Tri-State Time

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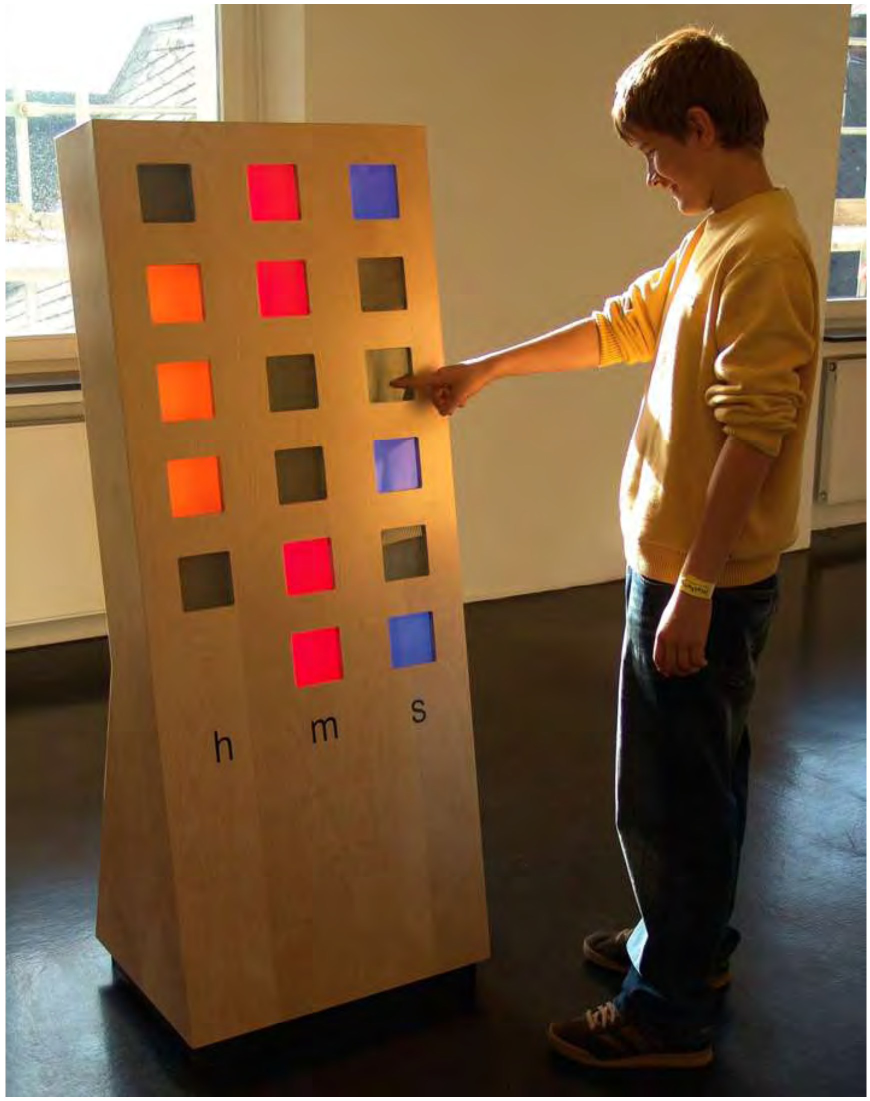
Inspired by a binary clock he saw at a mathematics museum the author of this design went one step further and came up with a more mathematically challenging timepiece...



This unusual large format digital clock in the photo shows the time in binary and is exhibited at the German Museum of Mathematics 'Mathematikum' in the town of Giessen, Germany [1]. The museum is the brainchild of Prof. Beutelsbacher and has been described as the first 'hands-on' mathematical museum in the world. The clock inspired Marco Freitag to design the PIC16C54 based binary clock featured earlier in this magazine [1]. After a visit to the museum the author was motivated to experiment with this alternative format for time representation which requires a little more concentration to read compared to the average clock.

The Trit

We are familiar with the role of the 'bit' in binary systems so it is probably not surprising to discover that in trinary systems we use the trit which is a contraction of the words 'trinary digit'. The basis of the trinary system (a.k.a. ternary or base three) is 3. The positional power of any number expressed in trinary (starting from the least significant position) is given by:

$3^0 = 1; 3^1 = 3; 3^2 = 9; 3^3 = 27$; etc.

The only numbers allowed to represent a value are 0, 1 and 2. To indicate that a value is written in trinary it is appended with a subscripted 3, for example

$1210_3 = 48_d$
$(1 \times 27 + 2 \times 9 + 1 \times 3 + 0 \times 1)$.

In order to display any value in trinary it is necessary to use a device which can have three visible states. Bi-colour LEDs have been chosen here to represent '0' (both LEDs off), '1' (green LED on) and '2' (red LED on).
The table (**Figure 1**) shows the decimal values of a clock reading together with its representation in trinary and the corresponding LED colours used for the display. It can be seen that for the hours (0 to 23) we need three bi-colour LEDs and the minutes (0 to 59) require four. It is also necessary to use a corresponding number of counters to count the seconds and minutes. The counters go from 0 to 2 while the third output resets the counter to zero and acts as a carry-out to increment the next in the chain. The AND gate IC11.B detects when the hour count reaches 24 and resets the hours while IC11.D does the same to the minute counters when they reach 60 and also increment the hour counter.

Counting the time

Reading the time on this clock can be a little challenging but in contrast the circuit diagram is quite simple to follow. In principle it shouldn't be too difficult to read the time providing you can count up to three…
All of the timing and counting for the clock is not hidden away somewhere inside a microcontroller memory but instead is done the old fashioned way by wiring the hardware counters and

Quartz clock with a trinary display

logic shown on the circuit diagram in **Figure 2**. A division ratio 2^{15} (32768) is necessary to provide a 1 Hz signal from the 32.768 kHz watch crystal X1. The 14 stage binary counter IC10 can manage 2^{14} which gives a 2 Hz clock output from pin 3. Resistor R39 has a relatively high value and this helps reduce loading on the crystal. A small watch crystal like this can dissipate a maximum power of around 1 μW (nominally 0.1 μW).

The D-type flip-flop IC12A is configured as a divide-by-two to produce a 1 Hz output while IC8 and IC9 provide a divide-by-10 and divide-by-six function to generate minute pulses. IC12.B drives the second pulses to LED D4 which alternates between red and green. The use of 5-stage Johnson counters (which can count up to 10) for IC1 to IC7 may seem a bit like overkill since they never need to count above three but these devices are less problematic to interface than some of the

trinary	decimal	trinary	decimal	trinary	decimal
0 0 0 0	0	0 2 1 0	21	1 1 2 0	42
0 0 0 1	1	0 2 1 1	22	1 1 2 1	43
0 0 0 2	2	0 2 1 2	23	1 1 2 2	44
0 0 1 0	3	0 2 2 0	24	1 2 0 0	45
0 0 1 1	4	0 2 2 1	25	1 2 0 1	46
0 0 1 2	5	0 2 2 2	26	1 2 0 2	47
0 0 2 0	6	1 0 0 0	27	1 2 1 0	48
0 0 2 1	7	1 0 0 1	28	1 2 1 1	49
0 0 2 2	8	1 0 0 2	29	1 2 1 2	50
0 1 0 0	9	1 0 1 0	30	1 2 2 0	51
0 1 0 1	10	1 0 1 1	31	1 2 2 1	52
0 1 0 2	11	1 0 1 2	32	1 2 2 2	53
0 1 1 0	12	1 0 2 0	33	2 0 0 0	54
0 1 1 1	13	1 0 2 1	34	2 0 0 1	55
0 1 1 2	14	1 0 2 2	35	2 0 0 2	56
0 1 2 0	15	1 1 0 0	36	2 0 1 0	57
0 1 2 1	16	1 1 0 1	37	2 0 1 1	58
0 1 2 2	17	1 1 0 2	38	2 0 1 2	59
0 2 0 0	18	1 1 1 0	39	2 0 2 0	60
0 2 0 1	19	1 1 1 1	40		
0 2 0 2	20	1 1 1 2	41		

Figure 1. Time represented in trinary together with the decimal equivalent. The colours indicate the bi-colour LED display.

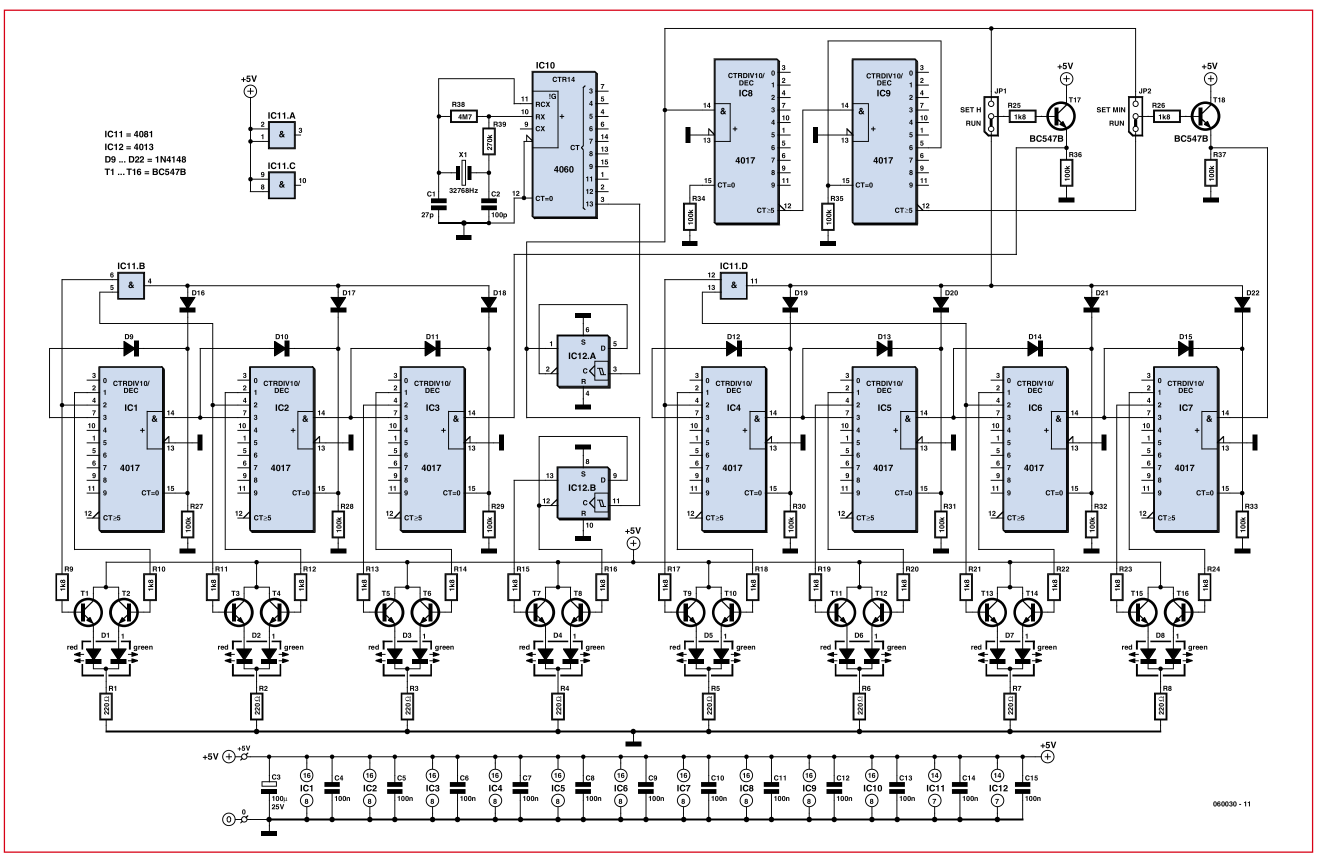


Figure 2. The circuit diagram shows a classic hardwired hardware approach.

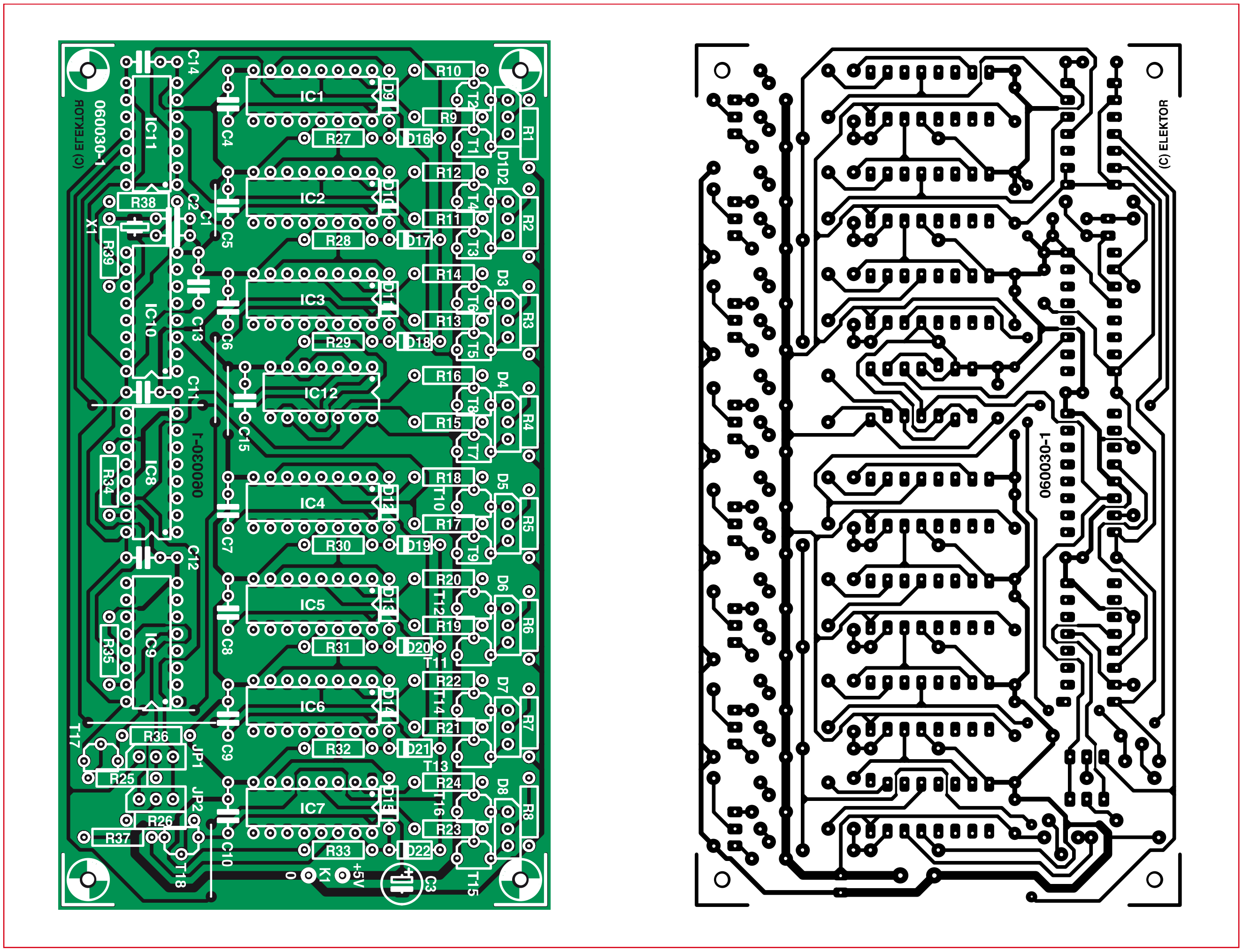


Figure 3. The finished PCB layout.

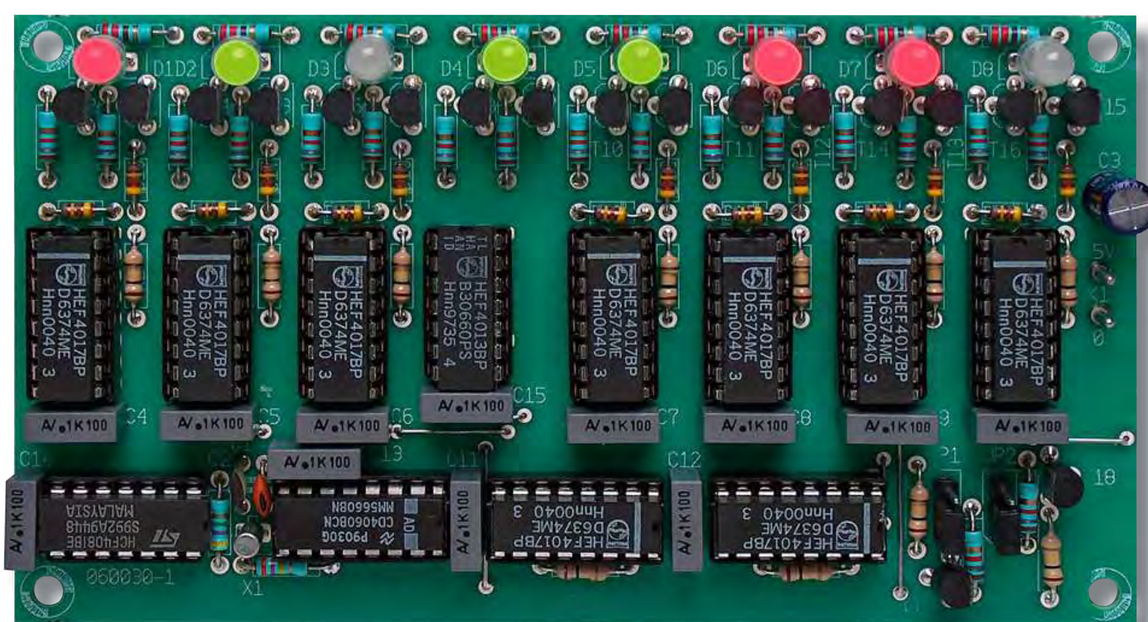


Figure 4. The prototype clock. Can you work out at what time the picture was taken?

other CMOS digital chips and produce a simpler circuit. With reference to the table LEDs D1 to D3 display the hours, D5 to D8 the minutes and D4 pulses at second intervals.

Setting the time

The PCB layout shown in **Figure 3** is rather reminiscent of a digital clock design from around 30 years ago when TTL technology was king. Thanks to CMOS circuitry and the LED outputs used in this design it consumes far less energy. The operating current depends on the number of LEDs illuminated which in turn is governed by the time of day. The prototype board shown in **Figure 4** draws between 22 and 88 mA. This current level would give a relatively short battery life but should be no problem for a low power 5 V, 100 mA mains adapter. The five volt supply does not need to be too precise; the circuit will function happily at any voltage between 4.5 and 6 V. To set the clock it is necessary to pull out the jumpers JP1 and JP2 from their RUN positions to the SET H (set hour) position and then SET MIN (set minute). The hours and the minutes will increment at second intervals until the correct value is achieved whereupon the jumpers are returned to their original position. The jumpers can be replaced by slide or toggle switches to make time setting easier.

With the component values given the accuracy of the crystal in the prototype was measured at +43 ppm which is within the quoted crystal tolerance. The crystal ran below its nominal value but those of you who have the means to measure the frequency accurately (or who have enough patience) can improve the accuracy by adjusting (trimming) the values of C1 and C2 slightly to change the capacitive loading on the crystal. Increasing the capacitance will slow the frequency.

(060030e)

Literature and Links:

[1] The German Museum of Mathematics: www.mathematikum.de

[2] Marco Freitag: 'Binary Clock', Elektor Electronics July/August 2006

COMPONENTS LIST

Resistors
R1-R8 = 220 Ω
R9-R26 = 1kΩ8
R27-R37 = 100kΩ
R38 = 4MΩ7
R39 = 270kΩ

Capacitors
C1 = 27pF
C2 = 100pF
C3 = 100µF 25V radial
C4-C15 = 100nF

Semiconductors
D1-D8 = bicolour LED, red/green, common cathode (e.g. Conrad Electronics # 185000)
D9- D22 = 1N4148
T1-T18 = BC547B
IC1-IC9 = 4017
IC10 = 4060
IC11 = 4081
IC12 = 4013

Miscellaneous
JP1,JP2 = 3-way SIL pinheader with jumper, or miniature changeover switch
X1 = 32.768kHz quartz crystal
7 wire links
PCB, ref. 060030-1 from www.thepcbshop.com