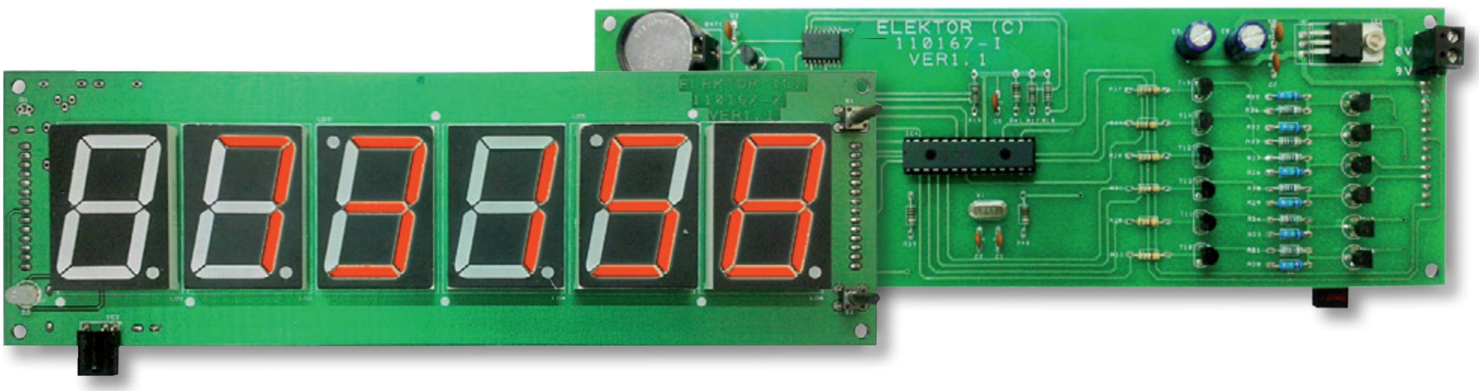
# Pretty Accurate Digital Wall Clock

## .000202943 % slow or fast max.

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The crucial component in this project is a Maxim IC type DS3231, qualified by its manufacturer as an "extremely accurate I$^2$C real time clock (RTC) with integrated temperature compensated crystal oscillator (TCXO) and crystal." Maxim also says that the integration of the crystal resonator enhances the long-term accuracy of the device, guaranteeing a maximum error of less than 64 seconds over a year, and over a temperature range 0 to 40 °C (32 to 104 °F). The device incorporates a battery input which maintains running of the device in the absence of external power.

### Circuit description

Hyper-accurate as it may be, the DS3231 is unable to do anything useful without the help of a few other components. Referring to the schematic in **Figure 1**, A PIC16F876A microcontroller (IC4) is used to interface to the RTC (IC3) as well as drive a bunch of 7-segment LED displays (discussed further on). The microcontroller has an I$^2$C port which makes for easy interfacing to the DS3231 RTC.

### Features

- PIC16F876A controlled
- Maxim DS3231SN RTC chip
- 1.5 inch red 7-segment LED displays
- Max. error 64 seconds per year
- Optional IR remote control
- 9V @ 500 mA max. power supply (DC adapter)
- Free C source code
- Free DesignSpark PCB files

The microcontroller clock operates at 20 MHz due to quartz crystal X1 and its two load capacitors C1 and C2, not forgetting the appropriate control word in the microcontroller "config settings". Port lines RA0-RA3, RA5 and RC1 of the PIC micro switch individual LED displays on and off through drivers/level changers T10-T21. Note the use of an npn/pnp transistor pair on each line to handle (1) the level conversion from 5-V swing (PIC side) to 9-V swing (display side), and (2) feeding current from the 9-V rail to each display via its CA (common anode) terminal under multiplex control.

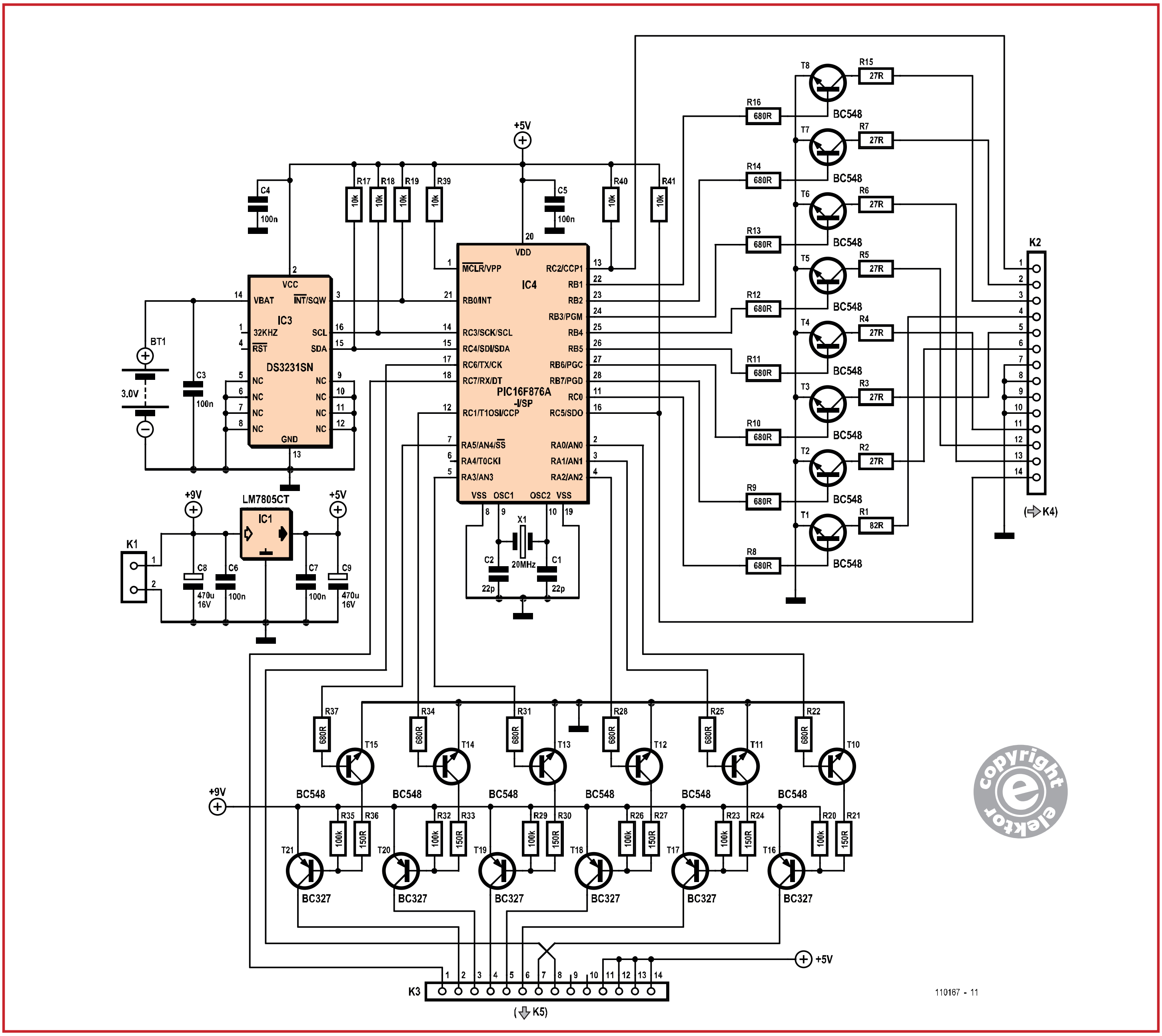





Figure 1.
Schematic of the microcontroller section. K3 connects to the common anodes of the 7-segment displays, K2 to the bussed segments.

The supply voltage for the PIC micro is regulated with a 5-V linear regulator (IC1), and the displays are connected to a higher (9-V) unregulated supply. This makes the design capable of driving bigger displays with a larger voltage drop per segment—such as 6.8 V—due to more LEDs in series. PORTB pins RB1-RB7, and RC0, activate the individual LED segments through an array of switching transistors T1-T8.

A 9-V, 500-mA unregulated power supply (power adapter) is sufficient for the circuit to provide good brightness, and a CR2030 lithium battery (BT1) is used as a backup supply for the RTC. On a prototype of the clock, a current consumption of 320 mA was measured on account of the display section operating in multiplex mode.

The design is for a simple 24/12 hour clock which incorporates six 7-segment LED displays and two input switches. The display section schematic is shown in **Figure 2**. One of the attractions of this design is it 1.5" bright red 7-segment LED displays, so the clock can be read easily from considerable distances. The displays are multiplexed at 1 kHz but provide sufficient average currents for high brightness. The individual segments (a-g) of displays LD1-LD6 and the decimal point (dp)

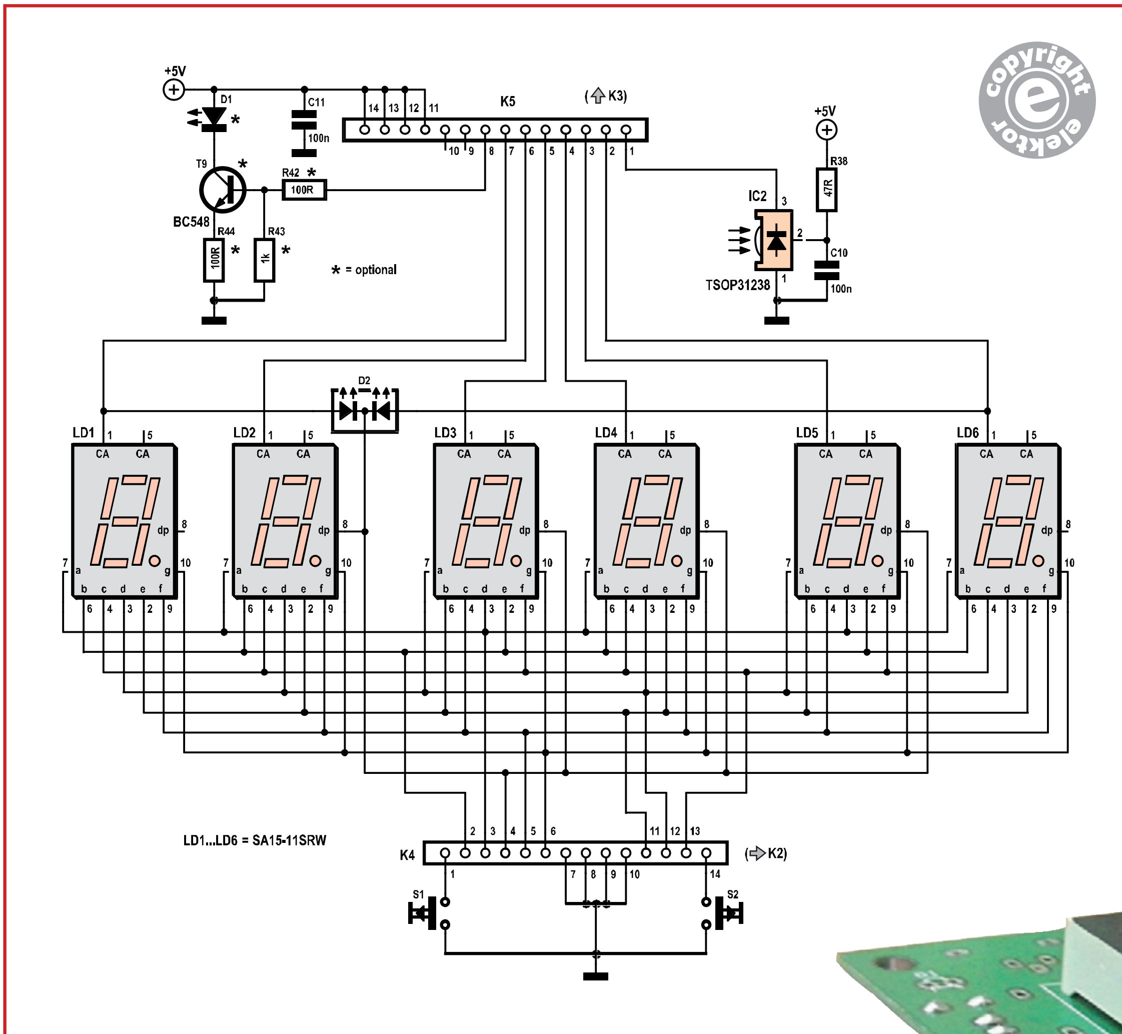
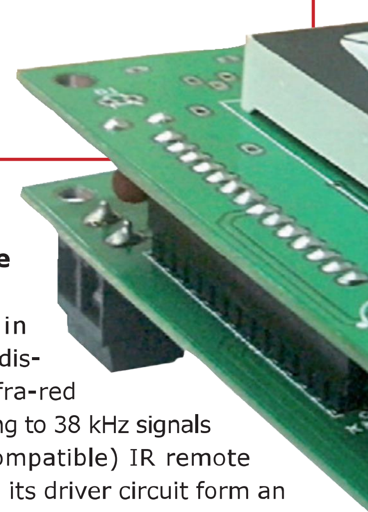



Figure 2.
Schematic of the display section. LD3 and LD5 are mounted upside down with adapted control in software, to create colons between hours and minutes, and minutes and seconds.



of the displays LD2-LD5 are connected together and brought out to pins on K4. Displays LD3 and LD5 are mounted upside down on the board (note the dots!) to create an oblique colon (:) between hours and minutes, and minutes and seconds. The PCB design takes care of this. The LED displays are multiplexed through their common-anode (CA) terminals, brought out to pins on K5 connecting to K3 on the microcontroller board. Pushbuttons S1 and S2 for controlling the clock functions are connected to the microcontroller also by way of K4 on the display board connecting straight to K2 on the microcontroller board. The display brightness can be adjusted as a user setting stored in the PIC micro. This function may be implemented using the flag 'DisplayOn' in the code.
Finally, on the display board, a bicolor LED (D2) is used to indicate AM (green) or PM (red if the clock operates in 12 hour mode.

**Infrared remote control: software ramifications**

The TSOP31238 in position IC2 on the display board is an infra-red receiver IC responding to 38 kHz signals from an RC5 (or compatible) IR remote control. LED D1 and its driver circuit form an infrared transmitter. An Infrared 'send' function was originally not implemented, hence if you do not need it, D1 and associated parts may be omitted.
As the Wall Clock project progressed, changes were made to the source code, as follows:

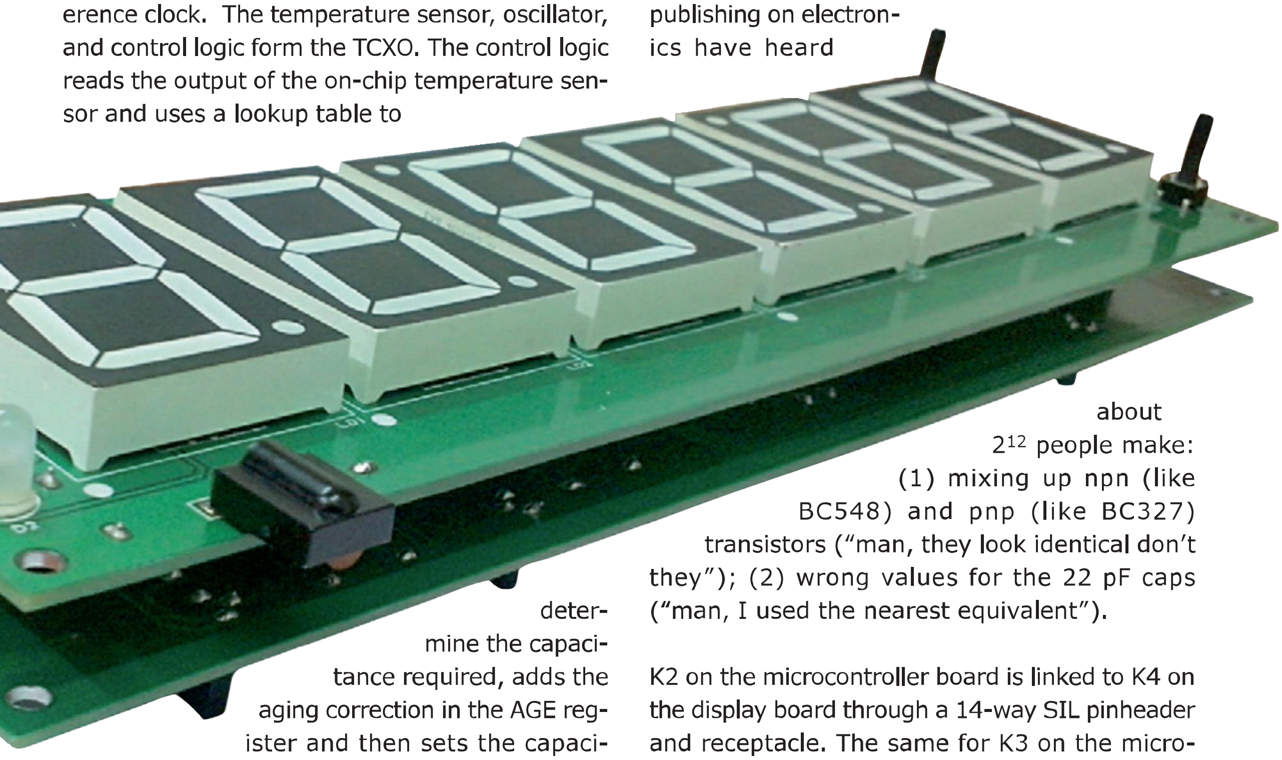
- Xtal changed to 20 MHz enabling the PIC to execute RC5 protocol section without any hiccups in the original code.
- RC5 protocol section implemented in the

interrupt routine, microcontroller now scans port pin RC7 status; checks received signal against RC5 protocol.
- In the main section: addresses and commands get extracted from the received RC5 data.
- If the command received is 16 or 17 (address and all other commands except 16 & 17 ignored) the program takes it as buttons S1 or S2 being pushed, respectively.
- Implemented Watchdog functionality in-order to avoid any uncertainty in the program.

With IR reception implemented you can control the clock from a distance wielding your (RC5 compatible) remote. Don't tell the kids!

### Real Time Clock (RTC) type DS3231

The DS3231 is a serial RTC driven by a temperature compensated 32-kHz crystal oscillator (TCXO), and provides a stable and accurate reference clock. The temperature sensor, oscillator, and control logic form the TCXO. The control logic reads the output of the on-chip temperature sensor and uses a lookup table to determine the capacitance required, adds the aging correction in the AGE register and then sets the capacitance selection registers. The AGE function is not used in this project—use of the aging register is not needed to achieve the given accuracy. With the clock source, the RTC provides seconds, minutes, hours, day, date, month, and year information, all accessible through the I2C bus. The device monitors its VCC level to detect power failures and to automatically switch to the backup supply when necessary.



On first power up the PIC microcontroller initializes the RTC to generate a 1-Hz square wave at the $\overline{INT}$/SQW pin by writing 0x00 to the RTC's control register. This is connected to the external interrupt (INT) of the microcontroller, effectively setting the PIC's INTF flag on each High-to-Low transition at RB0/INT. This is used to initiate a reading of the RTC's time registers. A 1-Hz (i.e. 1-second) flashing colon can also be derived from polling the status of RB0/INT.

### Construction

In terms of hardware the clock is divided into two sub-circuits: microcontroller/driver and display. Each is built on its own circuit board of which the component overlays are shown in **Figure 3**. Excepting the RTC, the entire design is implemented in old skool through-hole (TH) parts so should be easy to build if you apply care and precision in reading and soldering. Here are just two mistakes Elektor tech staff in their $35_{hex}$ years of publishing on electronics have heard about $2^{12}$ people make: (1) mixing up npn (like BC548) and pnp (like BC327) transistors ("man, they look identical don't they"); (2) wrong values for the 22 pF caps ("man, I used the nearest equivalent").

K2 on the microcontroller board is linked to K4 on the display board through a 14-way SIL pinheader and receptacle. The same for K3 on the microcontroller board and K5 on the display board. These connections allow the display board to be stacked on top of the microcontroller board.

### Operation

The circuit has only two pushbuttons to perform user control and adjustments. Press S1 for 1 second to take the circuit into time adjusting mode. Blinking digits means they're open to having the

## COMPONENT LIST

**Combined for microcontroller board, display board**

**Resistors**
(5%, 0.25W)
R1 = 82Ω
R2-R7,R15 = 27Ω
R8-R14,R16,R22,R25,R28,R31,R34,R37 = 680Ω
R17,R18,R19,R39,R40,R41 = 10kΩ
R20,R23,R26,R29,R32,R35 = 100kΩ
R21,R24,R27,R30,R33,R36 = 150Ω
R38 = 47Ω
R42-R45 = 1kΩ

**Capacitors**
C1,C2 = 22pF ceramic
C3-C7,C10,C11 = 100nF
C8,C9 = 470µF 16V radial

**Semiconductors**
D1 = LED, red, 5mm
D2 = LED, bicolor, e.g. Kingbright L-93WEGW
IC1 = LM7805CT
IC2 = TSOP31238 (Vishay Semiconductor)
IC3 = DS3231SN (Maxim Integrated Products)
IC4 = PIC16F876A-I/SP, programmed, Elektor Store # 110167-41
LD1-LD6 = SA15-11SRWA 7-segment display, CA (Kingbright)
T1-T15 = BC548
T16-T21 = BC327

**Miscellaneous**
BT1 = 3V Lithium button cell with holder.
K1 = 2-pin PCB screw terminal block, 0.2'' pitch.
K2/K4, K3/K5 = 14 pin SIL connector pair (pinheader and receptacle).
S1,S2 = pushbutton, PCB mount, tactile feedback, e.g. Alps SKHHALA010.
X1 = 20MHz quartz crystal.
PCB # 110167-1 (microcontroller board).
PCB # 110167-2 (display board).

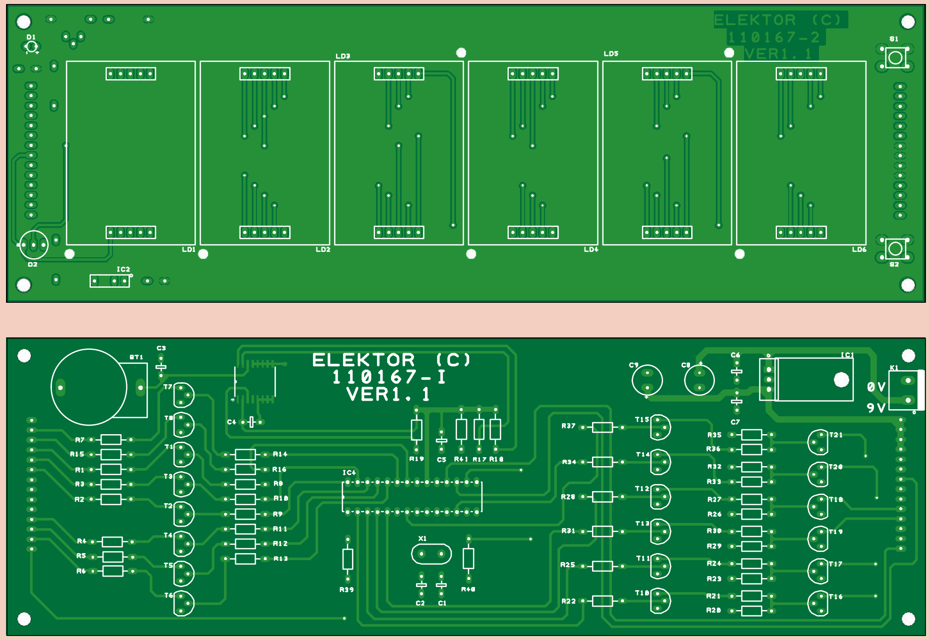



Figure 3. Separate printed circuit boards were designed for the microcontroller display sections, both using DesignSpark PCB. Boards shown at XX per cent of actual size. The display board accommodates Kingbright 1.5-inch (38 mm) SA15-11SRWA 7-segment displays.



displayed value changed by you, the user. Digits can be selected individually by a short press of S1—from seconds, through minutes, hours, 24/12 hour selection, to exit. Pressing S2 increments the selected digit to its highest value then rolls over, except for the 'seconds' digits, these will be changed to zero. Also, if the seconds exceed 30, the minutes' digits will increment by one. Pressing S2 ('up') with the clock not in time adjustment mode shows the temperature in °C with a minus sign for really cold rooms. The temperature sensor has an "accuracy" of ±3 °C and a resolution of 0.1 °C.

### Conclusion

The circuit provided here is a basic wall clock with sizeable (1.5") displays. Features such as alarm or synchronization between PC via infrared linking are optionally possible. The schematic, PCB design and PCB Gerber files produced by Elektor Labs India Dept. using DesignSpark PCB are available for free downloading at [1]. The same applies to the PIC source code written in C.

The project is expressly pitched at everyone wishing to extend it with their own functionality by adding software of their own creation, like display brightness adjustment mentioned above. Let the designer and the community at www.elektor-labs.com know how you are getting along.

(110167)

### Internet Reference

[1] www.elektor-magazine.com/110167