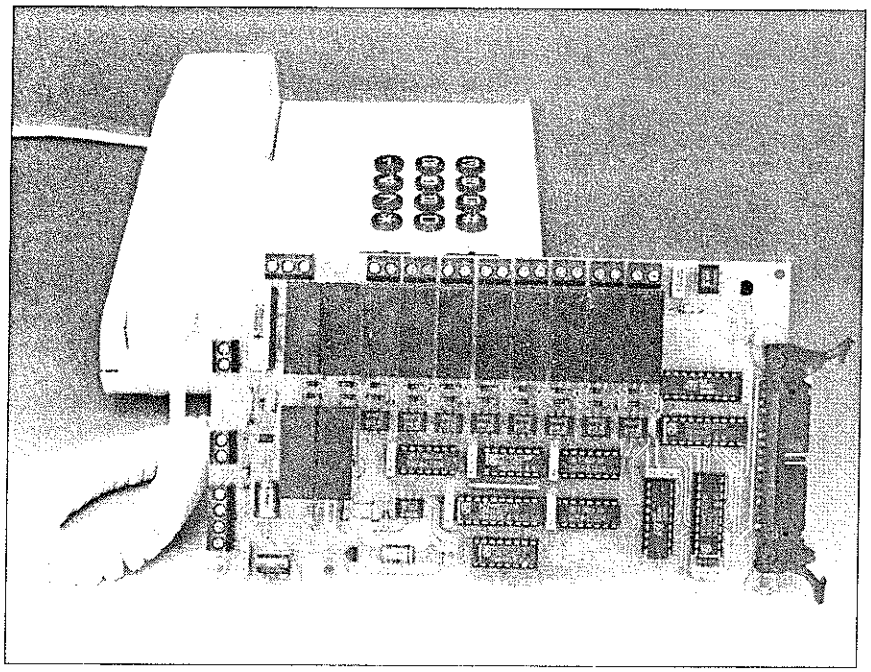
MICROPROCESSOR-CONTROLLED TELEPHONE EXCHANGE

The telephone exchange presented here allows up to eight pulse-dialling telephone sets to be connected, and has an option for connecting calls to or from an external (trunk) telephone line. The unit is controlled by the popular 8052-based BASIC computer we introduced a few years ago.

A. Rigby



MAIN FEATURES

- 8 internal lines
- 1 external line
- memory for 10 numbers
- internal through connections
- versatile computer control
- automatic hold for external line
- simple-to-extend
- can be interfaced to a PC
- selective external call acceptance
- shortcut dial codes for external number
- works with pulse-dialling telephone sets
- one optional relay for extra switching function

Since the telephone exchange is controlled by a computer, it is relatively easy to add or change certain features simply by extending or changing the control program. The nice thing about the 8052-based computer used here (Refs. 1 and 2) is that it can be programmed in BASIC, a computer language familiar to many. In the present application, the BASIC computer runs its application program from an on-board EPROM. All that is required to modify this program is a terminal or a PC running a communications program, and a three-wire link to the BASIC computer. With these tools, the user is at liberty to edit and extend the existing control program in order to 'customize' the telephone exchange. The terminal or PC is no longer required once the control program has been tested and found to work all right. If you have no intention to change the 'standard' control program, or lack the ability to program in BASIC, simply use the ready-programmed EPROM available for this project. In most cases, this standard control program will provide all the necessary functions users of a telephone exchange for a small network in the home or small office or workshop have come to expect.

Telephone: the basics

Before discussing the operation of the telephone exchange, it is useful to look at the basic operation of the telephone system. In the following discussion, it is assumed that pulse-dialling telephone sets are used. The operation of tone-dialling (DTMF) is not covered. Details on this system may be found in Ref. 3.

Figure 1 shows the general lay-out of a telephone connection. When the receiver is on the hook, the bell inside the telephone set is connected to the telephone line. When the receiver is lifted, the voice circuit of the set is connected to the telephone network, and a direct current flows through the microphone. The telephone extensions connected to the network receive their supply voltage from the local telephone exchange. All sets are connected to two lines and operate free from the earth line. The use of balanced lines is a simple, yet effective, way, to eliminate noise in the network. Since any noise induced on the network is, in principle, equally strong and of equal phase on the 'a' and 'b' lines, it is effectively inaudible.

Outgoing calls

The timing diagrams in Fig. 2 show the switching sequences during a telephone call. Again, only the 'a' and 'b' lines are involved in establishing the call. Normally, a voltage of 50 to 60 V exists between these lines. The exchange detects that a receiver is lifted when the line voltage drops to about 10 V, and a microphone current of about 20 mA is established. Next, the exchange sends the dial tone to the calling extension to indicate that a number may be dialled. In the pulse-dialling system, the current loop is interrupted repetitively. The pulse rate usually

lies between 9 and 11 pulses per second. The 'break' period is called 'pulse', and the 'connect' period is called 'pause'. The pulse length is generally defined as 61.5% ±3% of the period. Assuming that the period is 100-ms, the current is interrupted for periods of 58.5 to 64.5 ms. The pause allowed between successive numbers is 0.7 to 1 s.

The local exchange starts to call up the wanted extension with the aid of a ringing signal after the complete number has been received from the calling extension. When the call is answered, the exchange starts to put a cost count signal on the 'a' and 'b' lines. This signal is a sine-wave burst with an amplitude of about 50 V. Since it is the same on the 'a' and 'b' line, it is inaudible to the calling as well as to the called party. A cost counter, however, is connected asymmetrically to the network to allow it to detect the pulses. When either party rings off (puts the receiver down), the voltage between the 'a' and 'b' line reverts to the 'standby' level of 50 to 60 V.

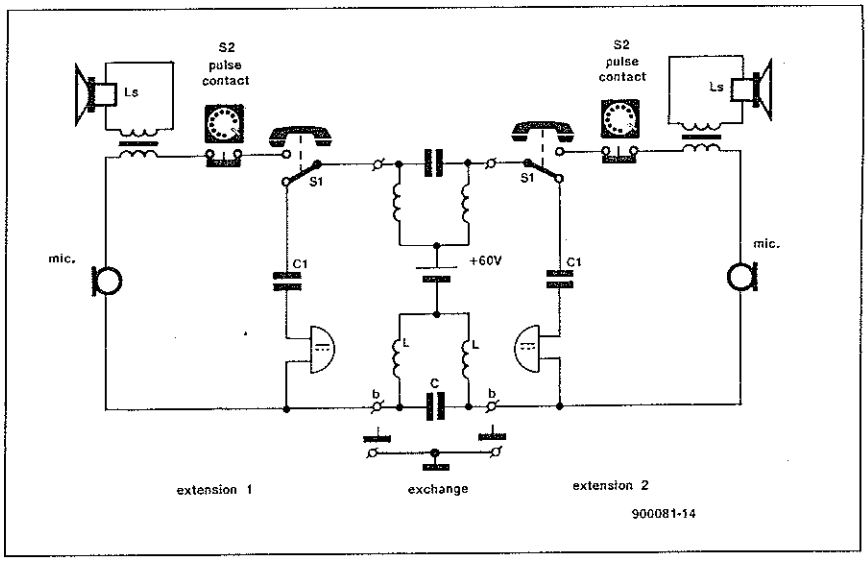


Fig. 1. Illustrating the basic operation of the two-wire telephone system.

Incoming calls

The operation of the telephone system in the case of incoming calls is illustrated in Fig. 3. An incoming call is detected by the ringing signal produced by the telephone set. The exchange calls up the extension by putting an alternating voltage of about 50 V_{PP} on the 'a' and 'b' lines. The fact that the signals on 'a' and 'b' are in anti-phase allows the telephone to detect the ring signal and actuate a sounder device (usually a small bell or buzzer). The ringing continues until the called party lifts the receiver to answer the call. If the call is not answered after a predetermined number of rings, the connection is broken (in the exchange discussed here, the maximum number of rings is set to 13). When the called party lifts the receiver before the last ring, the previously mentioned direct current flow is established, enabling the exchange to detect that the call is answered. The telephone conversation can begin!

Electronics at work

The signal sequences shown in Figs. 2a and 2b are generated and processed by the interface board of the telephone exchange, while the control functions are carried out by the BASIC computer. The function of the interface board, of which the circuit diagram is shown in Fig. 3, is to convert the digital signals supplied by the computer board to telephone network signals, and vice versa.

The eight interfaces that establish the connections with the telephone extensions are shown at the top of the circuit diagram. The extensions are connected either to the WAIT line or to the VOICE line. Extensions used for a telephone conversation are always connected to the VOICE line, which provides the necessary supply voltage. Extensions not involved in the conversation are connected to the WAIT line, and produce the 'engaged' tone when the receiver is lifted. A number can only be dialled when the exchange is back in the wait state with all extensions connected to the VOICE line.

The interface board is linked to the BASIC computer via connector K14, which carries all the necessary signals for proper communication between these units. The $\overline{Y7}$ signal supplied by the address decoder on the BASIC computer board is used to select the logic on the interface board. The line is actuated in the address range between $E000_H$ and $FFFF_H$, which is split into three parts with the aid of address lines A10, A11 and A12, giving buffer devices IC15, IC16 and IC17 their

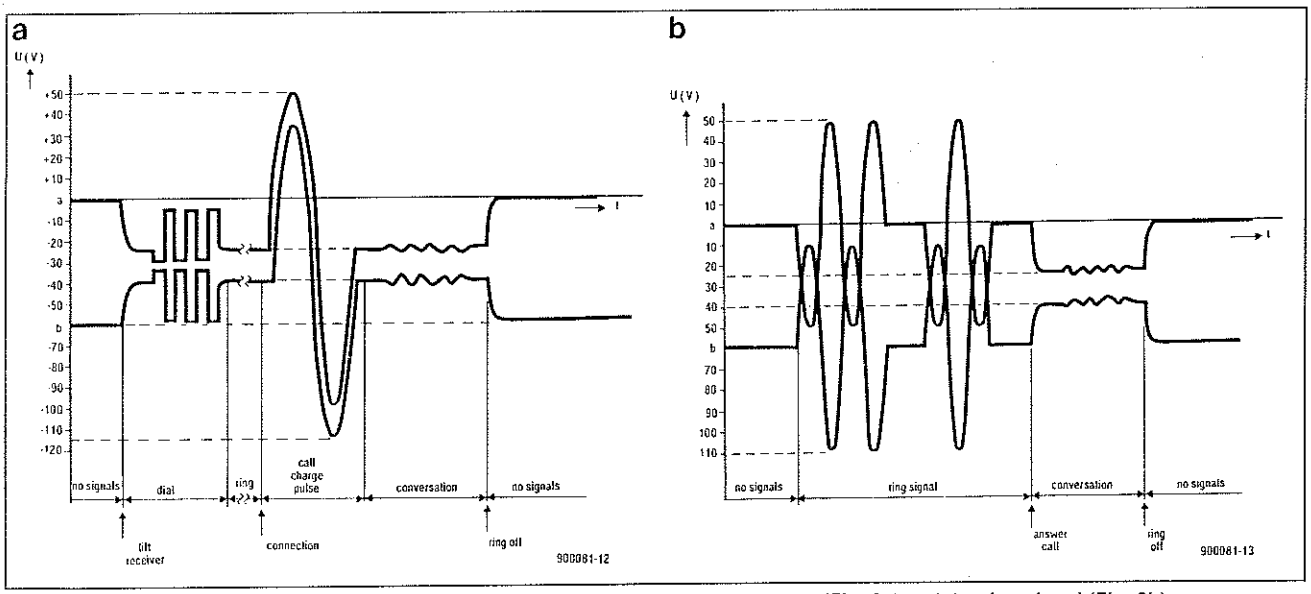


Fig. 2. Waveform sequences on the telephone lines, showing the call charge pulses (Fig. 2a) and the ring signal (Fig. 2b).

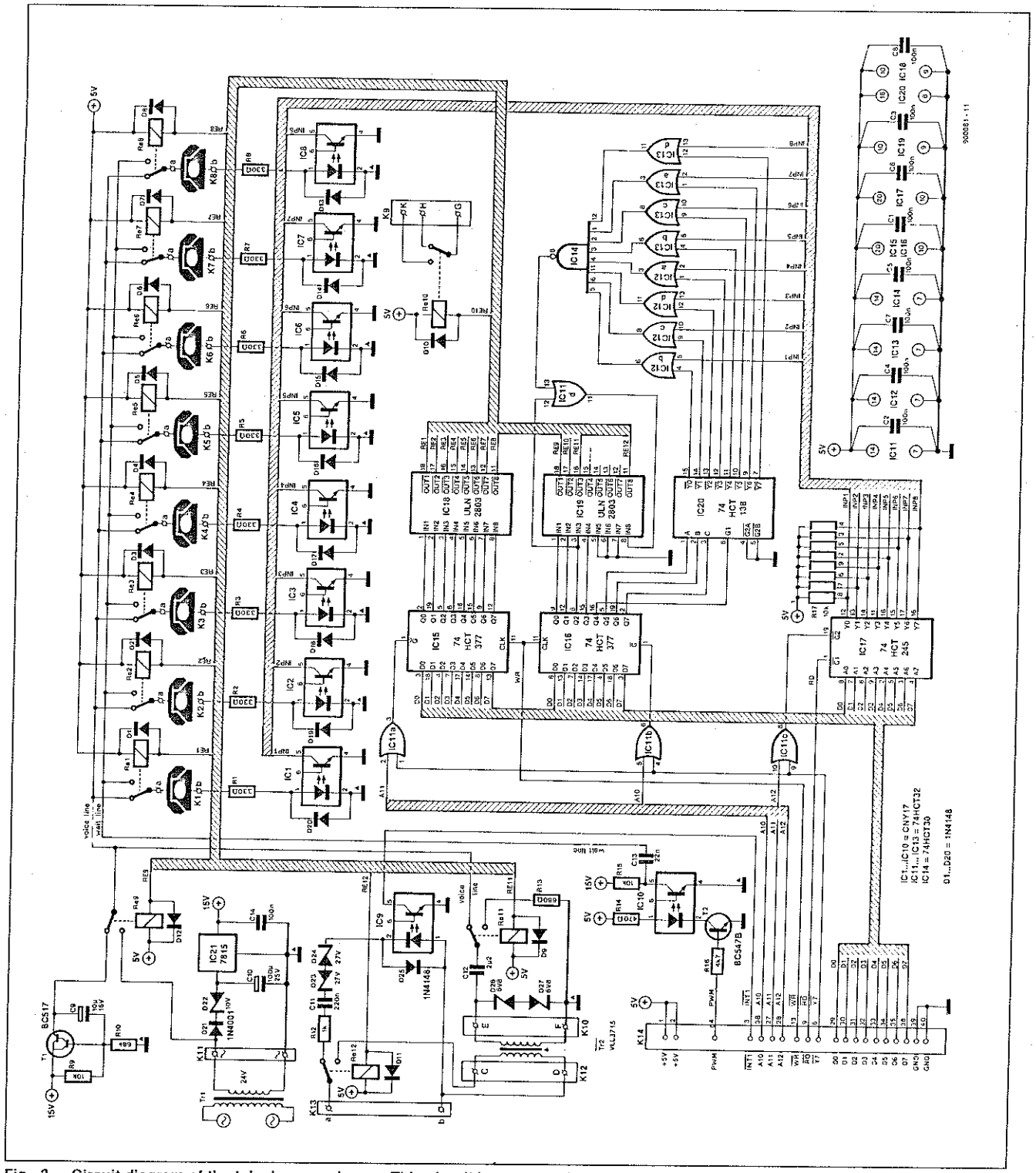


Fig. 3. Circuit diagram of the telephone exchange. This circuit is connected to the 8052-based BASIC computer via connector K14.

proper location in the memory map. The $\overline{INT}$ signal supplied by the interface board serves to wake up the BASIC processor from its stand-by state when a ringing signal is detected on the external line. The 8052 processor generates the 'engaged' tone on the PWM line. A dial tone is not generated—the network is free for dialling an extension when the receiver is silent upon being lifted. The remaining lines on K14 carry data signals, read and write signals, and the supply voltage.

Circuits IC15 and IC16 are latches that function as additional I/O registers for the control of the switching functions available in the exchange. Relays are used for the actual switching actions. Eight-bit register IC15 controls relays Re1–Re8 via the power drivers contained in IC18. These relays are used to switch the associated telephone sets between the VOICE and the WAIT line. The three least-significant datalines on IC16 switch relays Re9, Re10 and Re11. The first, Re9, is used to generate the ringing signal. In the stand-by state, transistor T1 is connected to the VOICE line, and provides all telephone sets with their supply voltage via the VOICE line. The gyrator configuration of the transistor prevents the supply short-circuiting voice signals from being superimposed on the di-

rect voltage. When Re9 is switched, the full transformer voltage is applied to the VOICE line. As a result, the bell in the extension connected to the VOICE line starts to ring. The calling party hears the ringing signal as a series of buzzing tones.

Relay Re10 is intended for optional extensions, such as a telephone-controlled door opener, and can be controlled by appropriate modifications to the BASIC control program.

Relay Re11 is used to transfer a call received on the external line to another extension in the network. By switching Re11, the external line is terminated at the required impedance. As a result, the line is held while the exchange is being used for internal calls.

Making a call

When the receiver on any of the extensions is lifted to make a call, a current starts to flow that causes the LED in the associated opto-coupler to light. This results in the relevant INP line being pulled low. The processor identifies the calling extension by reading the logic 0 it produces in IC17 at address $EFFF_H$. Next, a write command is issued to IC15 and IC16 (at addresses $FBFF_H$ and $F7FF_H$ respectively) to connect all other extensions to the WAIT line. These extensions are effectively disabled and produce the 'engaged' tone when the receiver is lifted.

The processor counts the dialling pulses produced by the calling extensions via IC17. The dialled number determines what happens next. When a 0 is dialled, relay Re12 is actuated, and the external line is selected to establish a connection to another telephone network or another exchange. The line transformer, Tr2, is connected to the external line, and all dialling pulses that follow the 0 are fed to the external line by Re12 being actuated in their rhythm. The relay contact switches between a low impedance (the line transformer) and a high impedance (the ring pulse detector). The dialling pulses are fed out of the exchange via IC11, IC12, IC13 and IC14, after the right OR gate (IC12a–IC12d or IC13a–IC13d) has been enabled via IC20. Gate IC11d ensures that dialling pulses produced by one of the internal extensions are not passed to the external line while this is on hold. This is an important feature when an call received via the external line is being transferred to another extension served by the exchange.

Receiving external calls

Calls that reach the exchange via the external line are detected by the ring pulse detector based around D23, D24, D25, R12, C11 and IC9. When a ringing pulse is detected, IC9 pulls the INT1 line of the BASIC processor logic low. Only those extensions allowed to accept calls from the external line remain on the VOICE line; all others are connected to the WAIT line. A ringing signal is placed on the VOICE line with the aid of Re9. A total of 13 rings with 2.5-second pauses is allowed. The first extension that answers the call is connected to the external line. Once again the telephone conversation can begin!

After it has been answered, the external call can be transferred to another internal extension. To do this, the active extension puts the receiver down and dials the number of the wanted extension. The external line is not disconnected until any receiver has been on the hook for more than five seconds. While the external caller is on hold, the answering extension dials another extension. The external line is connected to whichever extension remains on the line when the other puts the receiver down. If the wanted extension does not answer the call, another one may be tried. In all cases, however, the total time the receiver is down must not exceed five seconds. If none of the other extensions answers, the external caller may be connected again by dialling your own number.

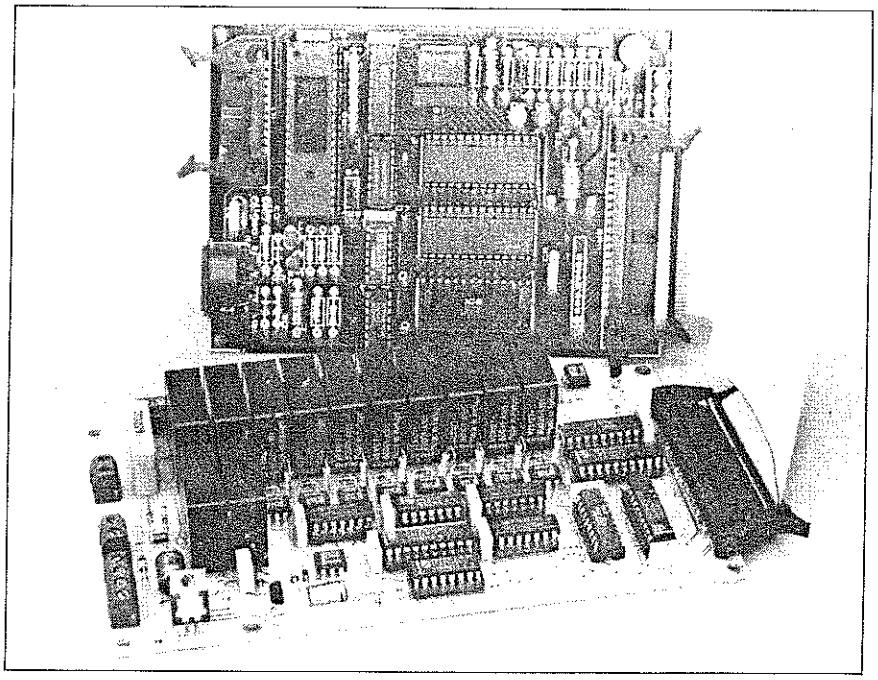


Fig. 4. Ready for use: completed BASIC computer and telephone exhange boards.

Construction

Figure 5 shows the track lay-outs and the component mounting plan of the double-sided, through-plated printed circuit board for the telephone exchange. The board has been designed to form a compact unit together with the BASIC computer. The greater part of the board space is reserved for the relays and the opto-couplers. Assuming that the ready-made board is used, the actual construction is unlikely to present problems if carried out with the necessary care. Accurate soldering is a must, though, to prevent short-circuits.

The two transformers are fitted as external parts on separate pieces of veroboard or stripboard to keep the overall size (and with it the cost) of the interface board as small as possible. Be sure to observe the necessary safety precautions because of the presence of the mains voltage on the mains transformer board. The BASIC computer is powered by a separate, regulated, 5-V supply.

The telephone sets and the transformers are connected to plastic or ceramic terminal blocks fitted on the PCB. The contacts of (optional) relay Re10 are available on connector K9 for experimental purposes.

The construction and operation of the BASIC computer is not covered here—for details, please consult Refs. 1 and 2. A small modification must be made to the existing circuit in regard of signals PWM, Y7 and INT1, which are not available on the expansion connector of the computer board. Three wire links are fitted to overcome this problem: connect pin 3 of K2 (INT1 signal) to pin 10 of K1. Next, connect pin 4 of K2 (PWM signal) to pin 15 of K1. Finally, connect pin 8 of K2 (Y7 signal) to pin 7 of IC3 (74HCT138). Since these wires go to previously unused pins of K2, they do not affect the normal operation of the BASIC computer.

The two boards are connected via a short length of flatcable fitted with IDC sockets that connect to K2 at the BASIC computer side and K14 at the interface board side. After

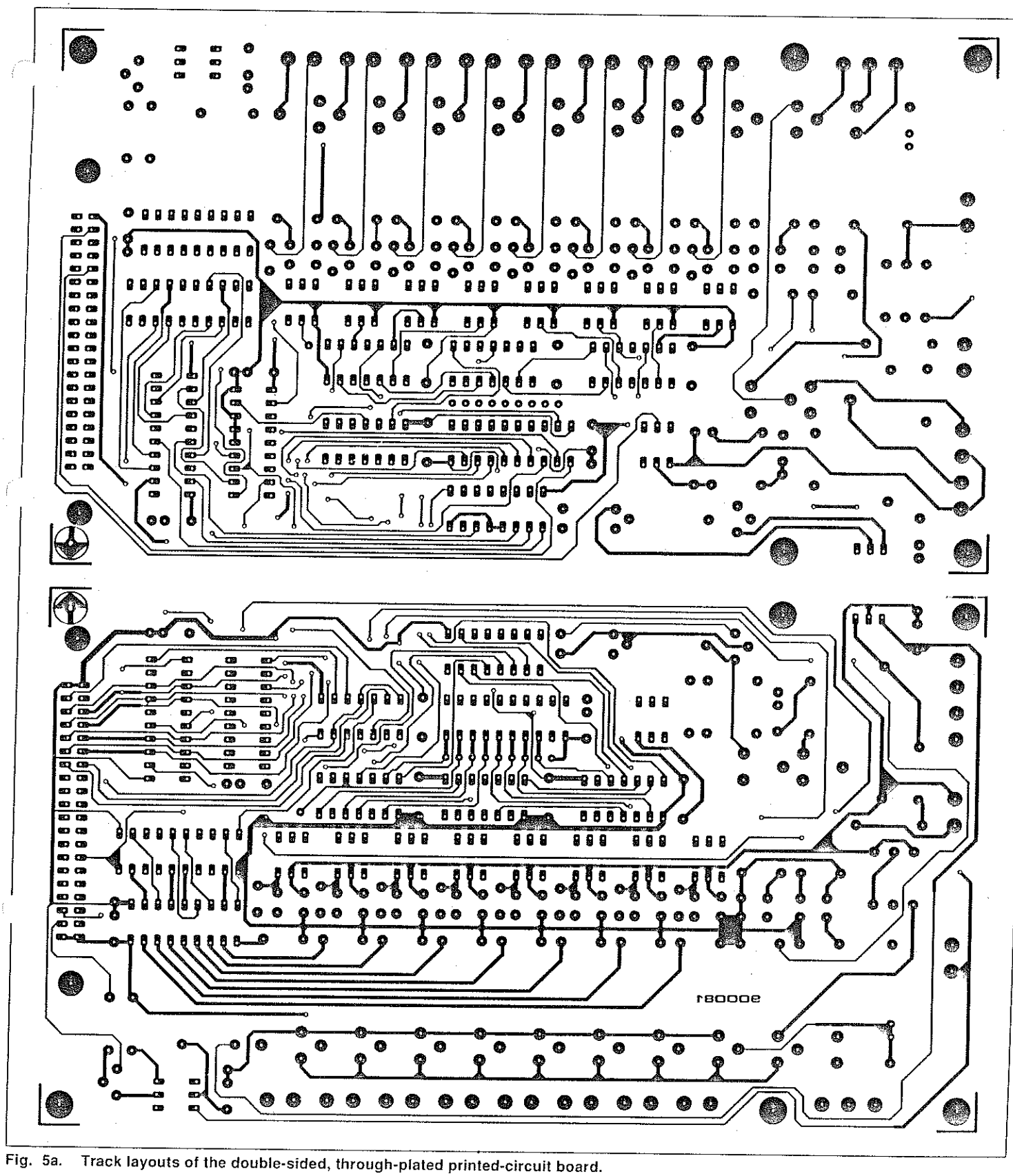


Fig. 5a. Track layouts of the double-sided, through-plated printed-circuit board.

fitting the system EPROM into its socket on the BASIC computer board, and resetting the system, the exchange is ready for use.

Control software

ftware is essential for any microprocessor-based system. The control program for the telephone exchange is written in BASIC with plenty of comment in the listing to explain the operation. As already stated, the program is supplied in the form of an EPROM. Those of you who want to change it may get out their terminal or PC, connect it to the BASIC computer, and suspend the program by typing control-C. Next, LIST the program, and edit it as required. RUN the program to check that it does what you want. The syntax requirements of the 8052 BASIC interpreter are covered in the relevant Intel manual, while possible problems with the communication between the terminal or PC and the BASIC computer are tackled in Refs. 1 and 2.

A short description is given of the function of the main routines in the control program:

- the internal numbers start with a '1', i.e., the extensions in the network have numbers 11 up and including 18.

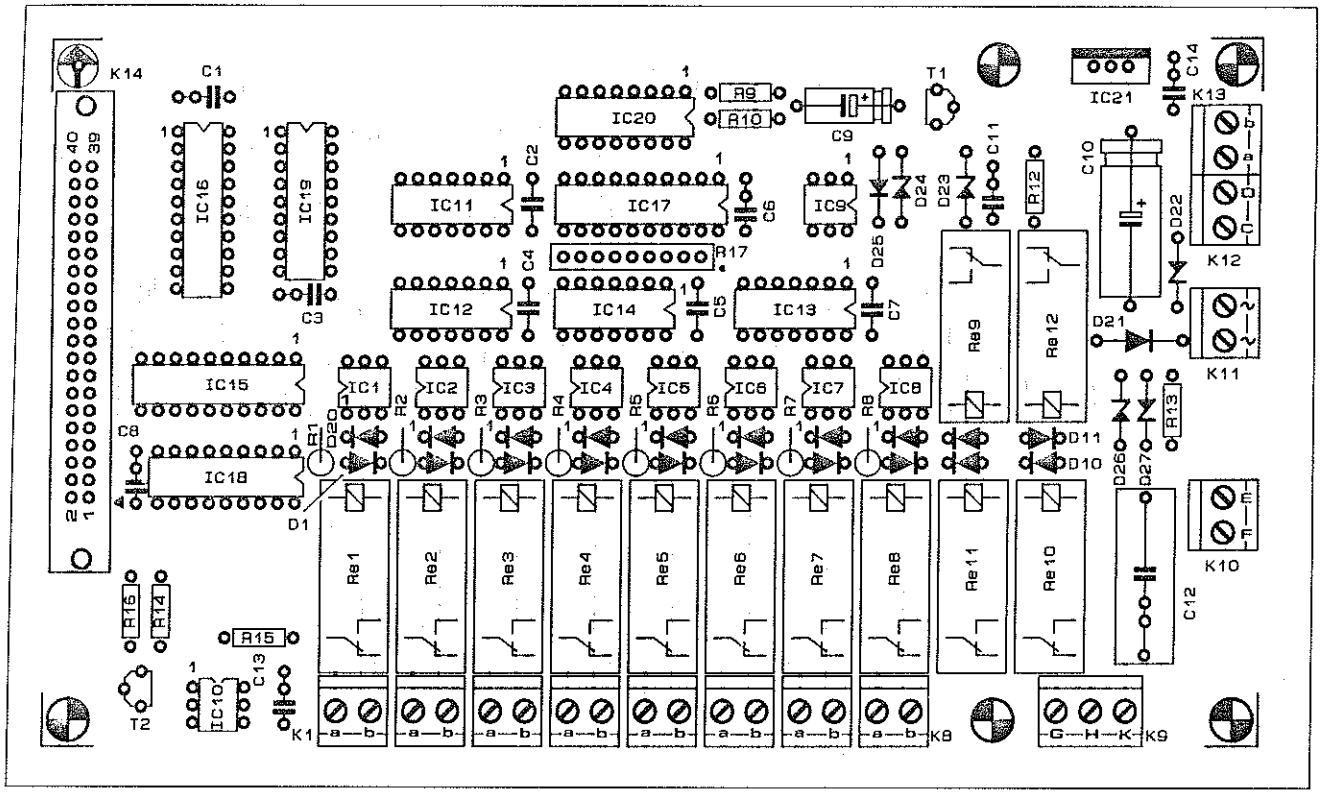


Fig. 5b. Component mounting plan.

COMPONENTS LIST

Resistors:

8	330Ω	R1–R8
2	10kΩ	R9;R15
1	68kΩ	R10
1	1kΩ	R12
1	680Ω	R13
1	470Ω	R14
1	4k7	R16
1	SIL array 8×10kΩ	R17

Capacitors:

9	100nF	C1–C8;C14
1	10µF 16V	C9
1	100µF 25V	C10
1	220nF	C11
1	2µ2 100V	C12
1	22nF	C13

Semiconductors:

10	CNY17	IC1–IC10
3	74HCT32	IC11;IC12;IC13
1	74HCT30	IC14
2	74HCT377	IC15;IC16
1	74HCT245	IC17
2	ULN2803	IC18;IC19
1	74HCT138	IC20
1	7815	IC21
1	BC517	T1
1	BC547B	T2
21	1N4148	D1–D20;D25
1	1N4001	D21
1	10V 0.4W zener diode	D22
2	27V 0.4W zener diode	D23;D24
2	6V8 0.4W zener diode	D26;D27
1	EPROM with control program for BASIC computer. Order code ESS 5941.	

Miscellaneous:

12	2-way PCB terminal block	K1–K8; K10–K13
1	3-way PCB terminal block	K9
1	40-way PCB-mount plug with eject headers	K14
12	5-V SPDT PCB-mount relay, Siemens type V23127-B0001-A101	Re1–Re12
1	24V 3.3VA mains transformer	Tr1
1	telephone line transformer type VLL3715T	Tr2
1	printed-circuit board	900081

- a total of ten shortcut codes is allowed for external numbers. These codes start with a '2', i.e., 20 up to and including 29 are available.
- the codes used for shortcut dialling are stored by first dialling '3'. Next, dial the code (0–9), followed by the number of the external connection. The processor stores the shortcut code and the associated number when the receiver is put down. All codes are available to all extensions in the network served by the exchange, and they may be changed at any time by any extension.
- a particular extension can be disabled from receiving external calls by dialling '5'. This can be undone by dialling '6'.

The function of dial numbers '4', '7', '8' and '9' is not fixed, although the software has built-in routines to intercept them. Number '8', for instance, could be used to switch on relay Re10, and number '9', to switch it off again. To be able to do this, you have to include the appropriate write command in the number interception subroutine, test the option, and program a new EPROM. ■

References:

1. BASIC computer. *Elektor Electronics* November 1987.
2. ROM-copy for 8052-BASIC computer. *Elektor Electronics* September 1990.
3. Dual-tone multi-frequency (DTMF) decoder. *Elektor Electronics* May 1989.

IMPORTANT NOTICE

The telephone exchange described here is not type-approved by British Telecom and may not be connected to the public switched telephone network (PSTN). In countries other than the UK, the relevant PTT authorities should be contacted about type-approval. In the text, 'external line' is meant to indicate a wire system other than the PSTN.