R2
1	22kΩ	R3
1	56kΩ	R4
Capacitors:		
2	100µF 25V radial	C1;C2
Semiconductors:		
3	1N4148	D1;D3;D5
1	green LED	D2
1	15V 0.4W zener diode	D4
1	BS170	T1
1	TL061	IC1
Miscellaneous:		
1	9-way sub-D socket for PCB mounting	K1
1	Printed circuit board 920127 (see page 70)	

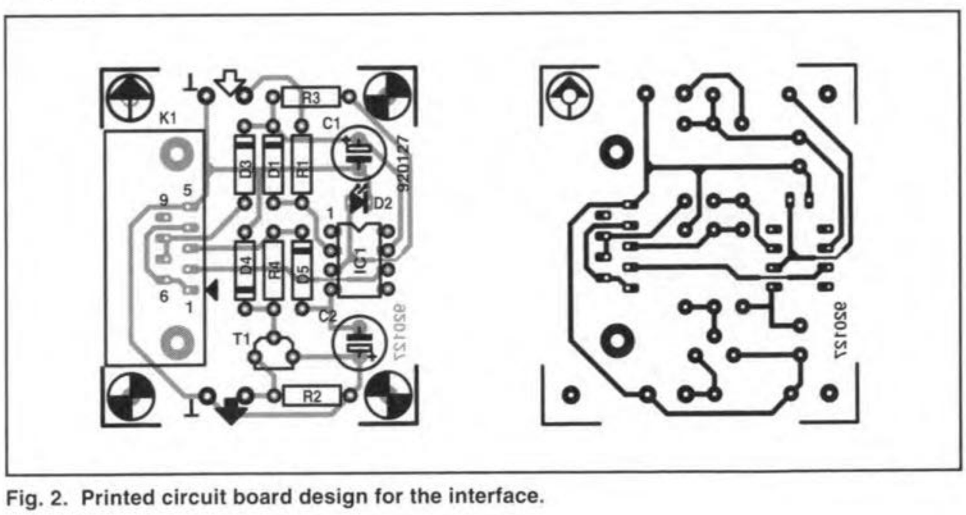


Fig. 2. Printed circuit board design for the interface.

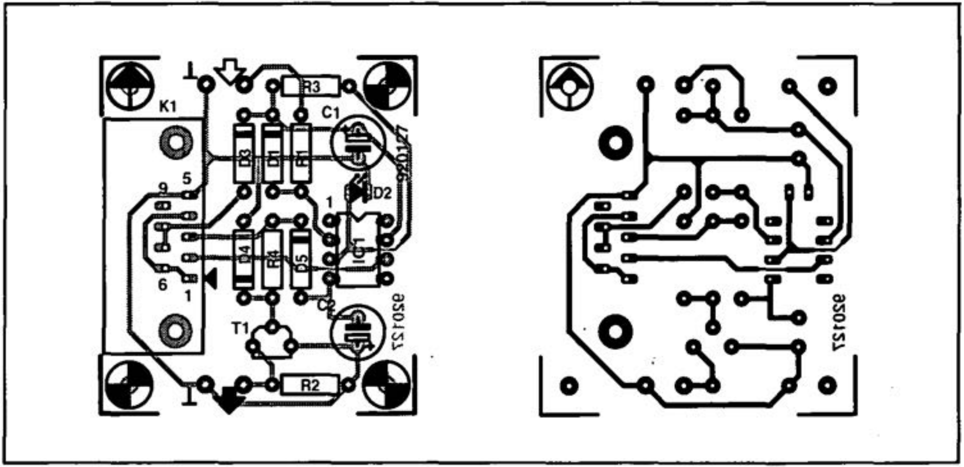


Fig. 2. Printed circuit board design for the interface.

NEW LOGIC SYMBOLS

by our technical staff

IN the late 1960s, the International Electrotechnical Committee, IEC, set up a working group to devise symbols for binary logic. The work of this group culminated in the early 1980s in IEC Publication 617: Graphical Symbols for Diagrams, Part 12: Binary Logic Elements. This standard, published in 1983, went into general circulation in early 1984. It takes into account the use of computer-aided drafting equipment and all symbols are designed on a grid.

The symbology contained in the standard provides that each symbol has one meaning only; rules are given how these symbols can be united to form the most complex logic functions. In a way, it may be compared to the higher programming languages: these, too, contain symbols (letters, ciphers, punctuation marks) that have one meaning; syntax is used to unite them into complete computer programs.

In spite of the standard having been published in 1983, even today many manufacturers feel obliged to give the 'old' symbol alongside the new IEC symbol. The reason for this is that, although the new symbols are far more informative than the previous ones, they have to be learned like a new language. And it remains true that most of us are conservative: we don't like change.

Nevertheless, we feel that the time has come to start using the new symbols in our drawings. Most technical schools and colleges, as well as the semiconductor industry, have been using them for years. The reason that we have been slower than usual in adopting a newer and better technique is a very practical one. Our design department has been investing in the acquisition and further development of computers and software that are able to provide the desired quality of graphics output—note that a 'normal' CAD system is *not* suitable. However, these systems have recently come 'on stream' and the department can now start using electronic means of reproducing the new symbols.

Do not think, though, that we are changing overnight: the move to using the new symbols will be a gradual one and will probably take until the end of the year. To prepare you for the change, a number of symbols for the basic functions, as well as a few more complex ones, are shown in the illustrations. We will publish the illustrations again in a number of future editions.

An important point to bear in mind is, though, that we are not adopting the new IEC symbols automatically in all cases: several are far larger than the previous symbols and their use might mean that the relevant circuit diagrams would become rather unwieldy for reproduction in the magazine. In such cases, we may choose a simplified symbol that is more akin to the old one. This will, of course, be made absolutely clear in the text, on the diagram or in the caption to the diagram.

Do not be put off by a first sight of the new symbols: they may seem complicated at first, but they offer excellent facilities for specifying designs without requiring precise forms of implementation. At the same time, they retain a precise specification of the required logic functions with the minimum amount of support documentation.

An excellent book for learning to understand the new symbols is *A practical introduction to the new logic symbols* by Ian Kampel, ISBN 0 408 01461 X, published by The Butterworth Group, Borough Green, Sevenoaks TN15 8PH, England.

TABLE 1

Dependency notation

The letter x in this table is used to denote an identifying number; substitution of an appropriate number is required in normal usage.

Ax	ADDRESS dependency
Cx	CONTROL dependency
ENx	ENABLE dependency
Gx	AND dependency
Mx	MODE dependency
Nx	NEGATE dependency
Rx	RESET dependency
Sx	SET dependency
Vx	OR dependency
Zx	INTERCONNECTION

TABLE 2

General qualifying symbols

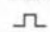
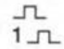
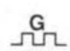
&	AND gate or function
≥1	OR gate or function
=1	XOR gate or function
=	Logic identity
1	The single input must be active (i.e, non-inverting buffer)
2*k*	An even number of inputs must be active
2*k*+1	An odd number of inputs must be active
X/Y	Coder or code converter (e.g., DEC/BCD, BIN/7-SEG)
MUX	Multiplexer
DMUX	Demultiplexer
Σ	Adder
P–Q	Subtractor
CPG	Look-ahead carry generator
π	Multiplier
COMP	Comparator
ALU	Arithmetic logic unit
	Retriggerable monostable
	Non-retriggerable monostable
	Astable, general symbol
	Astable, synchronously starting
	Astable, synchronously starting, stopping after completion of last pulse
SRGm	Shift register where substitution for m specifies number of bits
CTRm	Counter where substitution for m specifies number of bits
CTRDIVm	Counter/divider where substitution for m specifies cycle length
RCTRm	Asynchronous counter where substitution for m specificies cycle length
FIFO	First-in first-out memory
CT=m	If output: active if the counter state of the register content is m If input: when active, the counter state of the register content is set to m
I=0	Element is reset at power-up
I=1	Element is set at power-up
RAM	Random-access memory
DRAM	Dynamic random-access memory

Table 3 (opposite page). Qualifying symbols and symbols used inside the outline.

	General logic symbol
	Logic with common control
	Logic with common output
	Polarity indicator at input
	Polarity indicator at input (for information from right to left)
	Polarity indicator at output
	Polarity indicator at output (for information from right to left)
	Dynamic input (edge triggered) L → H
	Dynamic input H → L
	Internal connection
	Internal connection with negation
	Internal connection with dynamic character
	Internal connection with negation and dynamic character
	Internal (virtual) input
	Internal (virtual) output
	Output of a pulse-controlled element
	Bi-threshold (input with hysteresis)
	Open-circuit output
	Open-circuit H-type output
	Open-circuit L-type output
	Passive pull-down output (similar to 19 but containing internal pull-down resistor)
	Passive pull-up output (similar to 20 but containing internal pull-up resistor)
	3-state output

	Output with larger than usual output power (indicates direction of signal current)
D	Data input
J	J input
K	K input
R	R (reset) input
S	S (set) input
T	T (toggle) input
	Shift right (down)
	Shift left (up)
+	Count up
–	Count down
?	Query (interrogate) input
!	Compare output of an associative memory
o … m	Bit grouping symbol for inputs
o … m	Bit grouping symbol for outputs
P	Operand (P) input
Q	Operand (Q) input
>	Greater-than input
<	Less-than input
=	Equal input
>	Greater-than output of a comparator
<	Less-than output of a comparator
=	Equal output of a comparator

BI	Borrow-in input
BG	Borrow-generate input
BG	Borrow-generate output
BO	Borrow-out output (e.g., ripple)
BP	Borrow-propagate input
BP	Borrow-propagate output
CI	Carry-in input
CG	Carry-generate input
CG	Carry-generate output
CO	Carry-out output
CP	Carry-propagate input
CP	Carry-propagate output
CT=m	Content input
CT=m	Content output
	Line grouping symbol for inputs
	Line grouping symbol for outputs
	Non-logic input
	Non-logic output
∩	Input for analogue signals
#	Input for digital signals
∩	Analogue output
#	Digital output

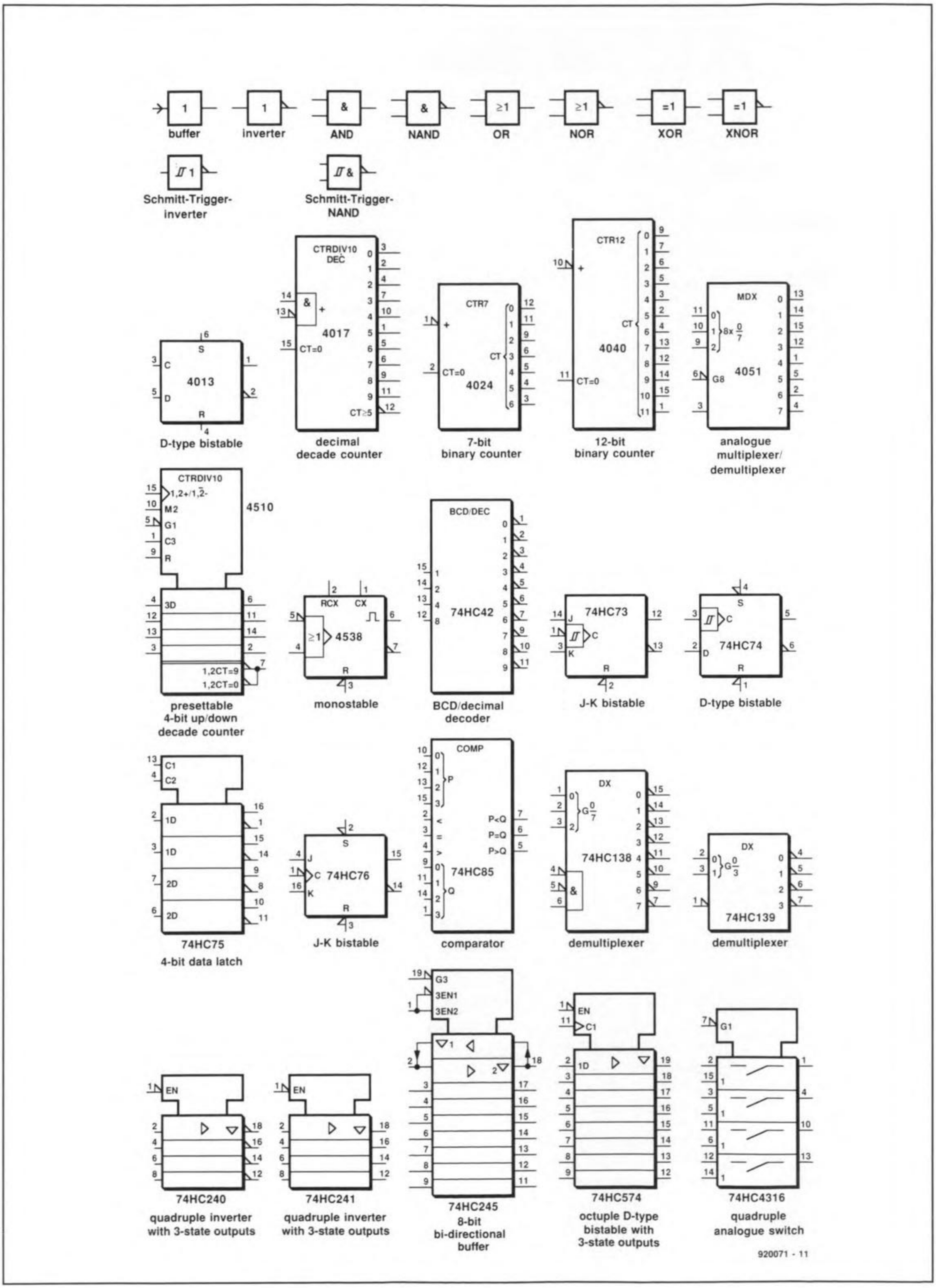


Fig. 1. A number of examples drawn according to IEC standard No. 617.