Elektor 1982

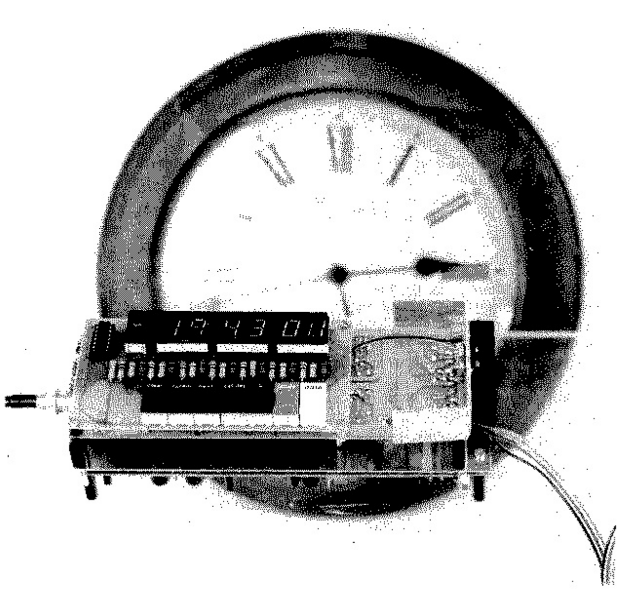
Circuits around 6502 and 6532 system

- 6502 housekeeper: a clock
- Talking clock
- Darkroom timer

6502 housekeeper

A programmable time-clock

With all the digital clocks and watches available today, it is surprising that time-switches are often such crude affairs. Given the relatively low cost of microprocessor chips, it seems 'logical' to do the job properly! This article describes a sophisticated time-clock, based on a 6502 microprocessor. It can be used to control a multitude of household appliances, such as cookers, burglar alarms and house lighting. Incidentally, since it must keep track of the time to do its job, it can also provide a digital display of time, day and date. In other words it is also a digital clock . . .



A 6502 microprocessor keeps track of the time and day of the week. It also calculates the date, even bearing leap years in mind, so that it will remain accurate until 'February 29th 2100'. . . (That is *not* a leap year, and most microprocessor-based 'perpetual calenders' go wrong at that point!).
Our electronic housekeeper is easily programmed. It provides four control outputs for switching purposes. Three of these are intended for 'daily needs' – 'on' and 'off' times are set on a 24-hours basis, and it is possible to select days of the week on which the sequence will not be executed. The times are accurate to within one minute. A fourth output is intended for a weekly cycle: ten 'on' and 'off' times are distributed over a seven-day period. The only restriction is that they must be set on a quarter-hourly basis.
The microprocessor checks the times entered; if a line seems to be switched off twice in succession, say, the 'housekeeper' will indicate this error immediately, during programming.
Obviously, this sort of thing requires an extensive program. A complete listing is included in this article, but we hope that enthusiasts will understand that we cannot explain it in detail . . . Describing the actual construction and operation of the time-clock takes up quite enough space as it is!

The hardware

Figure 1 contains the complete circuit diagram of the digital time-clock. At the heart of the circuit there is a 6502 CPU (IC1). The program for the clock and the switch functions is stored in a 2716 EPROM (IC3). The third large IC is a 6532 (IC2), which provides 16 I/O lines to control the display, scan the keys and read in the time data. In addition, the IC includes a timer (which generates seconds pulses) and another 128 bytes of RAM to store temporary data and the switch time entries.
Apart from the 16 I/O lines to IC2, an additional four output lines are needed for the different switching times. These are provided by the four-bit latch, IC4.
The clock generator is shown at the lower left in the circuit diagram. The output from a 4 MHz crystal oscillator is divided by four to obtain the 1 MHz clock signal. This division is done by two flipflops, FF1 and FF2. Another alternative would have been to use a 1 MHz crystal in the first place, but the solution used here is a much cheaper way to obtain a 'clean' squarewave.
When the unit is switched on, a '$\overline{RES}$' signal initiates the reset procedure. This signal is generated by the circuit around T1, T2, N3 and N4. Initially, T1 will not conduct but T2 will, effectively shorting capacitor C7 and ensuring that the output of N3 is at logic zero. T1 starts to conduct when the rising supply voltage reaches 4.5 V. As a result, T2 is turned off and C7 starts to charge.

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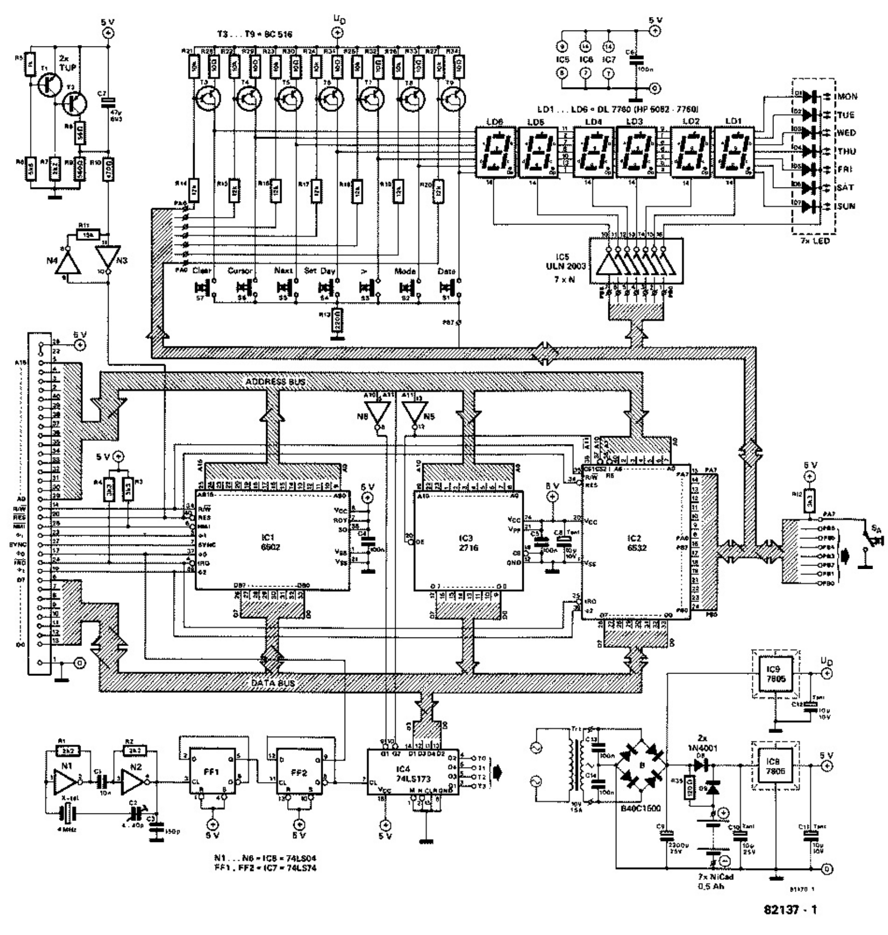

Figure 1. The circuit diagram of the programmable time clock. The 6502 CPU is situated at the centre of the circuit. The displays and their control unit are shown at the top and the power supply is located in the lower right-hand corner.

Due to the C7/R9 time constant, the output of N3 stays low for some time after the supply voltage has attained its nominal value. The circuit around N3 and N4 is included to 'sharpen up' the edges of the reset pulse. In passing, we can note that a reset pulse is also produced if the supply voltage briefly drops below the 4.5 V level for any reason, but this will be discussed later on.

One side of the six displays and 'days' LEDs is connected to the I/O lines by means of the buffer/inverters in IC5, and the other is linked to the darlington transistors, T3 . . . T9. The latter see to it that a constant current flows through the displays and the LEDs.

Two 5 V stabilisers, IC8 and IC9, produce the supply voltage. They both provide 5 V, IC9 feeding the LEDs and displays and IC8 looking after the rest of the circuit. This arrangement makes it easier to provide an emergency (NICAD) battery supply. The batteries are placed at the input of IC8. During normal mains operation, a 'topping-up' current flows continuously through the batteries by way of resistor R35. In the event of a power failure, the batteries will feed the main circuit via D9 and IC8. At the same time, a very low current will pass through the displays (by way of R35 and IC9). This system reduces the current consumption from 0.8 to 0.25 A, so that the NICAD

```
HEXDUMP: 0800,0FFF
       0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F
0800: D8 A9 FF AA E8 95 00 E0 3D D0 F9 A9 88 E8 95 00
0810: E0 47 D0 F9 A9 00 85 0F 85 21 8D 00 04 AA 95 48
0820: E8 E0 3E D0 F9 E6 4C E6 61 A9 7F 85 81 85 83 85
0830: 60 AA 9A 58 00 EA EA 20 44 09 C9 FF D0 F9 A5 87
0840: A2 00 A0 00 24 87 50 11 A2 00 E8 C8 20 8C 0B C0
0850: 28 F0 5C A5 80 10 F4 30 F1 20 8C 0B E8 E0 28 D0
0860: E3 A5 5F C9 59 D0 3F A2 96 20 8C 0B CA D0 FA A2
0870: 07 A0 06 20 9F 09 A2 05 B5 4F D5 55 D0 1F CA 10
0880: F7 A2 05 B5 55 95 4F 95 49 CA 10 F7 20 32 09 A2
0890: 08 86 61 A2 D8 86 9F 85 48 85 60 30 A1 A2 05 B5
08A0: 55 95 4F CA 10 F9 A2 FF 86 60 20 32 09 30 8F E0
08B0: 0A 90 F3 E0 1E 90 04 A9 80 D0 02 A9 00 85 63 A4
08C0: 5F C0 20 90 2B F0 3C A5 63 10 02 E6 5D A6 5E C0
08D0: 28 F0 38 C0 35 F0 32 C0 41 F0 3C C0 44 F0 42 C0
08E0: 49 F0 45 C0 57 F0 46 C0 58 F0 20 15 55 4A 95 55
08F0: A2 96 20 8C 0B CA D0 FA 18 98 F8 69 01 D8 85 5F
0900: 4C 3E 08 A5 63 30 E9 10 9D 56 55 46 5D B0 97 A9
0910: 00 85 5D E6 5E D0 D9 15 55 4A 4A 95 55 E6 5E D0
0920: CF 15 55 4A 4A 4A 10 F1 15 55 4A 10 EC 15 55 4C
0930: 1B 09 A2 0A A9 00 95 55 CA 10 F9 60 86 5B 84 5C
0940: 46 62 90 12 A2 02 B5 48 E0 02 D0 03 20 89 09 95
0950: 67 CA 10 F2 30 12 A5 4B 20 89 09 85 69 A5 4D 20
0960: 89 09 85 68 A5 4E 85 67 A6 4C A9 7F 38 6A CA D0
0970: FB 85 66 A5 60 F0 0A E6 11 E6 11 10 04 A9 FF 85
0980: 66 20 13 0B A6 5B A4 5C 60 A8 F0 06 C9 0F B0 02
0990: 09 F0 60 A0 00 20 0B 0A 49 60 D0 6E 99 48 00 20
09A0: 0B 0A 49 60 D0 64 99 49 00 20 0B 0A 49 24 D0 5A
09B0: 99 4A 00 20 0B 0A 20 0B 0A C9 08 D0 05 A9 01 99
09C0: 4C 00 B9 4B 00 C9 29 30 41 C9 31 30 11 6A 90 26
09D0: B9 4D 00 C9 08 10 02 49 FF 6A B0 1A 90 2C B9 4D
09E0: 00 C9 02 D0 25 B9 4E 00 29 13 F0 04 C9 12 D0 06
09F0: B9 4B 00 6A B0 14 A9 01 99 4B 00 20 0B 0A C9 13
0A00: D0 08 A9 01 99 4D 00 20 0B 0A 60 18 B5 48 F8 69
0A10: 01 D8 95 48 E8 60 48 98 48 8A 48 A9 00 85 81 A5
0A20: 82 85 64 C6 61 F0 08 A5 01 A9 79 85 9F D0 1B A9
0A30: 82 85 9E A5 1D F0 07 A5 48 D0 03 20 58 0A A2 00
0A40: 20 93 09 20 E9 0A A9 09 85 61 A5 64 85 82 A9 7F
0A50: 85 81 68 AA 68 A8 68 40 85 01 A2 02 A9 00 A8 8A
0A60: 0A 0A 0A 0A 85 0E B1 0E 0A A4 4C 0A 88 D0 FC 90
0A70: 08 A9 FE 25 01 85 01 B0 1F C8 C8 A5 4A D1 0E F0
0A80: 04 B0 CA 90 13 A5 49 C8 D1 0E 90 0C 88 C8 A9 01
0A90: 45 01 85 01 C0 09 D0 E2 06 01 CA 10 BF 66 01 E8
0AA0: E0 14 F0 25 20 D5 0A 98 C5 4C 90 F3 D0 1B B5 2A
0AB0: 4A 4A C5 4A F0 04 90 0E B0 0F B5 2A 29 03 A8 A5
0AC0: 49 D9 F3 0F 90 03 4C 9F 0A 8A 29 01 0A 0A 0A 05
0AD0: 01 8D 00 04 60 8A 48 4A AA B5 3E 90 08 4A 4A 4A
0AE0: 4A A8 68 AA 60 29 0F 10 F8 A2 00 8A 09 60 85 82
0AF0: 8A C9 09 D0 02 E8 8A 4A A8 90 09 B9 48 00 4A 4A
0B00: 4A 4A 10 03 B9 48 00 29 0F 09 30 85 82 E8 E0 0E
0B10: D0 D9 60 A9 40 85 1B A2 04 A9 02 85 1C B5 65 C6
0B20: 1C F0 27 30 29 4A 4A 4A 4A A8 B9 DB 0F A4 1B 84
0B30: 82 85 80 20 86 0B A5 21 C9 01 F0 07 25 1B F0 03
0B40: 20 86 0B 88 84 80 46 1B 10 D3 29 0F 10 DB CA F0
0B50: 09 E0 01 D0 C4 B5 65 4C 2D 0B A5 21 F0 04 C9 01
0B60: D0 03 20 86 0B A9 00 85 82 A9 BF 85 80 A5 82 D0
0B70: 09 A5 80 09 80 6A 85 80 B0 F3 A5 80 09 80 85 62
0B80: A2 FF 86 80 AA 60 A0 64 88 D0 FD 60 20 3C 09 C9
0B90: FD D0 F8 20 13 0B A2 7F 9A 20 44 0E 20 13 0B E8
0BA0: D0 FA 20 13 0B E8 F0 FA 20 13 0B E8 F0 F4 C9 EF
0BB0: F0 11 C9 BF F0 13 C9 DF F0 06 C9 FD F0 47 D0 E2
0BC0: 4C AF 0C 20 54 0E 4C 9C 0B A2 FF 86 69 86 68 A9
0BD0: 2A C5 0A F0 1D A9 02 C5 0B D0 02 86 66 A9 0A C5
0BE0: 0B F0 09 20 E6 0E E6 0B E6 0B 10 F1 20 48 0E 4C
0BF0: 9C 0B 86 66 20 E6 0E E6 0B A9 14 C5 0B D0 F5 20
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batteries used here will be able to stand in for about one and half hours.

The charge current flowing through the batteries is determined by the value of R35. This in turn depends on the transformer voltage and may be calculated as follows:

$$R35 = \frac{U_{C9} - 10}{20 \cdot 10^{-3}} = 50\,U_{C9} - 500\ \Omega$$

During prolonged power cuts the batteries may be discharged to such an extent that the stabilised supply voltage drops below 4.5 V. In that case, the reset circuit will introduce a reset to prevent errors in the program execution and failure of the display multiplexing unit (which might cause one of the displays to burn out!). The reset will also cause the programmed switching times to be lost. Fortunately, a power failure will rarely last longer than 90 minutes!

Instead of NICADs, two ordinary 4.5 V batteries may be connected in series, in which case R35 is omitted. They will have to be replaced after a year or two, of course. Some readers may even consider this emergency supply totally superfluous, in which case the batteries, R35 and D9 may be left out altogether and D8 may be replaced by a wire link.

The address decoding system does not need to be complete and a simple circuit (using only two inverters) will suffice, because the memory range consists of only three blocks (IC2 . . . IC4). The processor can deal with a total of 64K memory, but what happens here is that the same 4K memory block is repeated throughout the range. The three blocks are decoded by address lines A10 and A11:

A11	A10	
0	0	IC2
0	1	IC4
1	0	IC3
1	1	

Memory is mapped as follows:

*000	*400	*800
IC2	IC4	IC3
*3FF	*7FF	*FFF

(* = don't care)

The chosen structure is by no means coincidental. The EPROM is at the top end of memory, because that is where the NMI, RESET and IRQ vectors have to be fetched. IC2, the 'RIOT' (this stands for RAM, I/O, TIMER- — a well — organised IC, despite its name), is situated at the other end of the range for two reasons:

- Using the 6502 μP, 'zero page instructions (addresses 0000 . . . 00FF) are only 2 bytes long. If similar instructions are required on any other page they will consist of three bytes. This is a highly effective way in which to economise on memory space.
- Page 1 (0100 . . . 01FF) must contain RAM for the 'stack'. This requirement is met by not connecting address lines A8 and A9 to IC2 (RIOT will therefore occupy pages 0 . . . 3). This means that the 128 bytes of RAM in IC2 are used for two different purposes. The lower section belongs to page zero (0000 . . . 0069) for storing data (intermediate results and switching times), whereas the rest acts as the stack in page 1 (016A . . . 017F).

Finally, the address range between RIOT and EPROM is used for the latch (IC4).

Construction and calibration

Figures 2 and 3 show the printed circuit boards for the digital time-clock. One board contains the displays, LEDs and keys and the other accommodates the processor, with its associated components and the power supply. The boards are designed to be mounted one on top of the other, with the copper sides facing each other. Be careful when wiring the boards and inserting them into a case. Some mounting holes are drilled through wide copper tracks. Use

```
0C00: 44 0E 4C 9C 0B 20 44 0E A9 02 C5 0B F0 25 A5 69
0C10: 85 1A A5 68 85 1B C6 0B C6 0B 20 7C 0E A5 69 C5
0C20: 1A F0 04 B0 5F 90 08 A5 68 C5 1B F0 02 B0 55 E6
0C30: 0B E6 0B A9 02 C5 0A D0 06 A9 08 C5 0B F0 06 20
0C40: 54 0E 4C 08 0C 20 48 0E A5 69 85 5B A5 68 85 5C
0C50: 20 D5 0A C0 08 F0 28 84 1A E8 86 0B 20 AF 0E 98
0C60: C5 1A 90 20 F0 02 B0 11 EA A5 69 C5 5B 90 15 F0
0C70: 02 B0 06 A5 68 C5 5C 90 0B A5 0B C9 13 D0 C9 C6
0C80: 1D 4C 37 08 A9 CD 85 69 A9 DA 85 68 A9 DF 85 67
0C90: A9 FF 85 66 85 0D 20 13 0B C6 0D D0 F9 A9 2A C5
0CA0: 0A F0 06 20 50 0E 4C 9C 0B 20 68 0E 4C 9C 0B A6
0CB0: 69 E8 D0 04 86 69 86 68 A9 80 85 21 A9 2A C5 0A
0CC0: F0 30 A9 02 C5 0B F0 2A 46 21 A9 0C C5 21 D0 04
0CD0: A9 04 85 21 A9 02 C5 21 F0 1B A9 40 C5 21 F0 1C
0CE0: 4A C5 21 F0 30 4A C5 21 F0 25 4A C5 21 F0 23 4C
0CF0: 83 0D 4C 96 0D A9 00 85 21 4C 9C 0B 20 4D 0F A5
0D00: 69 18 69 10 C9 24 90 02 A9 00 85 69 4C FC 0C 4C
0D10: 3C 0D 4C 6E 0D 20 4D 0F E6 69 A9 20 25 69 F0 0C
0D20: A5 69 C9 24 D0 EF A9 20 85 69 10 E9 A5 69 29 0F
0D30: C9 0A D0 E1 A9 F0 25 69 85 69 10 D9 A9 2A C5 0A
0D40: F0 13 20 4D 0F A5 68 18 69 10 C9 60 90 02 A9 00
0D50: 85 68 4C 42 0D A9 18 85 21 20 4D 0F 18 A5 68 F8
0D60: 69 15 D8 C9 60 D0 02 A9 00 85 68 4C 59 0D 20 4D
0D70: 0F E6 68 A5 68 29 0F C9 0A D0 F3 A9 F0 25 68 85
0D80: 68 10 EB 20 4D 0F A2 2A E4 0A D0 04 A2 FF 86 0A
0D90: 20 48 0E 4C 83 0D A9 00 85 21 20 97 0F E8 D0 FA
0DA0: 20 97 0F E8 F0 FA 20 97 0F E8 F0 F4 C9 DF F0 49
0DB0: C9 EF F0 4F C9 FB D0 E8 A9 2A C5 0A F0 4B A9 80
0DC0: 85 0C A9 FF 85 66 46 0C 20 B6 0F E8 D0 FA 20 B6
0DD0: 0F E8 F0 FA 20 B6 0F E8 F0 F4 C9 DF F0 1B C9 EF
0DE0: F0 21 C9 FB F0 0A C9 F7 D0 E4 A5 0C 45 66 85 66
0DF0: A9 01 C5 0C D0 D0 4C 9A 0D 20 E6 0E A9 80 85 21
0E00: 4C C8 0C 20 E6 0E 4C C3 0B A0 01 A6 0B F0 04 CA
0E10: 20 D5 0A B9 EA 0F 85 66 49 FF 85 0C 20 B6 0F E8
0E20: D0 FA 20 B6 0F E8 F0 FA 20 B6 0F E8 F0 F4 C9 FB
0E30: F0 07 C9 F7 D0 EC 4C 96 0D 46 0C A5 0C F0 CA 38
0E40: 66 66 30 D8 A9 FF 85 0A E6 0A A9 03 C5 0A F0 18
0E50: A9 00 85 0B A9 2A C5 0A F0 16 E6 0B E6 0B A9 0A
0E60: C5 0B F0 E4 20 7C 0E 60 A9 2A 85 0A A9 FF 85 0B
0E70: E6 0B A9 14 C5 0B F0 CC 20 AF 0E 60 A9 00 A8 85
0E80: 1D A5 0A 0A 0A 0A 0A AA 05 0B 85 1C B1 1C 85 69
0E90: E6 1C B1 1C 85 68 86 1C A5 0B 6A 6A 90 0D A9 0B
0EA0: 05 1C 85 67 86 1C B1 1C 85 66 60 A9 0A 10 F1 A5
0EB0: 0B AA B5 2A A8 C8 F0 23 29 FC 4A 4A 85 69 B5 2A
0EC0: 29 03 A8 B9 F3 0F 85 68 8A 4A 90 16 A9 0A 09 30
0ED0: 85 67 20 D5 0A B9 EA 0F 85 66 60 88 84 69 84 68
0EE0: 30 E6 A9 0B 10 E8 A5 0A C9 2A F0 18 0A 0A 0A 0A
0EF0: 85 1C A0 00 A5 66 91 1C A4 0B A5 69 91 1C C8 A5
0F00: 68 91 1C 60 A0 00 A5 0B AA A5 69 0A 0A 95 2A A5
0F10: 68 F0 0B C8 C9 15 F0 06 C8 C9 30 F0 01 C8 98 15
0F20: 2A 95 2A A0 00 A9 7F C8 38 6A C5 66 D0 F9 8A 4A
0F30: AA B5 3E 90 0E 29 0F 95 3E 98 0A 0A 0A 0A 15 3E
0F40: 95 3E 60 29 F0 95 3E 98 15 3E 95 3E 60 20 81 0F
0F50: E8 D0 FA 20 81 0F E8 F0 FA 20 81 0F E8 F0 F4 C9
0F60: DF F0 09 C9 EF F0 0F C9 FB D0 E8 60 BA E8 E8 9A
0F70: 20 E6 0E 4C C8 0C A9 00 85 21 BA E8 E8 9A 4C 03
0F80: 0E A5 21 85 1A E6 0D E6 0D 10 04 A9 00 85 21 20
0F90: 13 0B A4 1A 84 21 60 E6 0D A9 70 25 0D D0 12 A5
0FA0: 66 49 FF 85 66 20 13 0B A5 66 49 FF 85 66 A5 62
0FB0: 60 20 13 0B D0 F8 E6 0D E6 0D 10 14 A5 66 85 1A
0FC0: A5 0C 45 66 85 66 20 13 0B A5 1A 85 66 A5 62 60
0FD0: 20 13 0B D0 F8 18 90 FE FF FF FF 40 79 24 30 19
0FE0: 12 02 78 00 10 23 7B 06 2F FF FF BF DF EF F7 FB
0FF0: FD FE FF 00 15 30 45 FF FF FF D5 0F 00 08 16 0A
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insulated spacers and screws here, as otherwise something may well go up in smoke!

The 'day' LEDs can best be flat rectangular types (such as HP 5082-4670). The days of the week can be indicated on the LEDs by means of transfer lettering. Different shaped LEDs may also be used and the days may be printed next to each on the front panel. A third option is to mount an LED array in a DIL package (a set of 10 LEDs, such as the MV 57164, for example) and carefully remove three of them with a saw.

The two regulator ICs must be properly cooled. The back of the metal case can act as the heat sink if the regulators are mounted directly onto it, but mica insulation and washers must be used. The pins of the regulator ICs should be soldered onto the board, by the way, not wired. It is quite feasible to separate the supply section from the rest of the board, if desired, and mount it elsewhere in the case.

The boards are connected so that both sets of PB0 . . . PB6, PA0 . . . PA6 and PA7 pins are opposite each other. The connection points can then be linked with short lengths of wire. Then connect the three power supply connections on either board.

Once construction is complete you could insert all the ICs, connect the transformer to the mains and check whether everything is working satisfactorily. If something is wrong, it would be quite a problem to trace the error without a logic analyser. But there is another method, and a few hints on how to test the hardware using an oscilloscope or a multimeter can make all the difference.

Don't connect anything up for the moment, except for the stabilisers IC8 and IC9. Don't insert the other ICs into their sockets yet! The same applies to the batteries. Now check whether the output voltage of the two stabilisers is 5 V. Switch off the supply and insert IC6 and IC7. Switch on the power again and see whether there is a symmetrical 1 MHz squarewave at pin 8 of IC7. Readers who do not own an oscilloscope may use a multimeter instead and the auxiliary circuit in figure 4a. If the oscillator is working properly, the meter will indicate about 0 V. (A reasonably good frequency counter is needed to check the frequency; calibrate the oscillator with C2.)

Now find out whether $\overline{RES}$ (pins 9 and 10 of IC6) is logic 1. If so, the code 'AA' is applied to the data bus by means of several wires and resistors, as shown in figure 4b. The indicated numbers refer to the connector pin numbers between IC1 and IC3 on the board.

Time to insert the 6502 (IC1) in its socket (turn the power off first!). After power up, a symmetrical squarewave with a frequency of 250 kHz should appear at A0 (connector pin 29), 125 kHz at A1, 62.5 kHz at A2, and so on down to 7.6 Hz at A15. R/$\overline{W}$ (connector pin 14) must remain high. If one of the above conditions is not fulfilled, first check whether AA is in fact being applied to the data bus. Again, this measurement does not require an oscilloscope and can be carried out by means of the auxiliary circuit in figure 4c. The circuit is connected to all consecutive pairs of address lines in turn: A15 and A14, A14 and A13, A13 and A12 . . . A1 and A0. Each time the meter should read either 0 V or 5 V. Any intermediate value indicates a fault. It is best to check whether there is a 7 Hz squarewave at A15 first by connecting the meter to it. The pointer will 'flutter' at this very low frequency (provided you are using a moving coil meter). Then check all the address line pairs with the auxiliary circuit.

The 'AA code' is now disconnected from the data bus. Remember, no soldering while IC1 is on the board! It will have to be removed from its socket each time. The next step is to mount the EPROM, IC3 (with the power off, of course!). Before switching on the power

2

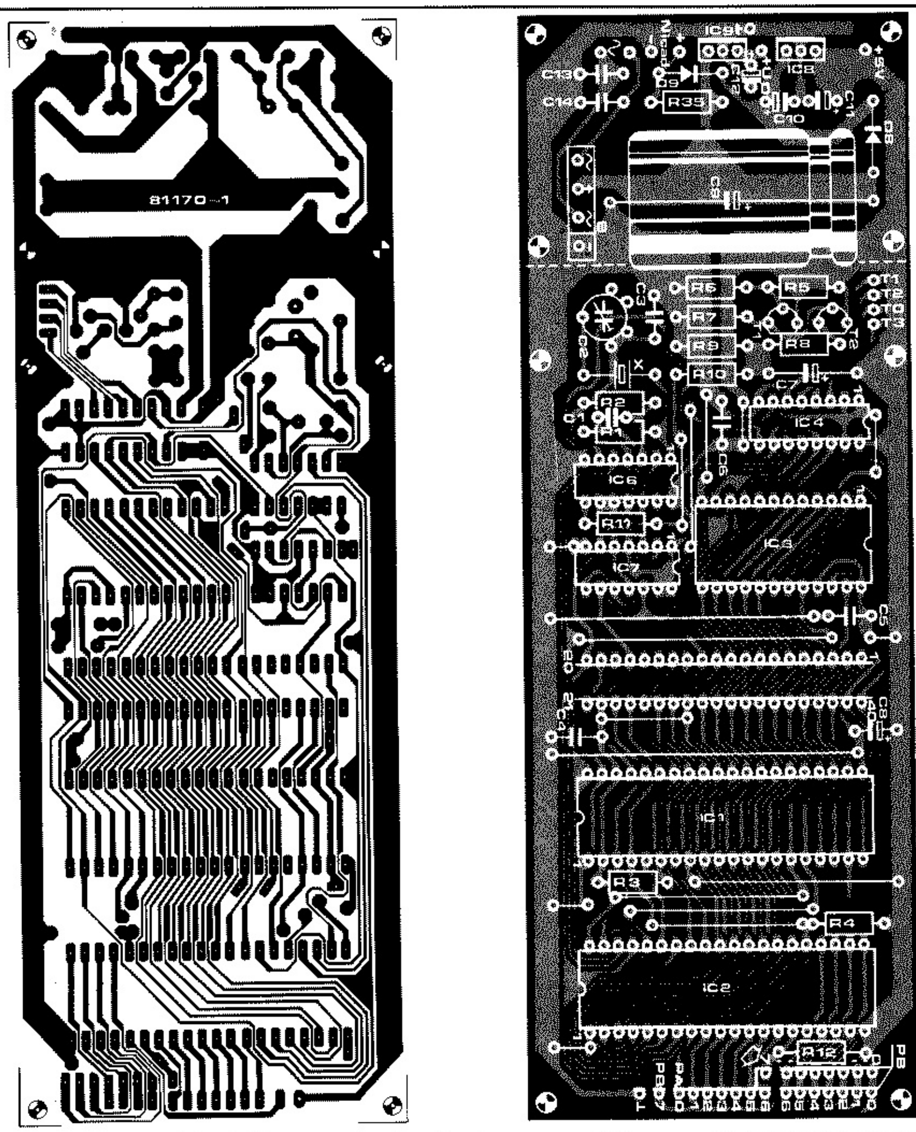

Figure 2. The main printed circuit board. This accommodates the entire microprocessor unit. The power supply section may be separated, if necessary.

Parts list

Resistors:
R1,R2,R7 = 2k2
R3,R4,R12 = 3k3
R5 = 1 k
R6 = 5k6
R8 = 56 Ω
R9 = 560 Ω
R10 = 470 Ω
R11 = 15 k
R13 = 220 Ω
R14 . . . R20 = 12 k
R21 . . . R27 = 10 k
R28 . . . R34 = 10 Ω
R35 = 120 Ω

Capacitors:
C1 = 10 n (cer.)
C2 = 4 . . . 40 p trimmer
C3 = 150 p
C4,C5,C6,C13,C14 = 100 n
C7 = 47 μ/6.3 V
C8,C11,C12 = 10 μ/10 V (tant.)
C9 = 2200 μ/25 V
C10 = 10 μ/25 V (tant.)

Semiconductors:
T1,T2 = TUP
T3 . . . T9 = BC 516
IC1 = 6502
IC2 = 6532
IC3 = 2716
IC4 = 74LS173
IC5 = ULN 2003
IC6 = 74LS04
IC7 = 74LS74
IC8,IC9 = 7805
D1 . . . D7 = LED red
see text
D8,D9 = 1N4001
B = B40C1500 bridge rectifier
LD1 . . . LD6 = DL 7760
(HP 5082-7760)

Miscellaneous:
Tr = 10 V/1,5 A mains transformer
S1 . . . S7 = digitast
X = 4 MHz crystal

3

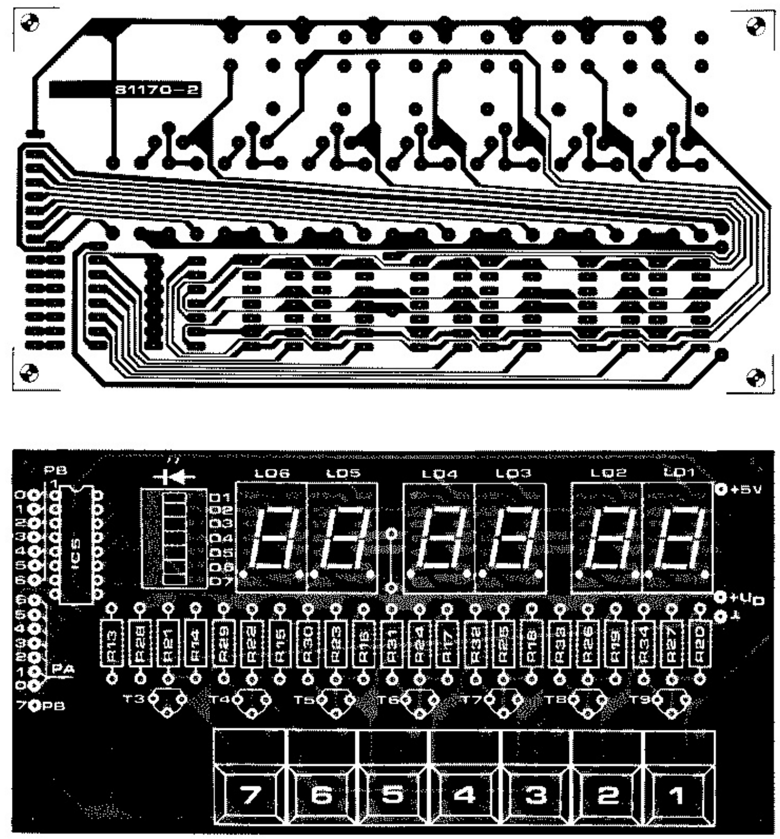

Figure 3. The display board contains the displays, LEDs, control electronics and pushbutton keys.

supply again, link pin 26 of the connector ($\overline{NMI}$) to pin 36 (A7). After power up, the address bus should read:

A15	A14	A13	A12	A11	A10	A9	A8
0	0	0	0	1	1	1	1

A7	A6	A5	A4	A3	A2	A1	A0
1	1	0	1	*	*	*	*

(A3 . . . AØ are not stable)

Furthermore, pin 20 of IC3 should be constantly low. If something is wrong, either the EPROM was not correctly programmed or N5 is not inverting the signal.

If everything is O.K. so far, pull out the mains plug for the last time, remove the connection between $\overline{NMI}$ and A7 and insert the remaining ICs. The clock should start to count from 00 00 01 as soon as the circuit is switched on.

Calibrating the crystal oscillator accurately is not an easy job. As mentioned earlier, the oscillator can be adjusted with C2, with a quality frequency meter connected to pin 8 of IC7. However, as few readers will be fortunate enough to own a really accurate frequency meter, here is an alternative method. It can be just as accurate, but it is rather more time-consuming . . .

First set the trimmer capacitor C2 in its centre position. Switch on a radio and wait for the time signal on the hour (1100, 1200, etc). Synchronise the clock on the sixth 'pip' of the radio time signal and press the start button. Let the clock run 'on its own steam' for several hours and then compare it to 'real time' again. Check whether the oscillator is 'fast' or 'slow' and readjust it with C2, if necessary. By repeating this procedure several times (over a period of a few days, if necessary) readers will be absolutely sure the oscillator is accurately calibrated.

Programming the timer

A pushbutton switch (S_A) is connected between the input and ground to start the time entry routine. Operation is as follows. After power up, the clock starts to count from 00 00 01. The clock is stopped by depressing S_A. The week/day LED then flashes. The desired day of the week may be selected with the > pushbutton (S3). Then the CURSOR key is operated (S6) and the tens/hour display starts to flash. The hours may be set by depressing > several times. The hours, minutes and seconds are all dealt with in the same manner. Once the 'second' units have been entered and the CURSOR key is operated again, the date will appear on the display. The same procedure is followed to enter the correct data, starting with the day and ending with the year (from left to right, in other words). Take care not to program an impossible date, as the clock might feel inclined to misbehave. After the year entry press the CURSOR key again. The time will then reappear on the display but no LEDs will flash. Now press the MODE key (S2) and the clock will start one second later. Readjust the time or date setting with the S_A key, if necessary. By the way, S_A doesn't have any effect unless the clock is 'ticking'!

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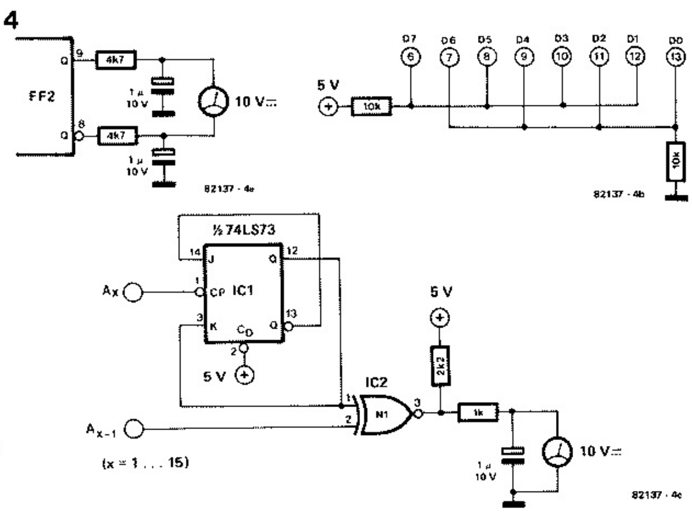

Figure 4. The auxiliary circuits for testing the digital time clock. They are only required if an oscilloscope is not available.

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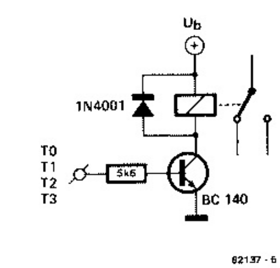
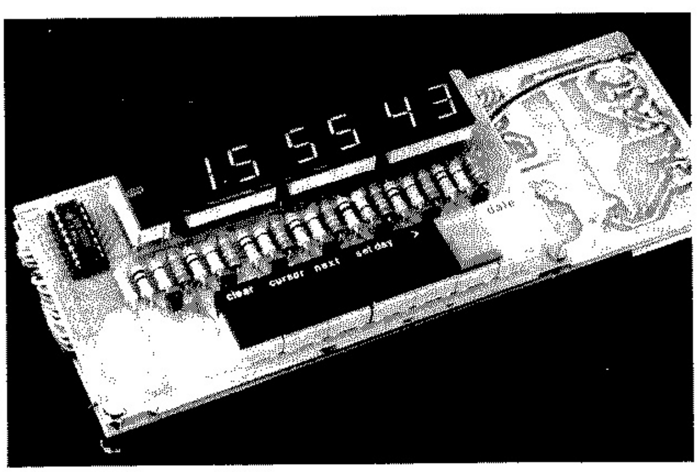


Figure 5. This tiny 'interface' enables outputs T0 . . . T3 to switch mains-powered equipment on and off.

Nothing happens if it is operated during the switch time entry routine, which is described below.

The four control outputs may be connected to any device that needs to be switched on or off at a specific time by means of a relay or a triac circuit. Outputs T0 . . . T2 can each program four switch times within 24 hours. In addition, the day of the week may be entered on which these switch times are to be processed. Every day at 00.00 hours the outputs T0 . . . T2 are automatically reset. The minimum switching interval (between 'on' and 'off') is one minute.

The fourth output, T3, can be programmed for a weekly cycle. It provides 10 'on' and 10 'off' times that can be set at fifteen-minute intervals. This line is automatically reset at the beginning of every week (at 00.00 hours on Monday morning).



The switch functions are as follows:

- S1, the DATE key, displays the date.
- S2, The MODE key, selects between the time display and the switch time entry.
- S3, the > key, increments the value on display that is indicated by a flashing cursor.
- S4, the SET DAY key, serves to program the days of the week.
- S5, the NEXT key, shows the next switching time on the display.
- S6, the CURSOR key, moves the cursor from left to right across the display (but not the right-hand digit: that indicates whether an 'on' and 'off' time is involved). The display selected by the cursor flashes to indicate that it may be altered, if necessary, with the > key.
- S7, the CLEAR key, deletes some or all of the switching times on a particular line (starting with the time currently on display).

As mentioned above, the right-hand display indicates whether the switching time shown refers to 'on' or 'off'. 'On' is represented by a '1' and 'off' by a '0'. Its neighbour shows the line number (0, 1, 2 or 3). A program example is included in this article to illustrate how the various keys work, and to give an idea of the facilities.

A return to the normal time display routine causes T0 . . . T3 to be modified according to the entered switching times. This occurs exactly one second after every minute period. During programming of the switching times, the outputs remain unchanged.

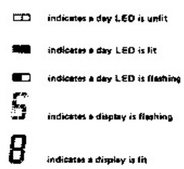
One final point. If an 'off' time is programmed and this turns out to precede the 'on' entry, depressing the MODE key will cause an ERROR message to appear on the display for a few seconds, followed by the first time that is programmed for the line where the error occurs. No return can be made to the time display. First the error must be corrected, after which the MODE key is operated to switch the processor back to time display.

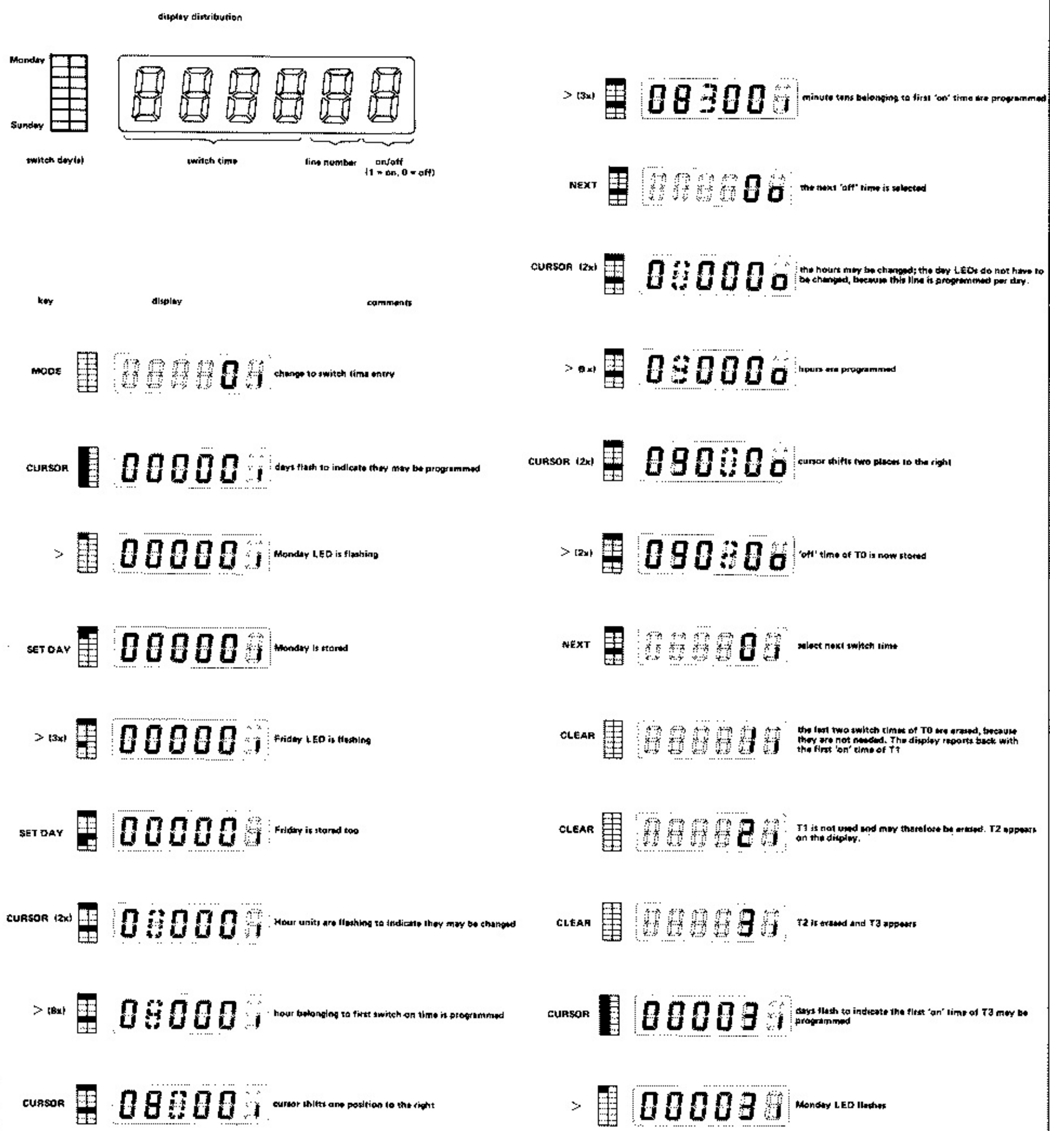
Switching mains-powered equipment

Readers who wish to switch mains-powered equipment 'on' and 'off' with the aid of the time switch require a small interface for each of the four switch outputs. Figure 5 provides a simple circuit for this purpose. The switch output controls a transistor by way of a resistor. The relay can then switch a device on and off. How much power may be switched depends on the type of relay. For the transistor shown, the relay current should not exceed 100 mA. If 12 V relays are to be used they may be connected directly to the time clock's power supply (across C9). This method ensures that the circuit is electrically isolated from the mains voltage. A solid state relay is of course equally suitable.

Program example

Switching times to be programmed:
line T0: switch on at 08.30 on Monday and Friday
switch off at 09.02
line T1: constantly '0'
line T2: constantly '0'
line T3: switch on at 20.00 on Sunday
switch off at 08.00 on Tuesday
switch on at 10.00 on Wednesday
switch off at 00.45 on Thursday





In a very short time every electrical appliance will be talking to you: the washing machine, vacuum cleaner, cooker and probably, the kitchen sink. This 'desirable feature' (?) is already evident in the new generation of digital clocks that are fast beginning to appear. A clock that actually tells the time is not such a bad idea after all, especially for the visually handicapped.
The UAA 1003 from ITT has been designed specifically to form the basis of a talking clock. It incorporates a complete speech generator designed specifically to 'tell the time'. Furthermore, it can be connected directly to

talking clock

give the 6502 housekeeper the gift of the gab!

More and more 'chattering chips' are appearing on the market. In December 1981 Elektor introduced the Talking Board with its extensive vocabulary. But, as this article points out, computers are not the only ones to talk. Even digital clocks can now be 'conversed with' thanks to the UAA 1003 from ITT, a single chip speech generator. Once the IC and a few other components have been added to the 6502 housekeeper described last month, the clock will well and truly be able to 'tell' the time!

the seven segment outputs of any (existing) digital clock.
Last month, Elektor published a versatile clock of its own, the 6502 housekeeper, and so it seemed a good idea to draw up a circuit for it using the UAA 1003. After leaving the 'operating table', the clock will be able to express the time both in digits and words.
As mentioned earlier, the speech circuit can be connected to 'ordinary' digital clocks, with the proviso, that their displays are of the CC (common cathode) type.

The speech generator

The UAA 1003 is a speech generator IC in a 40-pin package. The IC is shown in the form of a block diagram in figure 1. Digital techniques are used to store and process the required phonemes. By using data and redundancy reduction methods, it was possible to store a vocabulary of about 20 words and integrate the necessary control, decoder and D/A converter circuits, all on a single chip.
Every word generated by the speech IC contains a number of step-shaped pulses, each one having a fixed pulse duration of 10 ms. Every pulse is made of up to 128 different amplitudes which can each assume 16 values. This corresponds to 4-bit amplitude modulation. Different word segments are linked up according to the digital control signals that are applied.
The IC is currently available in two languages, English and German.
Let's examine the 'insides' of the IC as shown in the block diagram in figure 1. When the speech generator is 'switched on' via either of the two start inputs, the intermediate input data is read in. The decoder ROM and the control circuit establish the word order according to the data entered and then address the corresponding word parameters, after which the address logic fetches the speech segments from the speech ROM. The output digital code is processed inside a data regenerator before being sent to a D/A converter which delivers the actual speech signal.
The speech generator IC has a special feature in that it receives its time data from the clock's seven segment connections. However, the data inputs of the IC will only function provided the circuit is connected to a digital clock with common cathode displays that are not multiplexed.
Not all the segment connections are needed to decode the time. Segment connections c and d serve to decode the hour tens, a, b, e, f and g the hours, d, e and f the minute tens and finally,

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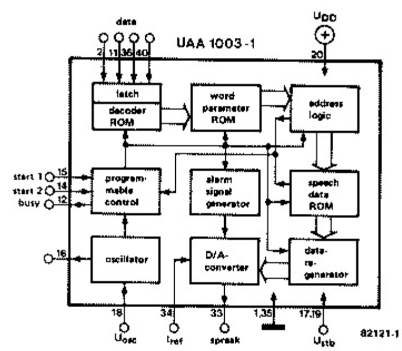

Figure 1. Block diagram of the UAA 1003. Phonemes are stored and processed in a digital manner.

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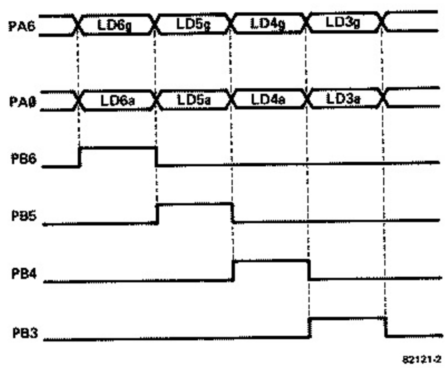

Figure 2. These signals for the display control in the 6502 housekeeper are also used to control the talking clock.

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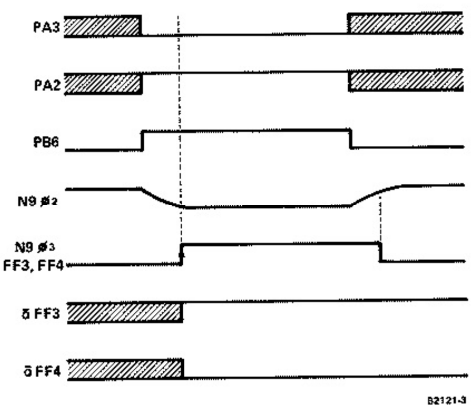

Figure 3. The signal waveforms. The PB signal can be seen to be delayed, as a result of which the clock signal for the flipflops does not arrive until the data is already available at the inputs. (In the example illustrated here there is a 2 at LD6).

a, b, e, f, and g the minutes. The data inputs of the IC have an internal pull-down resistor, enabling them to be connected directly to the segment outputs of the clock.

The pin assignment is as follows. There are two start inputs, pins 14 and 15. When the IC generates a positive pulse at pin 14 the time is announced in the manner described above. If this is produced at pin 15, however, the time is preceded by an alarm signal that lasts about one second. The 'busy' output (pin 12) is a kind of open collector output and has a low impedance while the time is being output. It may be used to control any external devices that are hooked up to the clock.

A DC voltage is applied at pin 18 so as to calibrate the oscillator frequency of the IC. The set frequency is available at pin 16 (a kind of open collector output too) for measurement purposes.

An external reference current must be applied to pin 34. The amount of current determines the level of the output signal. The speech output (pin 33) again produces an output current, as a result of which a resistor will also have to be connected to it in order to provide an output voltage.

Pins 17 and 19 constitute the stand-by power supply connections. They allow the IC to be connected to a stand-by supply whenever it is not used to indicate the time. This comes in handy if the circuit is battery-powered, for instance, but there is no need to go into that here.

Pins 20, 1 and 35 are the 'normal' power supply connections and the remaining IC pins are all data inputs.

Adapting the circuit to the 6502 housekeeper

As readers will remember, the 6502 housekeeper is more than just a clock. It can be used for timing all sorts of processes in the home, darkroom, workshop, etc. In short, a device well worth endowing with the power of speech! One minor problem has to be dealt with first: the displays on the housekeeper are multiplexed and, remember, that is precisely what the UAA 1003 does *not* cater for. Don't worry, this can be remedied by adding a couple of ICs, by way of an interface, to the circuit.

Figure 2 shows the various signals that control the displays in the 6502 housekeeper. The display segments are driven by PA0 . . . PA6 and lines PB3 . . . PB6 make sure that the four required displays are multiplexed. Using a set of D flipflops, the segment data belonging to the various displays must now be stored to allow all the signal information to be applied to the speech IC simultaneously. To ensure that the right information enters the right flipflops, the PB signals are used to read in the data on the PA lines. This means that the flipflops corresponding to the segments in display 6 must receive a clock pulse from line PB6, and so on.

If we take a closer look at the waveform on PB6, as shown in figure 3, the rising edge of the signal can be seen to appear virtually at the same time as the data on PA0 . . . PA6 (for LD6). The rising edge on PB6 must be slightly delayed, initially to make absolutely sure that the correct signals are read into the flipflops. This is taken care of by the R1/C1 delay network included in the circuit diagram in figure 4. A similar delay technique is also employed on the other PB lines.

The flipflops (IC2 . . . IC6) are situated to the left of figure 4. The seven segment data required by the UAA 1003 is permanently available at the outputs of the flipflops (as if the clock were a non-multiplexed type, after all). Theoretically, therefore, the flipflop outputs could be linked directly to the data inputs of the speech IC, were it not for another slight snag . . . The data on the PA lines is inverted with respect to the segment information. Fortunately, this can easily be remedied by connecting the Q̄ outputs of the flipflops to the data inputs instead of the Q outputs.

That just about covers all there is to say about the circuit diagram. We've already dealt with the UAA, so that only leaves the output amplifier, an LM 386 in this case. A bandpass filter consisting of R10, C5, R11, C6, C7 and P2 is included between IC1 and IC10. Potentiometer P2 acts as the volume control.

Finally, the stabilised 5 V voltage is provided by a 7805 chip, IC11. The whole circuit consumes about 150 mA current. P1 effects the only calibration needed for the circuit. This adjusts the internal clock frequency of the speech IC. The adjustment may either be carried out by ear (until the voice sounds human!) or by measuring the frequency at pin 16 of the IC. This should be about 25.6 kHz.

Connecting up the circuit

The circuit shown in figure 4 can be connected to the 6502 housekeeper without any difficulty. Lines PA0 . . . PA6 and PB3 . . . PB6 belonging to the talking clock board are simply linked to the corresponding connections on the main board of the 6502 housekeeper. The power supply may be connected up right after the bridge rectifier on the housekeeper power supply board. The ALARM input may be linked to *one* of the T0 . . . T3 switch outputs. Whenever the corresponding output goes high, a short alarm signal will be emitted, after which the time is announced. Usually, of course, pushbutton S1 is depressed to make the clock 'speak', but then the time indication will not be preceded by an alarm signal.

What about other digital clocks?

Other digital clock can be made to talk too, but this does call for a little more time, effort and components.

The simplest solution is to connect the circuit to a non-multiplexed clock with common cathode displays, as this, after all, is what the UAA 1003 was designed for. In that case, components IC2 . . . IC9, R1 . . . R4 and C1 . . . C4 may be omitted. The input of IC1 (points A, B . . . P) are connected directly to the corresponding display segments in the clock. Segment c pertaining to the hour tens display is therefore linked to point P, segment d to point N, and so on.

The logic levels of the digital clock pins from which the required signals are derived must meet the following parameters:

$0\,V \leqslant U_l \leqslant 0.3\,V$ (segment 'off')

$1.5\,V \leqslant U_h \leqslant 5\,V$ (segment 'on')

The 'low' level is usually correct due to the pull-up resistors at the inputs of the UAA 1003. The 'high' level should not be a problem either, as the operating voltage of a display segment is at least 1.6 V.

Making clocks with multiplexed displays talk is a different matter. Since in this case all the components must be mounted on the board (to store intermediate multiplexed data), the segment connections must be linked to inputs PA0 . . . PA6 and PB3 . . . PB6 in the normal manner. Note that the inputs respond to TTL levels here ($0\,V \leqslant U_l \leqslant 0.8\,V$ and $2\,V \leqslant U_h \leqslant 5\,V$). In the case of some inputs (such as PA5, for instance), a logic zero level at the

Parts list

Resistors:
R1 . . . R4 = 560 Ω
R5 = 22 k
R6 = 470 k
R7 = 1 M
R8,R9,R13 = 10 k
R10 = 680 Ω
R11 = 1 k
R12 = 10 Ω
P1,P2 = 10 k preset

Capacitors:
C1 . . . C4,C10,C12 = 100 n
C5 = 150 n
C6 = 33 n
C7 = 56 n
C8 = 47 n
C9 = 220 µ/10 V
C11 = 330 n
C13,C14 = 10 µ/10 V

Semiconductors:
T1 = BC 557
IC1 = UAA 1003-3 (English)
IC2 . . . IC4 = 74LS175
IC5,IC6 = 74LS74
IC7,IC8 = 74LS00
IC9 = 74LS132
IC10 = LM 386
IC11 = 7805

Miscellaneous:
LS = 8 Ω/0,5 W loudspeaker
S1 = pushbutton switch

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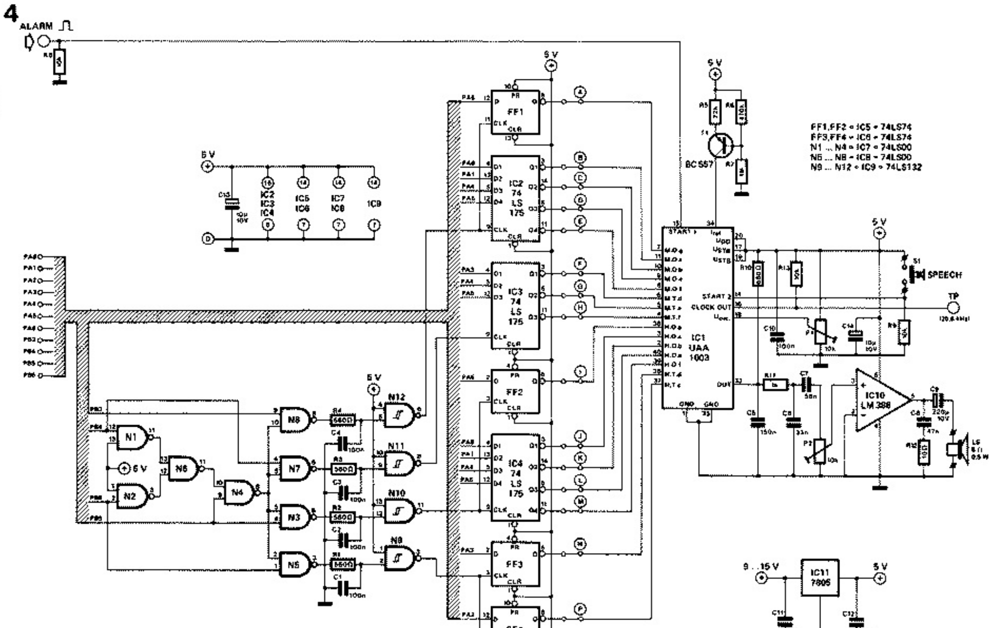

Figure 4. The circuit diagram of the talking clock. The flipflops to the left are required in connection with the multiplexed display control of the 6502 housekeeper.

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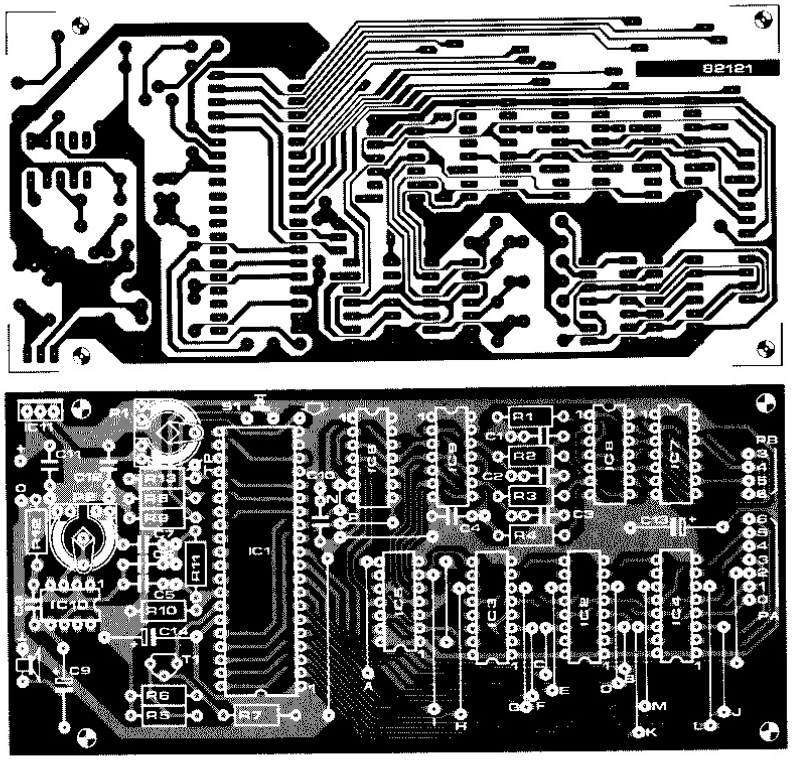

Figure 5. The printed circuit board and component overlay for the talking clock.

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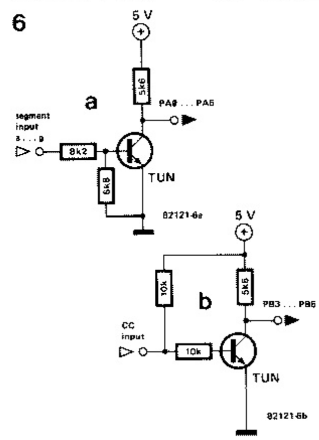


Figure 6. The interface circuits shown here have to be connected to the inputs, if the talking clock is to be combined with an ordinary clock having multiplexed CC displays. The PA and PB interfaces are depicted in figures 6a and 6b, respectively.

input will cause 1.2 mA (= 3 x LS TTL load) to be drawn from it. The segment control of such clocks does not usually meet these parameters. For this reason, an additional small interface will have to be connected to every input of the talking clock board.

The wire links to the clock will then be as follows:

PA0 – segment a
PA1 – segment b
• •
• •
• •
PA6 – segment g
PB6 – common cathode of hour tens
PB5 – common cathode of hour units
PB4 – common cathode of minute tens
PB3 – common cathode of minute units

The interface circuits are shown in figure 6. The circuit in figure 6a is connected to the PA inputs. It not only ensures that the input and output levels are well matched, but it also inverts the signal. This is necessary because the PA connections of the 6502 housekeeper provide the segment signals in an inverted form (which was taken into account in the talking clock design). The circuit illustrated in figure 6b refers to the PB inputs. Again, this circuit matches the logic levels and inverts the signals. Normally speaking, the common cathodes are driven by a transistor. The transistor conducts when its control signal is high. Thus, the principle for the PB lines and the buffer/inverters connected after them is the same as for the cathodes in the 6502 housekeeper. Every PB interface input has to be connected to the collector (and there to the CC of the display) of the 'CC' transistor just described.

The input sensitivity of the PA interface is:

$0\,V \leqslant U_l \leqslant 1\,V$
$1.5\,V \leqslant U_h$

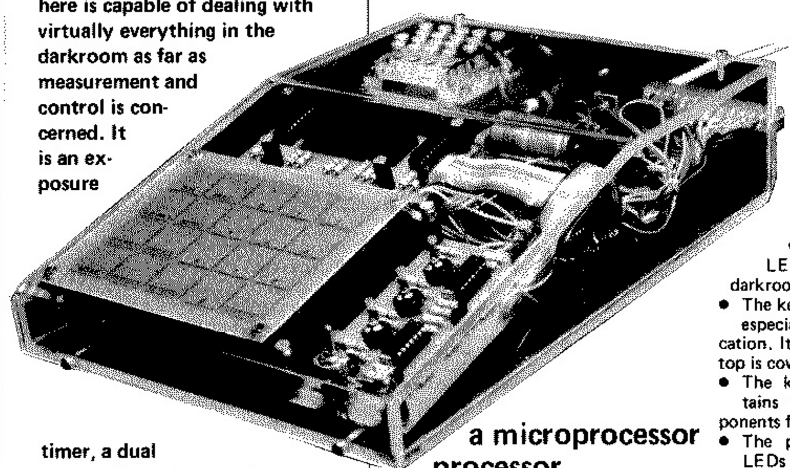
and that of the PB interface is:

$0\,V \leqslant U_l \leqslant 0.6\,V$
$0.6\,V < U_h$ (open input)

We are sorry to have to disappoint owners of digital clocks with common anode displays: this is the only type of clock which is not compatible with the talking clock board. Never mind, they will still be able to *see* what time it is . . . ◼

darkroom computer

The darkroom computer described here is capable of dealing with virtually everything in the darkroom as far as measurement and control is concerned. It is an exposure timer, a dual process timer, temperature meter, photometer and contrast meter.
The darkroom computer is based on the well-known 6502 microprocessor and a capacitive keyboard designed specifically for this application. Construction is relatively easy while overall cost is far less than the equivalent commercial systems.



PART 1

a microprocessor processor

The timing of publication of this article is no accident and was planned for the photographic enthusiasts among our readers who look forward to developing the results of their summer photographic sessions round about September. The darkroom computer was designed to take the guesswork out of the darkroom.
The microcomputer used is the 6502 and the system will cater for black and white processing as well as colour. For black and white processing, the computer functions as an exposure timer or process timer (for paper and film development), photometer, contrast meter and a temperature meter. For colour processing it is equipped with a second process timer with ten presettable time periods. However, it is not a colour analyser, since this would not only make the circuit far more complex, but mechanical construction would present difficulties. A detailed description of the uses of the darkroom processor are contained in the chapter headed 'Instructions for use'.
The darkroom processor is divided into several sections, each mounted on a separate printed circuit board and there are a total of seven boards in all:

- The processor board. A small 6502 system that forms the heart of the circuit.
- The display board. Obviously LED-displays are necessary for the darkroom.
- The keyboard. A capacitive keyboard especially designed for this application. It can be lit from behind and the top is covered with a protecting layer.
- The keyboard interface board contains the necessary electronic components for the capacitive keyboard.
- The process timer board. The 25 LEDs are used as the timing indicator.
- The photometer board, with which the light and contrast can be measured.
- The temperature meter board. For accurate temperature measurements of the several baths.

The project is fairly complex and for this reason it was decided to divide it into two separate articles. In this issue we will give a description of the computer itself together with its display and special keyboard. Instructions for use are also included. A closer look at the accesories; the process timer, the light meter and temperature meter will follow in the next article.

The microprocessor circuit

Regular readers may see from figure 1 that the microprocessor circuit is virtually identical to that of the '6502 housekeeper' that was published in the May 1982 issue. In fact the same printed circuit board is used. For a detailed description of the circuit we refer readers to this article as it will be covered only briefly here.
As can be seen from figure 1, the circuit consists of three main ICs. The 6502 microprocessor itself is IC1. This is

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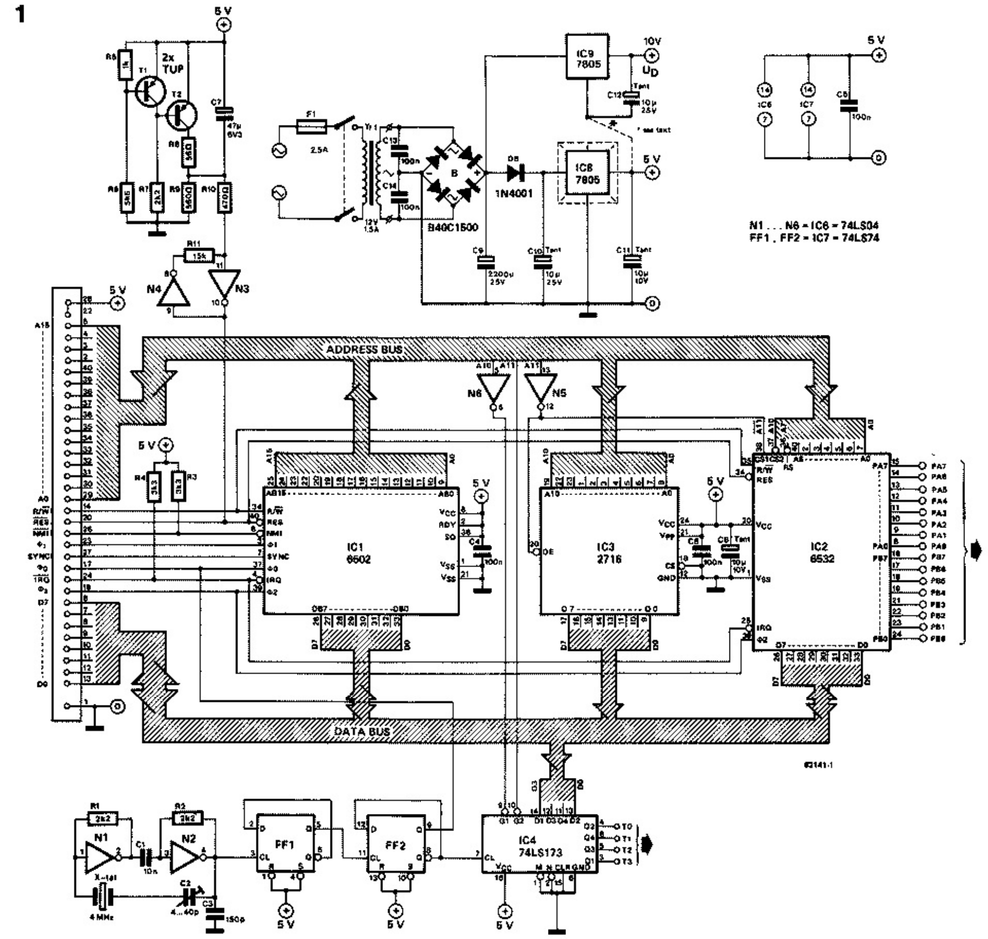


Figure 1. The circuit diagram of the microprocessor section. The system mainly consists of a 6502 microprocessor, a 2716 EPROM and a 6532 RIOT (which contains a RAM, I/O lines and a timer).

followed by the 2716 EPROM IC3, which contains the necessary software. The third major 'box' in the circuit, IC2, consists of a 6532. This IC is the interface between the computer and the outside world. It contains 16 I/O lines and takes care of the keyboard, display, process timer and the light and temperature meters. The 6532 also contains a timer which is used for the two process timers and the enlarger. The 128 byte RAM in the 6532 is used to store the temporary data and the process and alarm times given by the keyboard.

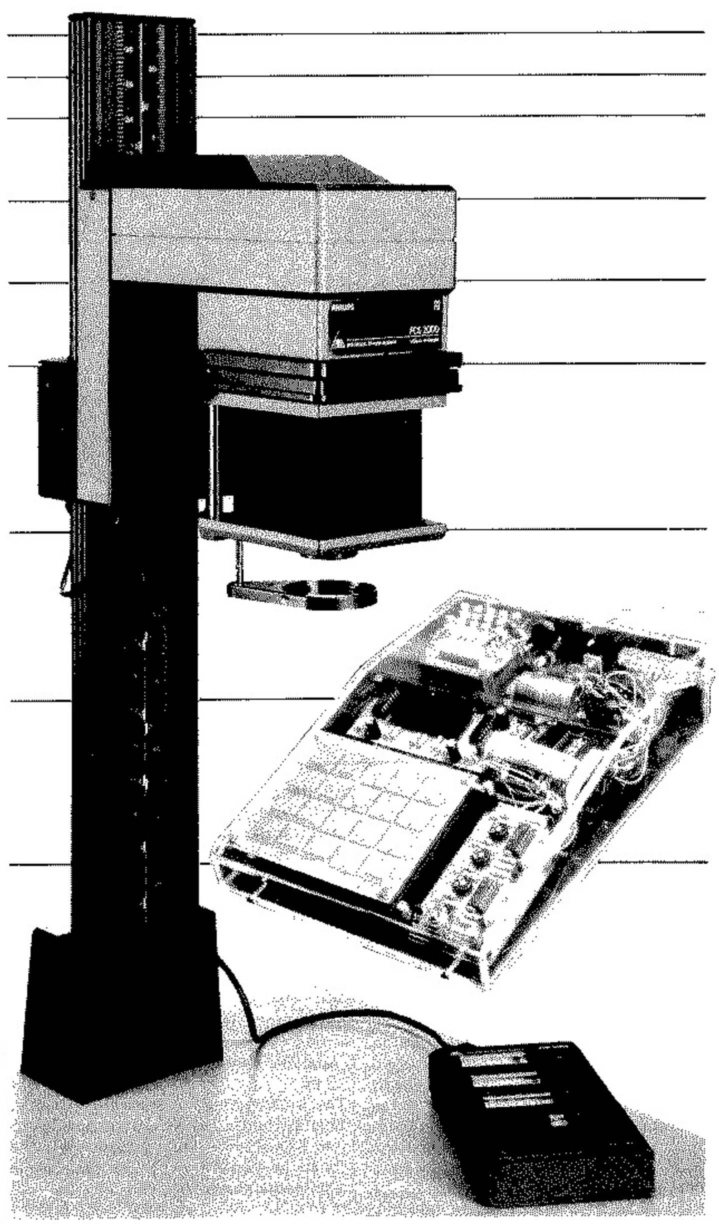
The 1 MHz clock signal required by the processor is supplied by a 4 MHz crystal oscillator and a divider-by-four, consisting of FF1 and FF2. The circuit around T1, T2 and N3 and N4 provides a reset signal when the power supply is initially switched on. The address decoding consists only of two inverters, N5 and N6, with which the complete memory range is divided into three blocks (IC2, IC3 and IC4). Finally, the supply voltage for the complete darkroom computer is produced by the two voltage stabilisers IC8 and IC9.

The readout consists of the four displays in figure 2, which are multiplied by PA0 . . . PA3 via the BCD-to-decimal decoder IC2. The displays are multiplexed and the data inputs to them are T0 . . . T3. The hexadecimal code on these lines is converted into the seven segment code by IC1. Each display is activated for about 25 ms.

The capacitive keyboard is in the form of a printed circuit board. It consists of 20 keys, arranged in 5 rows of 4 keys and each key pad only needs to be touched with a finger tip to operate. All the columns are pulled low in turn by IC2. The capacitance of the key pad will transfer the pulse to the 4 monostable multivibrators (MMV's) consisting of gates N1 . . . N8. If no key is touched, a logic 1 will appear on each of the PA4 . . . PA7 lines, via the transistor stages T2 . . . T5. However, when a key pad is touched, the scan pulse will be diverted to earth. The MMV associated with the row will not receive a scan pulse and the microprocessor then knows which key has been touched. A complete keyboard scan takes about 10 ms.

The footswitch S1 is shown in figure 2. This switch is connected in parallel to the START/ST. key and allows the timer to control exposure time while leaving the hands free.

It may be useful to have the safe light



operate in conjunction with the enlarger lamp. This facility is provided by the relay RE1 shown in figure 2. Transistor T1 will switch the relay on when a logic 0 appears on the PB5 line. When this line goes to logic 1, the relay will switch the safe light off and the enlarger on. The enlarger can also be controlled manually by means of switch S2 in order to refocus or change the enlargement size.
This is as far as we go with the description this month, more on the accesories will follow in the next article.

Construction

The basic darkroom computer consists of four printed circuit boards:

- The microprocessor board.
- The display board.
- The keyboard interface.
- The capacitive keyboard.

It is strongly recommended that the printed circuit boards are used in order to greatly simplify construction. However, it is possible to use an ordinary keyboard if preferred. In this case the following modifications must be made: The A/B wire link on the display board must be linked in the B position. Resistors R9 . . . R13 must be replaced by wire links. The normal keyboard (using 'make' contacts) is then mounted between the junctions of lines COL1 . . . COL5 and PA4 . . . PA7. Except for the four resistors R31 . . . R34, all the components situated between PA4 . . . PA7 and the keyboard may now be omitted. Obviously the printed circuit for the keyboard is not required.
A heatsink with a thermal resistance of 7°C/W must be used for the regulator IC8. In practice it may be possible to mount the regulator onto the inside of a metal case (if used). The pins of the regulator must be soldered directly onto the board. This would be ideal, provided that a mica washer and heat conductive paste are used. It is even possible to cut off the power supply section of the printed circuit board and mount it elsewhere, if that happens to be more convenient. In any event, ensure that the case is well ventilated or IC8 will get hot under the collar. There is a minor modification to the board with respect to IC9 (the second regulator).The track between the common terminals (centre lead) of this regulator and the earth plane at the edge of the board (the wide track) must be cut. The section of track left, connecting the common terminal of IC9 and the negative end of C12, must now be linked with a short length of wire to the +5 V output of IC8. This modification must be made because the board was disigned for the 6502 'housekeeper' which needed two 5 V rails. Here we need +5 V and +10 V. If a 7810 can be found it can be soldered directly into the board in the position for IC9 without the need for any modifications, but they are very thin on the ground. No heatsink is required for IC9. Do not forget to check that the

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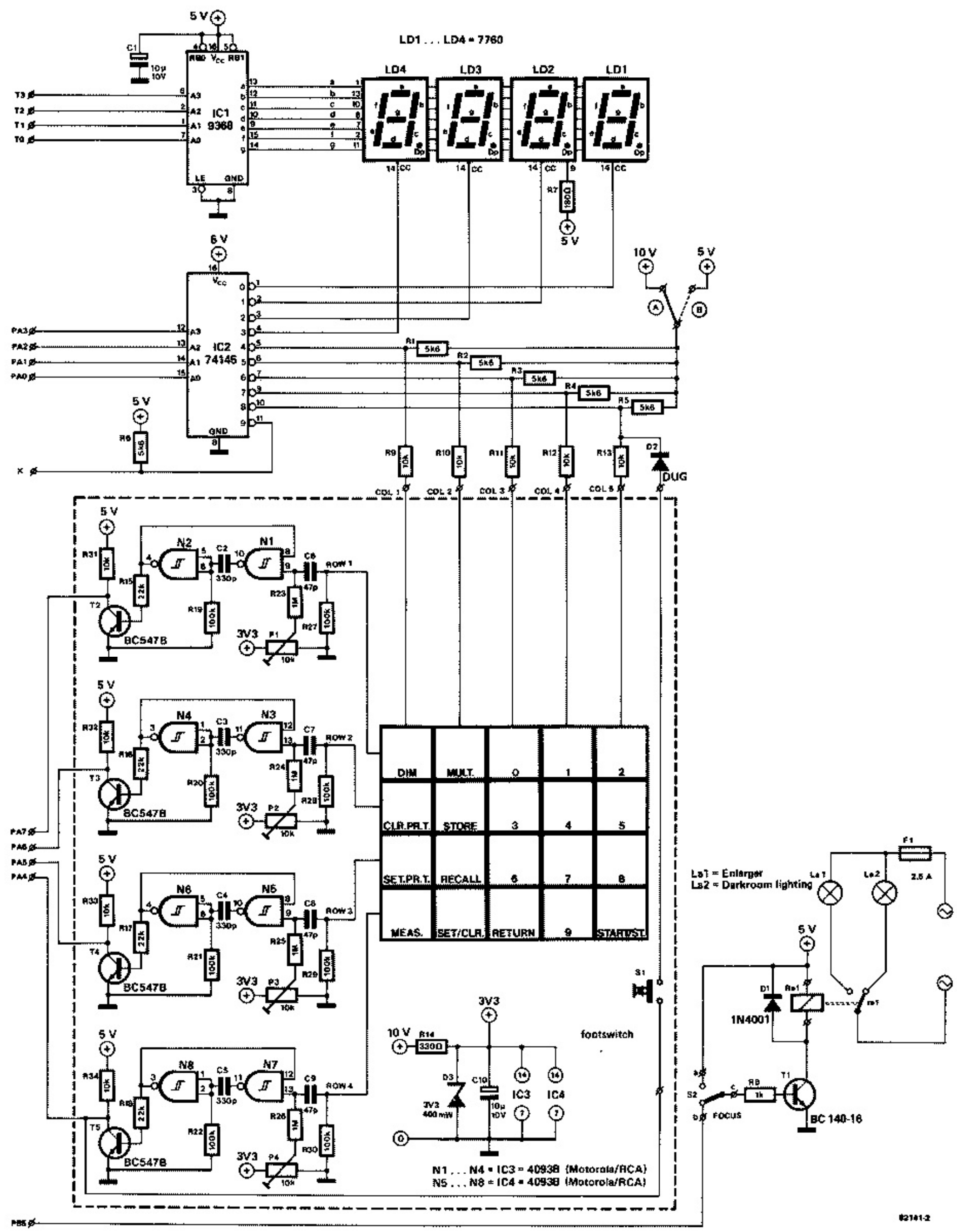

Figure 2. The circuit diagram of the display and keyboard. It is a capacitive keyboard which requires only a light touch to operate.

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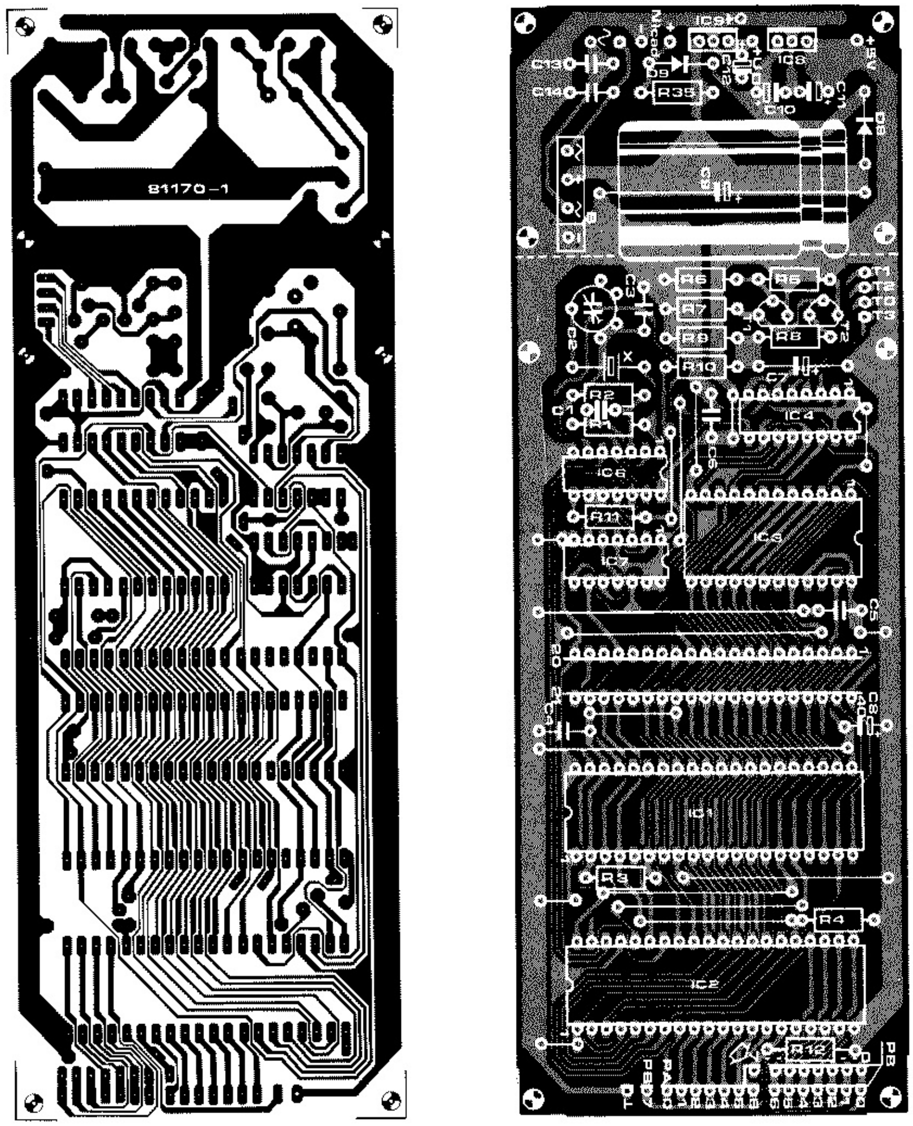

Figure 3. The track layout and component overlay for the microprocessor printed circuit board. This is EPS 81170-1 from the '6502 housekeeper' (MAY 1982). Resistors R12, R35 and diode D9 are not required.

Parts list for the microprocessor board

Resistors:
R1,R2,R7 = 2k2
R3,R4 = 3k3
R5 = 1 k
R6 = 5k6
R8 = 56 Ω
R9 = 560 Ω
R10 = 470 Ω
R11 = 15 k

Capacitors:
C1 = 10 n ceramic
C2 = 4 . . . 40 p trimmer
C3 = 150 p
C4,C5,C6,C13,C14 = 100 n
C7 = 47 μ/6,3 V
C8,C11 = 10 μ/10 V Tantalum
C9 = 2200 μ/25 V
C10,C12 = 10 μ/25 V Tantalum

Semiconductors:
T1,T2 = TUP
IC1 = 6502
IC2 = 6532
IC3 = 2716
IC4 = 74LS173
IC6 = 74LS04
IC7 = 74LS74
IC8 = 7805
IC9 = 7805 (or 7810)
D8 = 1N4001
B = B40C1500 bridge

Miscellaneous:
Tr = 12 V/1.5 A transformer
X = 4 MHz crystal
heat sink for IC8 (7°C/W or better)

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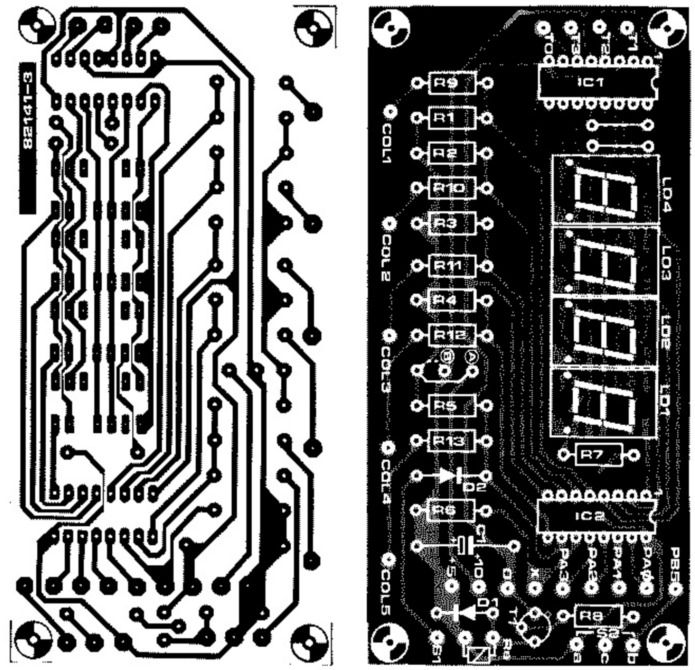

Figure 4. The display board. Wire link A must be fitted when using the capacitive keyboard. Link B must be made when a conventional keyboard is used. In this case, resistors R9 . . . R13 are replaced by wire links.

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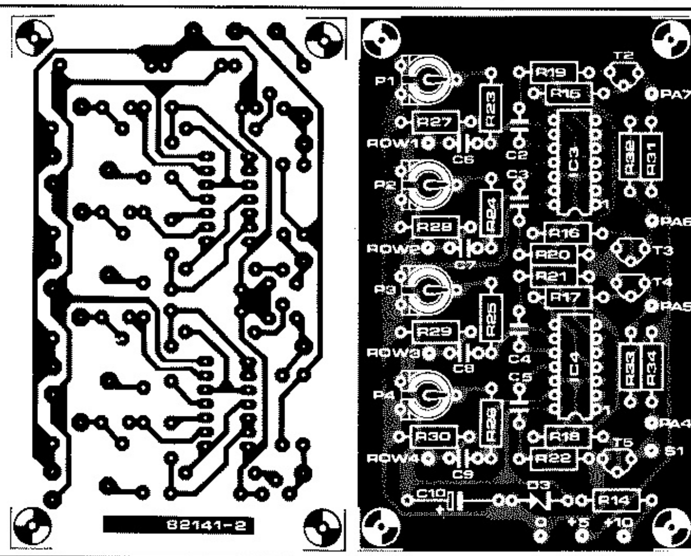

Figure 5. The printed circuit board for the keyboard interface. A footswitch can be wired between S1 of this board and S1 of the display board.

Parts list for the display and keyboard interface boards

Resistors:
R1 . . . R6 = 5k6
R7 = 180 Ω
R8 = 1 k
R9 . . . R13,R31 . . . R34 = 10 k
R14 = 330 Ω
R15 . . . R18 = 22 k
R19 . . . R22,R27 . . . R30 = 100 k
R23 . . . R26 = 1 M
P1 . . . P4 = 10 k presets

Capacitors:
C1,C10 = 10 μ/10 V
C2 . . . C5 = 330 p
C6 . . . C9 = 47 p

Semiconductors:
T1 = BC 142
T2 . . . T5 = BC 547B
D1 = 1N4001
D2 = DUG
D3 = zener diode 3V3/400 mW
IC1 = 9368
IC2 = 74145
IC3,IC4 = 4093B (RCA or Motorola)
LD1 . . . LD4 = 7760

Miscellaneous:
S1 = footswitch (push to make)
S2 = changeover switch
F1 = 2.5 A fast fuse
Re = relay with changeover contacts 5 V (max.) 100 mA

power supply functions correctly before inserting any expensive ICs into their sockets. It is also a good idea at this stage to check for any short circuits on the printed circuit board.

A 1 MHz symmetrical square wave must appear at pin 8 of IC7. A multimeter together with the test circuit of figure 7 can be used to measure this clock frequency. The meter must indicate 0 V on both the Q and $\overline{Q}$ outputs when a square wave is present. Of course it is also possible to use a frequency meter if one is at hand, in which case the frequency can be set accurately with C2.

Check that the output of N3 (pins 9 and 10 of IC6) goes high after switching the power on. The code AA (10101010) must now be put on the data bus by means of the small test circuit in figure 7b. The circled numbers refer to the board connector pins (between IC1 and IC3). Now IC1 can be fitted into its socket (ensure that the power is off when doing so). The connector must now have symmetrical square wave signals at the following points: Pin 29 A0 250 kHz, A1 125 kHz, A2 62.5 kHz and so on down to a frequency of 7.6 Hz at A 15.

Pin 14 of the connector (R/$\overline{W}$) must be logic 1. If a fault exists it must be verified at first that AA really is present on the data bus (by means of a multimeter). The easiest method of checking all the frequencies is with the aid of an oscilloscope. However, the circuit in figure 7c together with a multimeter can also do the job. The circuit is connected to a pair of adjacent address lines (A15 and A14; A13 and A12; . . . A1 and A0). The meter will indicate either 0 V or 5 V if all is well. Any other value will indicate either a short circuit or an open circuit on one or other of the two lines. If everything is in order, AA can be removed from the data lines. Remember to take IC1 out of its socket before using the soldering iron on the board.

The above tests should ensure that the printed circuit board assembly has been completed correctly. All the ICs may now be fitted into their sockets.

Only one point needs particular attention on the display board. This is the wire link A mentioned earlier on in this text when an ordinary switch type keyboard is to be used. As stated, the link must be in position B in this case.

The connections between the keyboard and the other boards must be kept as short as possible whatever type of keyboard is used. The capacitive keyboard itself needs some attention before being wired in. It is manufactured from printed circuit board material with a red colour on the underside. However, in contrast to a normal printed circuit board the top is covered in a thin layer of hard plastic to prevent damage and oxidisation of the key pads. On the underside the row contacts are already interconnected

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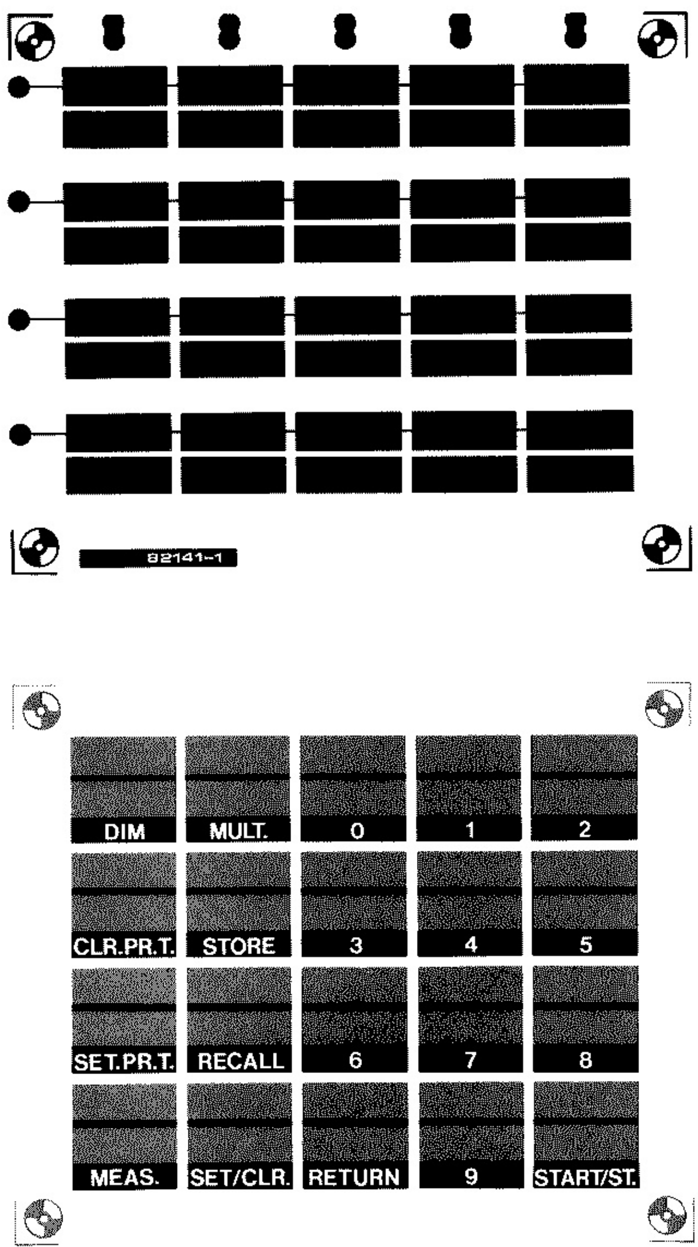


Figure 6. The keyboard. The front is covered by a protective layer. As explained in the text, it can be illuminated from behind.

during manufacture. The same is not true of the column contacts. These connections must be made carefully using thin enamelled copper wire. Bearing in mind that the keyboard is capacitive and therefore good operation is only guaranteed when the wire links are as near identical as possible. The photograph illustrates the completed keyboard and can be used as a guide. The footswitch is connected between S1 on the display board and S1 on the keyboard.

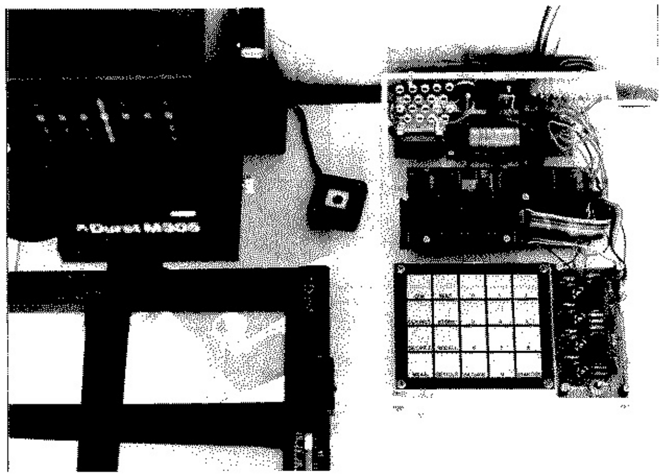
The finished printed circuit boards can now be mounted in a case and wired as shown in figure 8. The drawing also illustrates how the display board and the keyboard interface must be placed in relation to the keyboard if optimum results are to be achieved. It is important that the leads between these three boards are kept very short. Allow a space of at least 3 cms behind the keyboard for the illumination. More of this in a minute! Normally the keyboard will not require screening but if the keyboard is not mounted parallel to the front panel of the case it may be necessary. In this case a sheet of thin aluminium will have to be placed behind the board and earthed. It may be preferable to complete the wiring and check the operation first in order to see if screening is required. All connections to the outside world can be made via sockets on the rear panel of the case. One 14 way connector will cater for all the external circuits , but it may be more convenient to use separate sockets if the process timer, the light meter and the temperature meter are not all required. Two sockets for the enlarger and the safe lights will be necessary and these should be positioned as far away from the keyboard as possible. This also applies to all 220 V wiring for obvious reasons.

When using an enlarger with a halogen lamp (together with a transformer) it is recommended that a filter network, consisting of 100 Ω and 100n/400 V in series, is wired between the relay and the enlarger. This will keep interference to a minimum.

The keyboard illumination

It is obviously very necessary that the keyboard is made visible for it to be used with any great succes in the darkroom, and we went to great pains to make this possible.

Four or six 6 V/50 mA miniature bulbs can be uniformly distributed behind the keyboard. These can be mounted in miniature sockets fitted into a sheet of white (or red) plastic or perspex placed underneath the keyboard. Sides can then be glued to form a box to prevent any stray lights from escaping. While the box must remain 'light tight' it must definitely not be air tight, since these bulbs can generate a surprising amount of heat.



The lamps can be fed with an unstabilised d.c. voltage and their brightness can be adjusted be means of series resistors. These will need to be of a fairly high voltage. The lighting system can be made even more attractive if the lamps together with the displays could be dimmed to cope with the changing conditions. The circuit in figure 9 will provide this facility. It can be constructed on a small piece of Veroboard. The output must be connected to pin 1 of IC2 on the display board. The value of R4 must be reduced to 10 Ω if 6 lamps are being used instead of 4. The maximum brightness can be set by P4. The supply voltage for the lamps and the dimming circuit is derived across C9. Before inserting the bulbs into their sockets ensure that their supply is set to 6 V by P1. This is important since the voltage level across C9 is about 18 V. Transistor T3 of the dimmer circuit must be provided with a heat sink.

Practical tests

When construction and wiring are completed (for this section) it will be possible to check that all the operations are correct. Before going any further the darkroom computer will only operate correctly if the EPROM, IC3, contains the correct program. The listing of this

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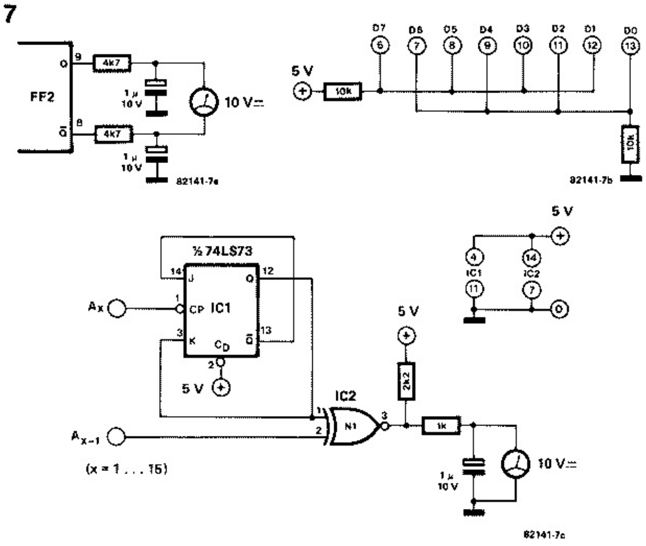

Figure 7. The processor board can be tested without a scope, by using the three auxiliary circuits shown here together with a multimeter.

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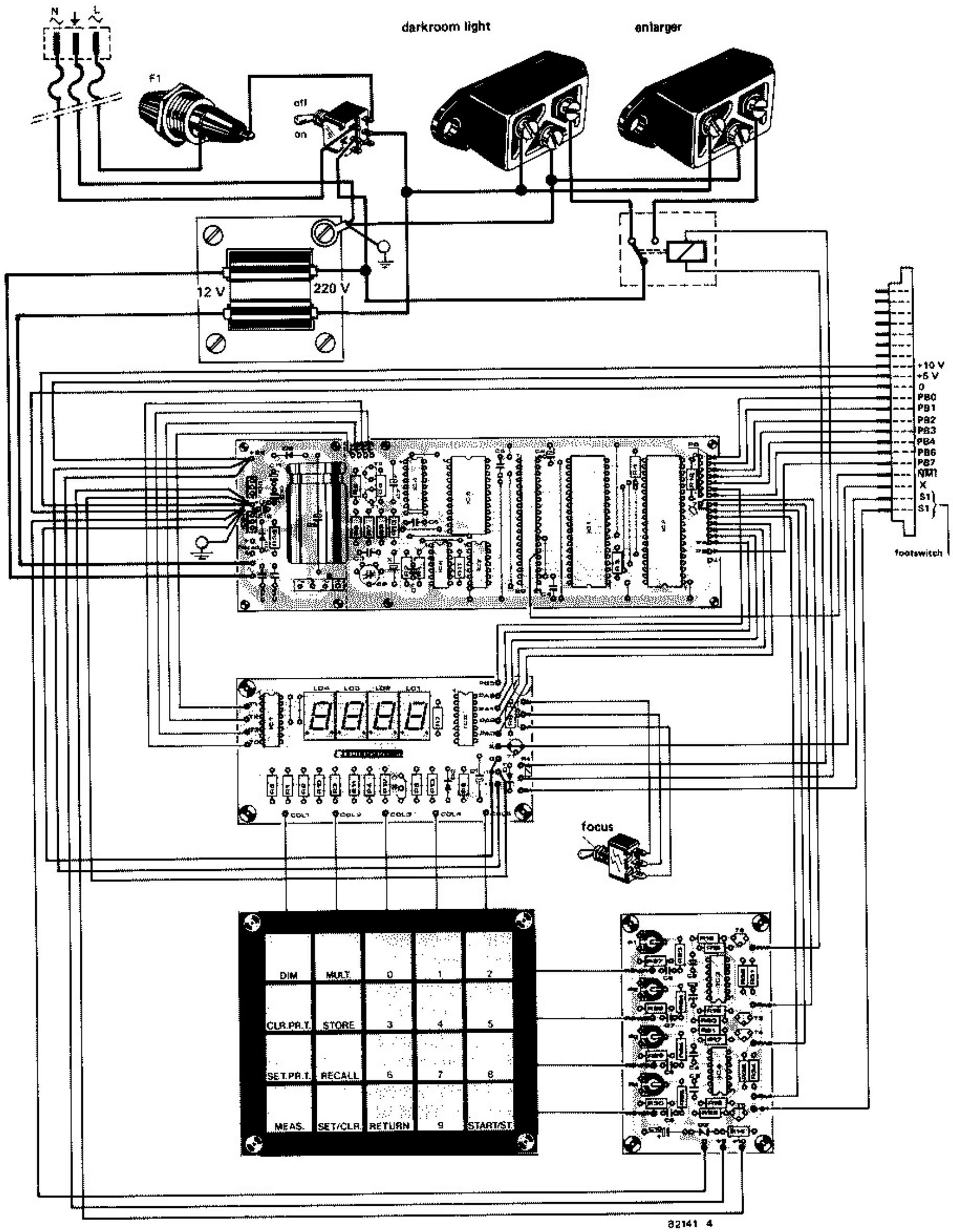

Figure 8. The interconnections between the printed circuit boards is shown here. The relationship between the keyboard interface, display board and the keyboard itself must be followed in order to keep the wiring between these boards as short as possible.

program is shown in the accompanying table 1.
The links PA5, PA6 and PA7 between the processor board and the keyboard interface must be disconnected. Check that presets P1 . . . P4 are set to zero, before the power supply is switched on. The display should now read 000.0. This brings us to the calibration procedure of the keyboard printed circuit board. For this purpose potentiometer P4 must be turned anti-clockwise very slowly, while intermittently touching the MEAS key. At a certain point the sign 'd' will appear on the display. When this occurs do not rotate P4 any further. When touching the RETURN key, 000.0 must appear again on the display. The display must show 000.9 when touching the keys SET/CLR and 9 respectively. When touching the START/ST. key the relay must be activated and switched off again after 0.9 seconds. If one of the keys does not operate correctly, P4 must be rotated slightly further and the procedure described above repeated until all keys react equally well.
The darkroom computer must then be switched off and PA5 reconnected. Switch the computer on again and turn P3 until key SET.PR.T. reacts correctly, 'd' appears on the display. Repeat this procedure with links PA6 and PA7 and the potentiometers P2 and P1. Before doing this it is best to take a look at the instructions for use in order to become familiar with the functions of the various keys. This helps to avoid mistakes. For example, the START/ST. key will not react at all if it has been touched after the MULT. key. Only keys 0 . . . 9 and RETURN react after MULT. has been touched.

9

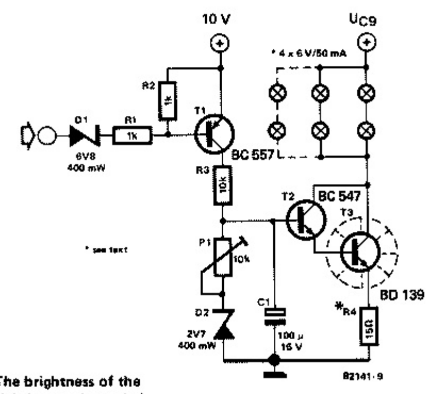

Figure 9. The brightness of the keyboard lighting can be varied continuously with the addition of this circuit.

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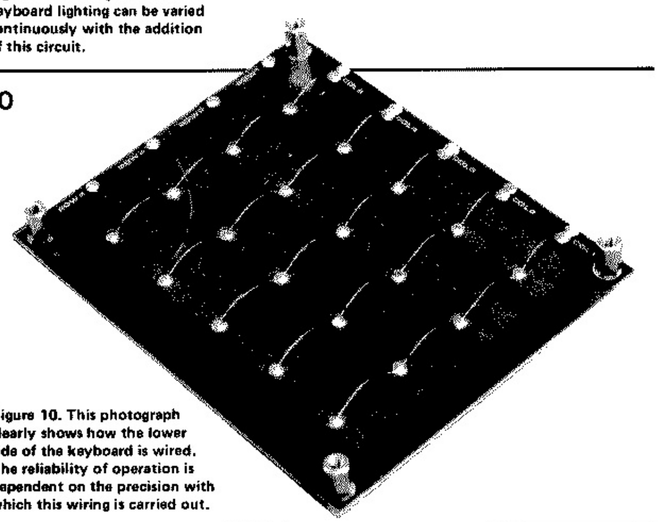


Figure 10. This photograph clearly shows how the lower side of the keyboard is wired. The reliability of operation is dependent on the precision with which this wiring is carried out.

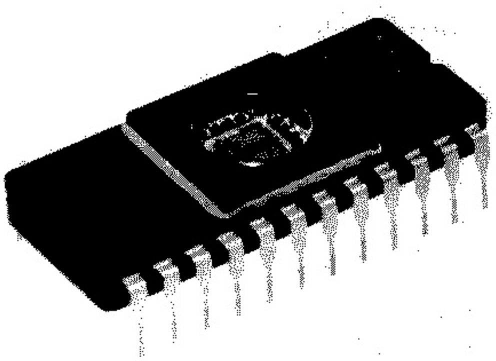
Ready for use

Adjustment of the four potentiometers completes the construction and calibration procedure of the basic darkroom computer. It can already be used in this form in the darkroom. However, not all functions will be operational of course.
To reach this aim, the constructor must add the three circuits being published in the next article. Anyway, the darkroom computer can already be used as exposure timer, as memory to store the various times and as a process timer with ten different times at its disposal. Last, but not least, it also works as continuous brightness control for the displays!

Instructions for use of the darkroom computer

This chapter deals with the operation of the darkroom computer. Since it describes the function of each key it may be an advantage to have the computer at hand, so that the theory can be 'converted' into practice right away. The instructions for use deal with the complete computer system and include the circuits that will be published later.

The keys that will function with the basic set-up are marked with a *:
DIM* : The brightness of the seven segment display is controlled by this key. They will be at maximum brightness when the computer is first switched on. Touching and holding this key will cause the displays to become dimmer until they go off altogether. If the key is still held they will gradually return to maximum brightness. The light level will remain constant at the level occuring when the key is released.
STORE* : The time period shown on the display can be stored in memory with this key. There are ten different time periods available (0 . . . 9). The time is stored as follows; for example, the time is to be stored in memory 4. Simply touch STORE and then key 4. A 'd' will appear on the display when the STORE key is used to advise that the computer is 'waiting' for a number. When a number is entered it will appear for one second on the display. The number is stored when the display blanks. The ten memories available are also used for the second process timer.
RECALL* : This key is used to recall the data from the memories. The memory address and then the memory data will appear on the display when the RECALL key is followed by a number key.
SET/CLEAR* : The display will read 000.0 if this key is touched. A time between 0 and 999.9 seconds can now be selected by the number keys.
START/ST.* : The enlarger can be switched on and off by means of this key. The lamp of the enlarger will be switched on by the relay after a time is fed in and the START/ST. key is touched. As mentioned before, the safe light is switched off when the enlarger is switched on and vice versa. This happens automatically. The time originally set will then appear on the display and can be used again by touching the START/ST. key a second time. The enlarger can be switched off at any time by this key. The START/ST. key is also used to start and stop the second process timer (see SET.PR.T. 2).



	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
800:	D8	A9	0F	85	8D	85	81	A9	7F	85	83	AA	9A	A0	62	A2
810:	00	20	BB	0B	A9	04	85	03	A9	FE	85	09	A9	10	85	2A
820:	58	00	EA	EA	20	C4	0B	C9	0E	D0	3B	C6	03	20	A4	0C
830:	A5	2A	85	43	A5	2B	85	44	20	C4	0B	C9	12	F0	1A	C9
840:	0A	B0	F5	A2	00	86	43	86	44	20	B6	0C	20	C4	0B	C9
850:	12	F0	06	C9	0A	B0	F5	90	F0	A5	43	85	2A	A5	44	29
860:	0F	85	2B	4C	DC	0C	C9	11	D0	13	A9	00	85	43	85	44
870:	20	C4	0B	C9	0A	B0	06	20	B6	0C	4C	70	08	C9	0F	D0
880:	14	20	A4	0C	20	C6	0C	20	EF	0C	A5	0C	95	10	A5	0D
890:	95	20	4C	DC	0C	C9	10	D0	11	20	C6	0C	20	EF	0C	B5
8A0:	10	85	43	B5	20	85	44	4C	24	08	C9	0A	D0	1D	A6	09
8B0:	F0	09	C6	09	20	DC	0B	10	F5	30	0D	A6	09	E0	FE	F0
8C0:	ED	E6	09	20	DC	0B	10	F3	4C	24	08	C9	13	D0	2D	A5
8D0:	43	D0	04	A5	44	F0	25	A5	44	C9	A0	B0	1F	20	A4	0C
8E0:	E6	31	20	C4	0B	C9	13	F0	04	A5	0A	F0	F5	A9	DF	25
8F0:	82	85	82	A9	00	85	31	85	0A	4C	DC	0C	C9	0C	D0	46
900:	20	A4	0C	20	C6	0C	20	EF	0C	E0	00	D0	3C	A5	1A	85
910:	43	A5	1B	85	44	20	DC	0B	10	FB	E6	33	F0	1B	20	DC
920:	0B	30	F7	20	DC	0B	30	F2	C9	12	F0	0D	C9	0A	B0	03
930:	20	B6	0C	A9	00	85	33	F0	DC	78	A5	43	85	1A	A5	44
940:	85	1B	58	4C	DC	0C	4C	25	0A	E0	02	D0	6F	A9	00	85
950:	2E	A9	02	85	5F	A6	2E	20	C7	0E	20	DB	0E	C9	0A	B0
960:	13	20	B6	0C	A6	2E	A5	43	95	10	A5	44	95	20	20	C7
970:	0E	4C	51	09	C9	0F	D0	1A	A5	44	29	0F	D0	0A	A5	43
980:	D0	06	A9	00	85	2E	F0	C9	E6	2E	A5	2E	C9	0A	D0	C1
990:	F0	F0	C9	12	D0	03	4C	DC	0C	C9	13	D0	B4	A9	3C	85
9A0:	5C	85	5E	85	5F	20	DB	0E	C9	13	F0	04	A5	0A	F0	F5
9B0:	A9	00	85	5E	85	0A	85	5A	85	2E	F0	95	E0	01	F0	03
9C0:	4C	03	09	86	43	A9	0A	85	44	E8	86	03	A2	0E	86	2E
9D0:	A5	42	D0	37	F8	18	A5	43	69	01	85	43	D8	C9	26	F0
9E0:	41	20	DC	0B	10	08	E6	33	E6	33	F0	E8	D0	F3	E6	03
9F0:	A5	43	A6	2E	95	34	A9	00	85	33	20	DC	0B	E6	33	E6
A00:	33	D0	F7	C6	03	C6	2E	30	19	10	C9	E6	03	A6	2E	B5
A10:	34	85	43	F0	0D	20	DC	0B	E6	33	E6	33	D0	F7	C6	2E
A20:	10	EB	4C	DC	0C	C9	0B	D0	47	20	A4	0C	20	C6	0C	20
A30:	EF	0C	A9	00	E0	02	B0	05	95	07	4C	DC	0C	D0	0E	78
A40:	85	1A	85	1B	85	07	85	08	85	57	58	F0	ED	E0	03	D0
A50:	0B	78	A2	0E	95	34	CA	10	FB	58	30	DE	E0	04	D0	CC
A60:	A2	10	A0	0A	20	BB	0B	A2	20	A0	0A	20	BB	0B	F0	CA
A70:	C9	0D	D0	5B	20	A4	0C	20	C6	0C	AA	D0	64	20	E9	0C
A80:	20	FF	0C	A5	82	29	DF	85	82	A5	2A	D0	07	A5	2B	D0
A90:	03	4C	4B	0D	A0	0C	A2	47	20	83	0D	20	8F	0D	20	EB
AA0:	0D	A2	47	A0	04	20	BB	0B	A9	10	85	49	A2	2A	A0	4F
AB0:	20	EF	0D	20	8F	0D	A0	4F	20	ED	0D	20	E5	0D	20	8F
AC0:	0D	20	01	0E	A5	45	D0	C9	A5	46	D0	C5	4C	24	08	C9
AD0:	0A	B0	03	4C	24	08	C9	12	F0	F9	C9	14	B0	F5	4C	27
AE0:	08	C9	01	F0	29	C9	02	D0	1F	20	EF	0C	C6	03	A9	00
AF0:	85	59	20	88	0E	10	FB	20	88	0E	30	FB	20	88	0E	30
B00:	F6	C9	12	D0	ED	4C	DC	0C	20	EF	0C	4C	77	0A	20	E9
B10:	0C	20	FF	0C	20	01	0E	20	8F	0D	A5	43	85	4B	A9	0D
B20:	85	43	A9	01	85	03	20	C4	0B	C9	01	D0	F9	A9	04	85
B30:	03	A5	4B	85	43	20	FF	0C	A5	82	29	DF	85	82	20	01
B40:	0E	20	EB	0D	20	8F	0D	A2	4B	A0	4F	20	EF	0D	A0	47
B50:	20	ED	0D	20	42	0D	20	8F	0D	A9	06	85	0B	A2	43	A0
B60:	04	20	83	0D	A9	F0	25	46	D0	07	C6	0B	10	F1	4C	4B
B70:	0D	A2	47	A0	08	20	BB	0B	A0	FE	C8	C6	98	4A	AA	BD
B80:	E5	0F	C5	46	90	F4	F0	01	88	A9	25	85	4B	88	30	05
B90:	20	71	0D	F0	F8	A5	0B	0A	0A	0A	0A	85	4C	A9	00	85
BA0:	4B	20	71	0D	A2	4F	A0	04	20	BB	0B	A9	30	85	4F	20
BB0:	8F	0D	A9	C0	05	44	85	44	4C	24	08	A9	00	95	00	E8
BC0:	88	D0	FA	60	A5	0A	D0	13	20	DC	0B	10	F7	A5	0A	D0
BD0:	0A	20	DC	0B	30	F7	20	DC	0B	30	F2	60	A5	5A	F0	0A
BE0:	A9	18	E6	5B	25	5B	F0	0E	D0	20	E6	58	A5	58	C9	01
BF0:	D0	14	C6	57	30	08	A9	40	05	82	85	82	D0	12	A9	00
C00:	85	57	85	58	F0	04	C9	80	D0	06	A9	BF	25	82	85	82
C10:	A2	00	E6	05	8A	4A	A8	B9	43	00	90	04	4A	4A	4A	4A
C20:	8D	00	04	20	6D	0C	E8	E4	03	D0	E9	E0	04	F0	0C	86
C30:	0B	A2	0F	20	6D	0C	A6	0B	E8	D0	F0	78	86	80	48	68
C40:	A5	80	58	49	FF	A0	0F	84	80	29	F0	D0	09	E8	E0	09
C50:	D0	E9	A9	FF	D0	16	A0	FF	C8	0A	90	FC	84	04	8A	E9
C60:	04	0A	0A	18	65	04	AA	BD	D1	0F	85	00	60	A5	09	F0
C70:	1D	A5	05	29	60	F0	0D	A5	06	4A	90	24	A5	07	05	82
C80:	85	82	E6	06	86	80	A0	00	C8	EA	C4	09	90	FA	A9	0F
C90:	85	80	A9	E0	25	82	85	82	C8	C4	09	C0	FF	90	F9	60
CA0:	A5	08	90	DA	A5	43	85	0C	A5	44	85	0D	60	A5	0C	85
CB0:	43	A5	0D	85	44	60	A2	04	06	43	26	44	CA	D0	F9	A5
CC0:	00	05	43	85	43	60	A9	01	85	03	A9	0D	85	43	20	C4
CD0:	0B	C9	12	F0	07	C9	0A	B0	F5	85	43	60	A9	04	85	03
CE0:	20	AD	0C	A2	7F	9A	4C	24	08	A5	82	09	20	85	82	20
CF0:	DC	0B	E6	30	E6	30	D0	F7	A9	04	85	03	A6	43	60	A0
D00:	08	84	0F	A0	0C	A2	47	20	BB	0B	86	01	A5	02	F0	FC
D10:	A5	82	10	08	A5	02	F0	2A	A5	82	30	F8	A5	02	F0	22
D20:	A5	82	10	F8	A2	4B	A0	04	20	BB	0B	A5	02	F0	13	A2
D30:	4B	20	5B	0D	A5	82	30	F3	20	71	0D	A2	4F	20	5B	0D
D40:	F0	CE	A2	03	B5	4F	D0	12	CA	10	F9	A5	82	29	DF	85
D50:	82	A9	EE	85	43	85	44	4C	E3	0C	60	F8	18	A0	03	B5
D60:	00	69	01	95	00	E8	B5	00	69	00	95	00	88	D0	F6	D8
D70:	60	F8	18	A2	00	B5	4B	75	47	95	47	E8	8A	49	04	D0
D80:	F4	D8	60	16	00	36	01	36	02	36	03	88	D0	F5	60	A9
D90:	00	85	0C	A2	43	A0	04	20	BB	0B	A9	F0	25	52	D0	0B
DA0:	A2	4F	A0	04	20	83	0D	E6	0C	10	EF	A2	00	A0	03	F8
DB0:	38	B5	47	F5	4F	95	53	E8	88	10	F6	D8	90	0C	E6	43
DC0:	CA	B5	53	95	47	CA	10	F9	30	E1	C6	0C	30	16	A2	43
DD0:	A0	04	20	83	0D	A0	04	46	52	66	51	66	50	66	4F	88
DE0:	D0	F5	F0	C7	60	A2	4B	A0	47	D0	04	A0	4B	A2	43	18
DF0:	8A	69	04	85	0B	B5	00	99	00	00	E8	C8	E4	0B	D0	F5
E00:	60	A9	14	85	0E	78	20	0F	0E	58	C6	0E	D0	F7	60	A4
E10:	07	D0	0E	A5	08	85	07	84	08	A5	1D	85	1C	A5	1F	85
E20:	1E	A2	01	B5	07	D0	12	A5	2F	F0	2E	F6	07	A9	00	85
E30:	2F	A5	1A	95	1C	A5	1B	95	1E	F8	38	B5	1C	E9	01	95
E40:	1C	B5	1E	E9	00	95	1E	D8	D0	37	B5	1C	D0	33	B4	07
E50:	C8	C0	1A	D0	02	A0	00	94	07	A5	1A	95	1C	A5	1B	95
E60:	1E	A0	0E	B9	34	00	F0	16	C9	20	90	05	38	E9	0C	D0
E70:	07	C9	10	90	03	38	E9	06	D5	07	D0	02	E6	57	88	10
E80:	E2	CA	10	9F	E8	86	2F	60	A5	59	F0	37	A0	03	A2	FF
E90:	CA	D0	FD	88	D0	F8	86	44	86	59	A9	99	85	43	A9	60
EA0:	85	83	A9	09	85	80	F8	18	A9	01	65	43	85	43	A9	00
EB0:	65	44	85	44	B0	06	A5	82	29	01	D0	EC	D8	A9	7F	85
EC0:	83	85	80	20	DC	0B	60	B5	10	85	43	8A	0A	0A	0A	0A
ED0:	85	53	B5	20	29	0F	05	53	85	44	60	A5	0A	D0	13	20
EE0:	F3	0E	10	F7	A5	0A	D0	0A	20	F3	0E	30	F7	20	F3	0E
EF0:	30	F2	60	E6	5D	A5	5D	25	5F	F0	04	A9	04	D0	02	A9
F00:	03	85	03	20	DC	0B	60	48	8A	48	98	48	D8	A9	00	85
F10:	81	A5	32	F0	03	4C	BE	0F	A5	01	F0	12	85	02	A5	0F
F20:	F0	08	A9	F4	85	9F	C6	0F	10	59	85	01	85	02	E6	32
F30:	A9	60	85	9F	65	59	A5	31	F0	25	A9	20	05	82	85	82
F40:	38	F8	A5	43	E9	01	85	43	A5	44	E9	00	85	44	D8	B0
F50:	0E	A9	DF	85	0A	25	82	85	82	A9	00	85	43	85	44	20
F60:	0F	0E	A5	5E	F0	1D	E6	60	A6	2E	B5	10	D0	18	B5	20
F70:	29	0F	D0	12	E6	0A	A9	00	85	60	A9	0E	C5	60	D0	03
F80:	20	C7	0E	4C	C4	0F	C6	5C	D0	F0	A9	3C	85	60	85	5C
F90:	F8	38	A5	43	E9	01	85	43	A5	44	E9	00	85	44	D8	29
FA0:	0F	D0	D7	A5	43	D0	0F	85	5A	85	60	E6	57	E8	86	2E
FB0:	E0	0A	F0	C0	D0	C4	C9	01	D0	C0	85	5A	F0	BC	C6	32
FC0:	A9	19	85	9E	A9	0F	85	81	68	A8	68	AA	68	40	E6	2F
FD0:	40	0A	0B	0C	0D	0E	0F	10	11	00	03	06	12	01	04	07
FE0:	09	02	05	08	13	10	11	13	14	16	18	20	22	25	28	32
FF0:	35	40	45	50	56	63	71	79	89	99	CE	0F	00	08	07	0F

Table 1. The hexdump of the darkroom computer program that is stored in the 2716 EPROM.

RETURN*: This key is used to return from a certain function to the main program, in order to select another function. It can be used when a key has been touched by accident, which applies to the CLR.PR.T.; SET.PR.T.; MEAS; STORE; RECALL and MULT. The 'old' data appears on the display again after the RETURN key is used (except for the RECALL key).

0 . . . 9*: These keys are used to read in a certain time and to choose a particular function with keys that have more than one function.

SET.PR.T. (SET PROCESS TIMER): The three functions of this key set the process and alarm times. A 'd' will be displayed (indicating that a decimal key must be used now) after this key has been touched. The following choices are:

–0 : The time can now be entered. The time shown on the display remains there for 3 seconds after the last key was touched and then disappears, indicating that it has been stored.

–1 : It can now be determined at which LED of the timing indicator the alarm must sound, as follows: After the command SET.PR.T.–1 has been given, the code 02 will appear on the display. The number on the display is increased by 1 per second until number 25 is reached. This will be followed by a return to the 'old' data (02) on the display. The number displayed indicates the number of a certain LED. For example, it is required to sound the alarm at the 6th LED. Any key touched when the number 06 is shown will add an 'A' to the display. This indicates that the alarm will go off at this LED number. The alarm can be set 15 times in this way. After the 25 numbers have been scanned, the timer returns to the main program. Giving the command SET.PR.T–1 again causes all alarm numbers (with the 'A') to appear on the display again. It is now too late to make any changes. To be able to do that alarm registers must be cleared again.

–2* : This key initialises the programming of the second process timer. This timer can store a maximum of 10 different time periods ranging from 0.1 to 99.9 *minutes*. Three of the four displays show the first time period in minutes. The fourth (left) display becomes dim and flashes very quickly. This indicates the memory location in which the number shown on the other displays is stored (0 . . . 9). The time period will be stored in this memory address when the STORE key is touched. The number of the next memory location will then be displayed and the same procedure can be repeated. As stated before, this can be done 10 times. The following must be carried out if less than 10 process times are used, when the last required time is stored (for example, the third), the command 00.0 must be entered. The first time period will then re-appear on the display when the STORE key is used. The second process timer can now be started by operating the START/ST. key. The left display will behave 'normally' again. Now the countdown for one process time begins. When 00.1 appears on the display, the buzzer announces that the last 6 seconds (of that particular time) have been reached. At the end of the period the buzzer produces one long tone and the countdown for the next process time begins. The first time period re-appears on the display and the left display starts to flash again, after the last process time has passed. It is now possible to either start again (START/ST.), change the process time or return to the main program (using the RETURN key). The process timer can be stopped whenever required. In this event the timer jumps back to the first process time and remains there until the START/ST. or RETURN key is touched again.

CLR.PR.T. (CLEAR PROCESS TIMER): This key also combines several possibilities. Again 'd' is displayed when this key is touched to indicate that a number key must be used next. Now, there are several possible options:

–0 : The LED that is furthest to the right on the process timer is now cleared.

–1 : If lit, the second LED goes out when touching this number. If only one LED is lit, nothing wil happen at this command.

–2 : Both LEDs will go out. Furthermore the LED running period is then wiped out.

–3 : All alarm points for the process timer are cleared, in other words, all alarms are silenced.

–4* : All ten process times for the second process timer are cleared. In all 4 cases, the number entered is displayed for approximately 1 second, after which the computer returns to the main program.

MEAS. (MEASURE) : All measuring functions are controlled by this key. The three possibilities are:

–0 : Light measurement. The enlarger is switched on as soon as the '0' key has been touched. The '0' remains visible on the display for a moment before it disappears. The display is blank for two seconds while the computer measures the amount of light that falls on the light sensor. This value is converted into an exposure time and the result appears on the display. The enlarger then switches off. The calculation made by the computer is based on the brightness of the enlarger lamp (the more light falling on the sensor, the shorter the exposure time) and the multiplication factor that can be added by means of the MULT. key. We will come back to that later on. An incorrect (light) value will be indicated on the display by EEE.E.

–1 : Contrast measurement. The relationship between the lightest and darkest spot on a negative. First place the light meter on the lightest part of the negative being projected. Then touch the keys MEAS. and 1 respectively. The display will blank for 2 seconds after which 'd' will appear (the enlarger remains on). The meter is then placed on the darkest area of the negative and key 1 is touched. After 2 seconds, the left display will indicate a C and the others a number relating to the contrast. The contrast ratio is indicated in light values; This is the logarithm to the base 2 of the ratio between the lightest and darkest spot. The value obtained in this way can help in choosing the right kind of paper for a certain negative (the bigger the contrast ratio, the softer the paper will need to be).

The enlarger lens should not be fully open, but be on, for example f 5.6, when taking the measurements. Ensure also that the scale of enlargement is not too big, otherwise the measurement of the dark areas would fall out of the measuring range.

The minimum contrast ratio that can be measured is 1.0, which relates to a light/dark relationship of 2 : 1. C 00.0 will appear on the display with any lower ratio. The maximum contrast that can be measured is 12.0, a value that is only very, very rarely reached!

–2 : Temperature measurement. About 1 second after the '2' key has been touched, the temperature will be indicated on the display. This value is accurate to within 0.1°C. The display flashes very weakly showing that it is temperature that is being displayed. Returning to the main program can only be done by means of the RETURN key.

MULT. (MULTIPLIER) : This key enters the multiplication factor. A three-figure number (which is always 01.0 when the computer is initially switched on) appears on the display after this key has been used. A number entered will now appear on the display.

The multiplication factor is used in the light measurement (see MEAS. –0); the exposure time internally measured by the computer is multiplied by this factor and the final result is displayed. The multiplication factor depends on the type of paper being used and sometimes on the scale of enlargement. More details will follow in the darkroom computer part 2.

Again the constructor can only return to the main program by using the RETURN key.

There are still two 'ordinary' switches that need to be described.

START PR.T. (START PROCESS TIMER) : This switch is situated on the process timer containing the 25 LEDs. The first LED starts to 'run' when this switch is used. Operating the switch once again causes the second LED to run as well.

FOCUS*: The enlarger can be switched on and off by means of this switch. ◼