PICRONOS L.E.D. WALL CLOCK

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Part One

Ancient and modern techniques display timely brilliance on a grand scale!

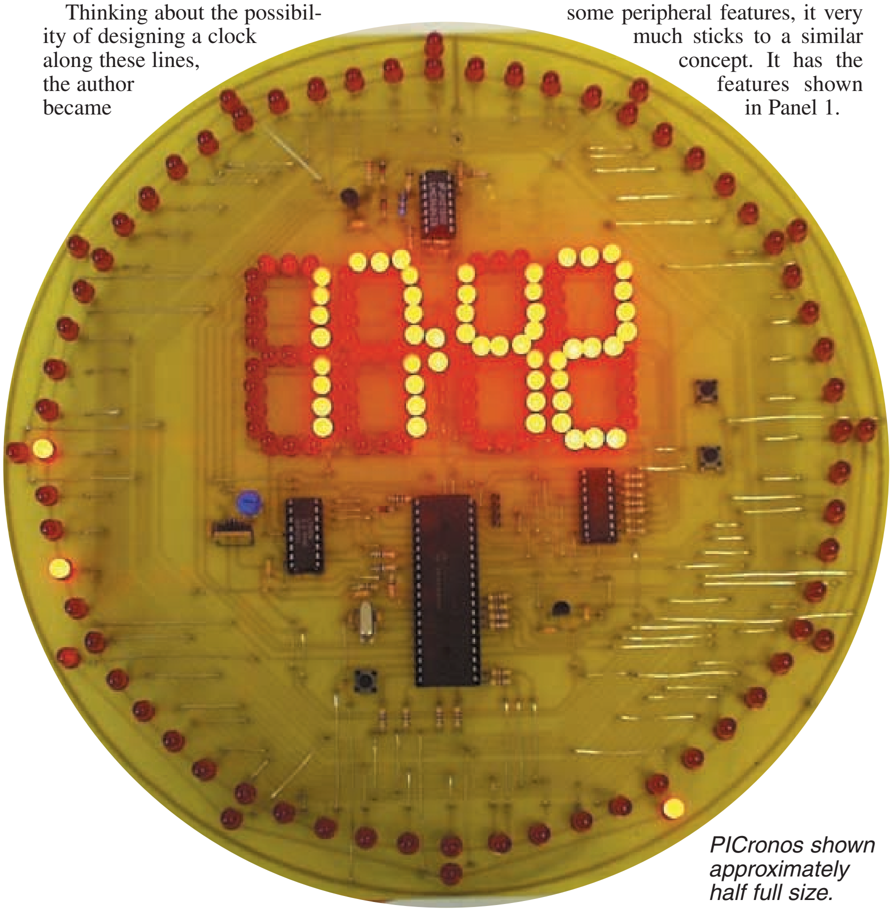
PORTUGUESE reader Fernando Bentes de Jesus emailed us during the Autumn of 2002, saying that his favourite electronically-controlled wall clock had "ticked its last tock" and that it could not be revived. He asked if we knew of anyone who might be interested to design a replacement.

Questioning him further, he explained that in essence his "dream clock" consisted of 60 light emitting diodes, arranged in a circle having a diameter of 24 centimetres, and displayed the seconds count. In the centre were eight digits with each segment comprised of several l.e.d.s. These displayed hours, minutes and calendar information.

Thinking about the possibility of designing a clock along these lines, the author became intrigued by the thought of designing one that embraced both old and new technologies – old in the form of l.e.d.s for the display rather than a liquid crystal screen, and new in the form of a PIC microcontroller (inevitably!).

Making some sketches, he ended up designing the circuit and printed circuit board for one over a weekend! With refinements, and after further discussions with Fernando, plus a *lot* of programming time, the clock presented here is that same one. Its achievement turned out to be a real exercise in multiplexing.

Whilst the design is not exactly the same as Fernando's ideal, which also included some peripheral features, it very much sticks to a similar concept. It has the features shown in Panel 1.



PICronos shown approximately half full size.

PANEL 1 FEATURES

- Crystal controlled
- Circular display having diameter of 9·8 inches (250mm)
- Inner ring of 60 l.e.d.s displaying both seconds and minutes
- Outer ring of 12 l.e.d.s displaying hours in conventional (analogue) 12-hour format
- Inner zone of 100 l.e.d.s in 4-digit 7-segment numerical format, cyclically displaying hours (24-hour format) and minutes, months and days of month, and temperature in degrees Celsius to one decimal place
- Three switches provide adjustment for all display values, and for the precise calibration of the timing accuracy to compensate for normal manufacturing tolerance in the controlling crystal's oscillating rate
- Powered at 9V to 12V d.c. via a mains supply adaptor, with battery back-up
- Current consumption only 65mA (thanks to heavy multiplexing of l.e.d.s)
- Adjustable brilliance of the l.e.d. numerals to suit personal taste

MATRIXED ARRAYS

The use of multiplexing in this design was essential, to cut down on the current consumption and the number of logic gate devices that would otherwise have been required. Additionally, heavy use is made of matrixed arrays. The most significant example of this is in the circle of 60 l.e.d.s., whose array structure is shown in Fig.1.

In this matrix, applying positive power (e.g. +5V) to one of the eight horizontal connections (numbered 9 to 16) allows current to flow through any of the l.e.d.s in that row if its cathode (k) is taken low (e.g. to 0V) via a suitable ballast resistor. The cathodes are also mutually connected in groups of eight columns (numbered 1 to 8). By selecting which row and column are activated, any one (or more) of the l.e.d.s can be turned on.

For instance, applying power between connections 9 and 1 will cause current to flow through the top left l.e.d., D1. So that none of the other l.e.d.s in the other rows are turned on, their anode row connections are held at 0V. Similarly, to prevent other l.e.d.s in a column being turned on, their cathode connections are held positive.

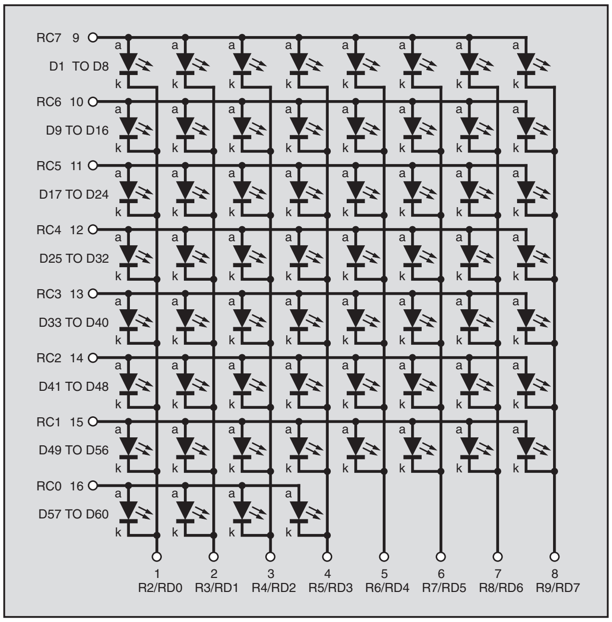


Fig.1. Matrixed array for the l.e.d.s that display minutes and seconds.

In theory, eight rows and eight columns can control 64 l.e.d.s. In this clock, though, only 60 l.e.d.s need to be controlled. Thus the last four positions of the matrix are left unused.

The other notations alongside each row and column (e.g. RC7 and R2/RD0) refer to the control points as shown later in Fig.5.

Multiplex control is used on this matrix. The 60 l.e.d.s are jointly used to show not only a seconds count but also a minutes count. This is achieved by first selecting the matrix co-ordinates for the seconds, turning on the required l.e.d. for a brief period, and then selecting the matrix co-ordinates for the minutes, and turning on that required l.e.d. for the same period. The alternating between the two matrix selections is so fast (around 400Hz) that both l.e.d.s appear to be on at the same time.

A second matrix is used for the l.e.d.s of the analogue hours display, as shown in Fig.2. Seven lines basically control this matrix, although it too is multiplexed by the control source, in conjunction with the 7-segment digits, i.e. as part of a 5-way multiplex switching format.

The basic l.e.d. format of a 7-segment digit is shown in Fig.3, and matrix diagram in Fig.4. Each of the four digits is identically arranged. Three l.e.d.s are connected in series for each of the horizontal segments (segment letters A, G and D), and four l.e.d.s are in series for each of the vertical segments (F, B, E and C). Different values of ballast resistor (R13 to R19) are used for the vertical and horizontal segments to achieve equal brilliance.

All four digits are multiplexed. There are four current source connections, each made to the primary anodes of all seven segments in one digit. The final cathodes of the like-lettered segments of all four digits are connected together (e.g. A to A, B to B). The seven connection paths control current sinking from the segments.

As with the matrix displays, any digit and any of its segments can be turned on as required, in this case using 11 control lines (four source plus seven sink). Again multiplexing is used in the control sequence so that each digit appears to be active simultaneously.

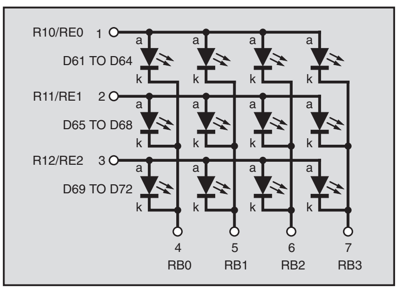


Fig.2. L.E.D. matrix for hours.

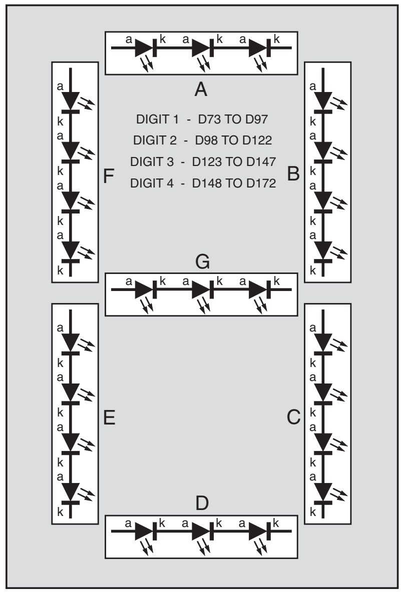


Fig.3. Basic format of a 7-segment digit.

CONTROL CIRCUIT

The control circuit diagram is shown in Fig.5. A PIC16F877 microcontroller, IC1, is the principal component, routing the many multiplex and matrix voltages as required. The PIC is operated at 3·2768MHz, as set by crystal X1.

The circuit should be read in conjunction with the previous illustrations. For example, the matrix display for the minutes and seconds l.e.d.s D1 to D60 that is shown in Fig.1 is represented by the block diagram connected to PIC pins RD0 to RD7 (Port D) and RC0 to RC7 (Port C). Port C provides the current source for the matrix rows, and Port D sinks the current from the matrix columns, via ballast resistors R2 to R9.

Port E is primarily used to provide the power source, via ballast resistors R10 to R12, for the hours matrix in Fig.2, The connection to switch S3 at resistor R11 is discussed later, as are the functions of switches S1 and S2.

The function of Port B is two-fold. In its first role, via pins RB0 to RB3, it provides current sinking from the hours matrix fed from Port E. Secondly it controls the gating of the digital display segments via IC4.

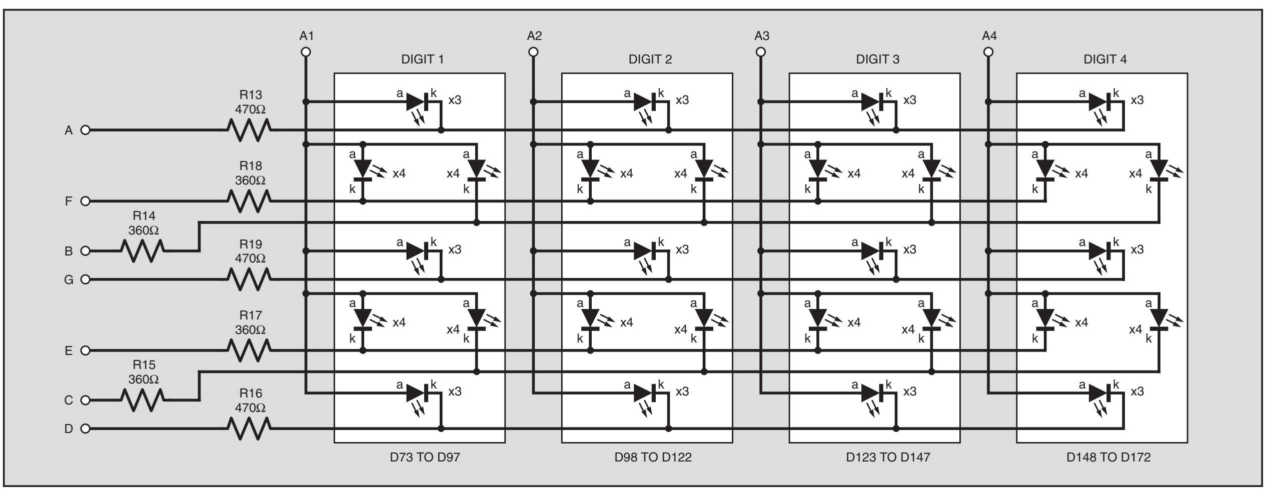


Fig.4. Interconnections between the four 7-segment digits. The x3 and x4 notations indicate the number of l.e.d.s in a segment.

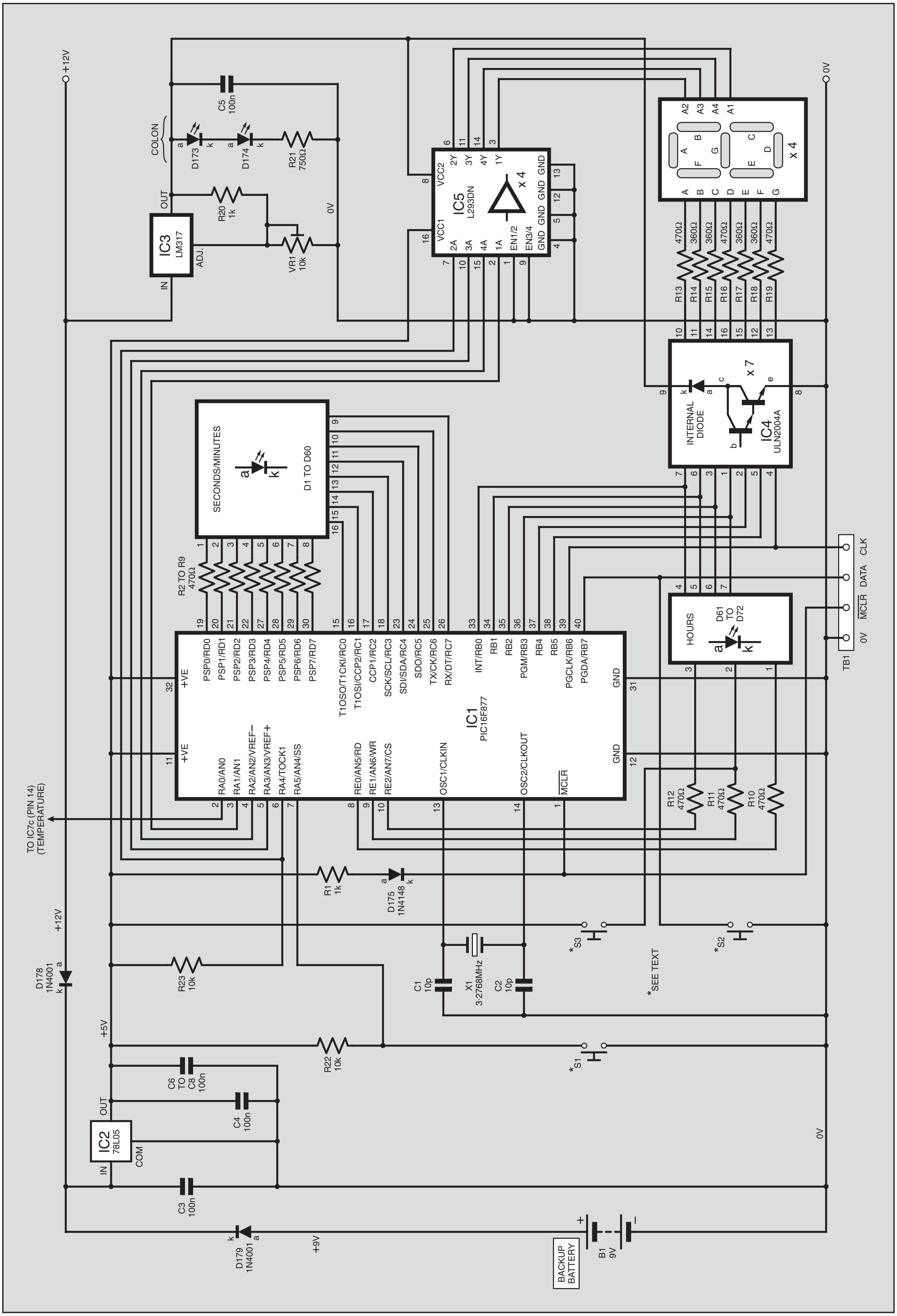


Fig.5. Main control circuit for the PICronos L.E.D. Wall Clock.

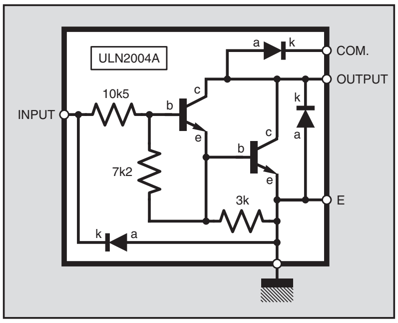


Fig.6. Single Darlington within IC4.

Device IC4 is a type ULN2004A and contains seven Darlington transistors which have open-collector outputs. The schematic diagram for one of the transistors is given in Fig.6.

The input to the base of the first transistor in the pair has an internal current-limiting resistor (10k5Ω) which allows the device to be controlled without the use of an external ballast resistor. The input is also protected against negative-voltages by an internal diode.

The open-collector output from the pair is also provided with internal protection diodes, to make the device suitable for use with inductive loads. Strictly speaking they are not needed in this design, but they have been connected anyway.

The Darlingtons are controlled by Port B (RB0 to RB6), and their outputs sink current from the digital display segments via resistors R13 to R19.

The anodes of the digital displays are indirectly controlled by Port A (RA1 to RA4). Because RA4 has an open-collector output, it is biased to the +5V line via resistor R23.

The digital displays are powered at a voltage higher than the 5V that supplies the PIC. This enables the brilliance of the displays to be more readily placed under external control, as discussed shortly. An interface is required to enable the 5V control voltage from the PIC to select the path through which the higher voltage, up to around 12V, is routed to the display anodes.

4-DIGIT DRIVER

The interface device used is the L293DN type previously chosen for the author's *PIC Big Digit* display (electro-mechanical digits) of May '02 (so too was the ULN2004A). Its internal functions and truth table are illustrated in Fig.7. Although not shown, this device also has internal protection diodes, between the outputs and the two power rails. They are irrelevant to this circuit as the device is not controlling inductive loads.

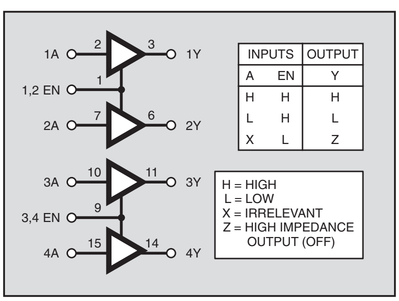


Fig.7. Schematic functions and truth table for IC5.

The L293DN requires two positive power supplies. One needs to be suited to the voltage level swing at the device's inputs, in this case a supply of +5V is fed to VCC1 at pin 16. The output needs the second power source to be suited to the output voltage required by the circuit being controlled. It is supplied via VCC2 at pin 8.

POWER SUPPLY

The design is intended to be powered by an external supply capable of delivering between about 9V and 12V d.c. at about 65mA, via a mains-power adaptor for example. It is recommended that the supply should be capable of delivering at least 100mA to provide plenty of "headroom". Whilst a current of 65mA may seem low for a circuit having nearly 200 l.e.d.s, it is the multiplexing technique that has enabled a low current consumption to be achieved.

Two power supply inputs are provided, via diodes D178 and D179. The connection for the main power supply is via diode D178. The other path is intended for connection of a back-up battery, of 9V at about 30mA maximum. This enables the clock to continue running in the event of a power failure at the main source, but without the l.e.d. digits being active.

If a backup battery capable of being kept on permanent trickle charge is used, a suitable charging resistor could be connected across diode D179. Its value should be chosen to suit the battery concerned (refer to its data sheet).

The principal incoming power supply is directly connected to the input of adjustable voltage regulator IC3. This is an LM317 device whose output voltage is controllable by potentiometer VR1 in conjunction with feedback resistor R20. Its purpose is to allow the brilliance of the 7-segmented digits to be varied, and that of the two l.e.d.s D173 and D174. These two form the "colon" between digits 2 and 3. It is a static colon and is not under PIC control.

Note that the brilliance of the l.e.d.s in the two rings (D1 to D72) is fixed.

If the variable brilliance facility is not needed, omit VR1, R20 and IC3. Then link the IN and OUT pads of IC3's position.

It is worth noting that although red l.e.d.s were used throughout in the prototype, it might be beneficial to make those in the outer hours ring a different colour (e.g. bright green or blue) so that they stand out better from the inner ring when seen from a distance.

When purchasing the l.e.d.s remember that considerable cost savings can be made by buying in bulk. The author paid 6p per l.e.d. by buying 200, even though fewer are actually required. L.E.D.s can be bought at even lower prices from some suppliers, but before buying ensure that their pin spacing and diameter is consistent with the spacing allowed on the board.

For the sake of readers who may wish to modify parts of the software to suit their own needs, resistor R1, diode D175 and connector TB1 allow the PIC to be programmed by a suitable external programmer, such as the author's *Toolkit TK3* of Oct/Nov '01, to which readers are referred for more information (also see later). R1 and D175 should be retained even if the programming option is not required, although TB1 may be omitted.

TEMPERATURE SENSING

A temperature sensing and display facility has been included. Its analogue circuit diagram is shown in Fig.8.

Temperature sensing is performed by the familiar LM35CZ. This basically outputs a voltage that varies by 10mV per degree Celsius. It is used in a configuration given in the device's data sheet, with which two diodes are used in series between the device's negative terminal and the 0V line.

This allows the device to output a voltage relative to negative temperatures. However, it is fully agreed with Fernando that anyone experiencing sub-zero temperatures where this clock is placed should emigrate to a warmer climate. With this in mind, the clock has not been tested for negative temperatures!

The lower-cost LM35DZ could be used instead without circuit modification if the negative temperature option is not needed. It is worth considering though, whether you might like to have the sensor outdoors so you know how cold it is there on a winter's day while you are warm and snug!

If the latter technique is used, it might be worthwhile adding the resistors and capacitors (RT, CT1, CT2) shown in Fig.9. These help to keep the input signals stable for long cable lengths, and should be mounted at the board end. They will need

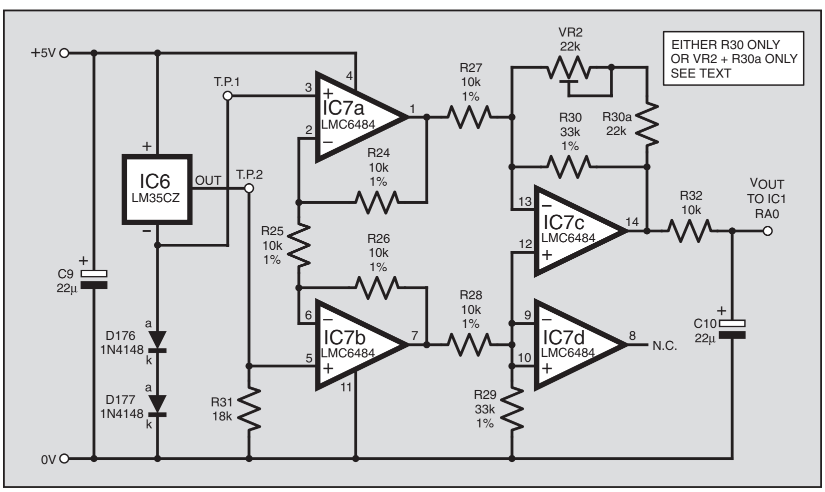


Fig.8. Temperature sensing circuit.

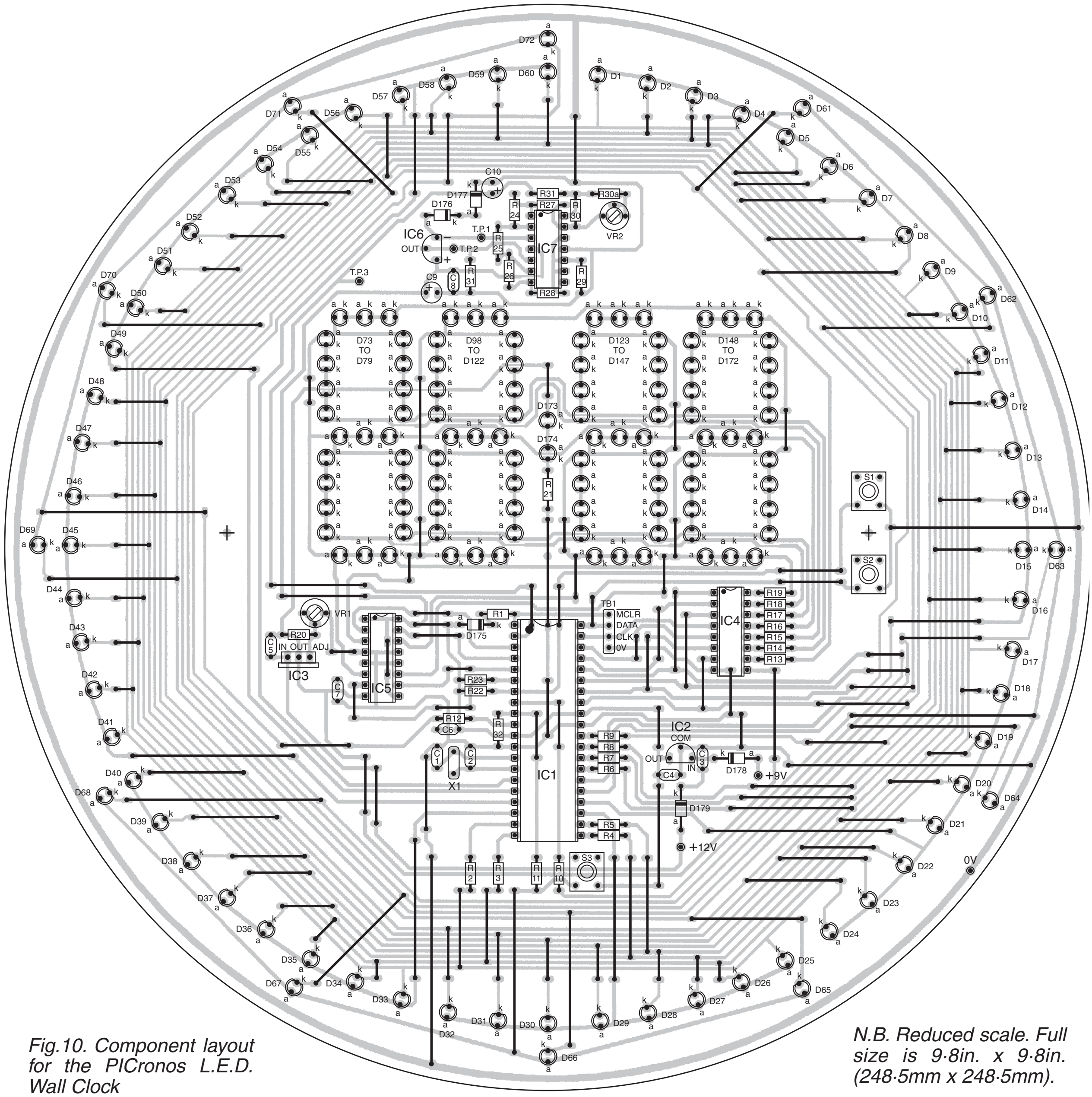


Fig.10. Component layout for the PICronos L.E.D. Wall Clock

N.B. Reduced scale. Full size is 9·8in. x 9·8in. (248·5mm x 248·5mm).

COMPONENTS

Resistors

R1, R20	1k (2 off)
R2 to R13, R16, R19	470Ω (14 off)
R14, R15, R17, R18	360Ω (4 off)
R21	750Ω
R22, R23, R32	10k (3 off)
R24 to R28	10k 1% 0·25W (5 off)
R29, R30	33k 1% 0·25W (2 off)
R30a	22k (see text)
R31	18k

All 0·25W 5% except where stated.

See SHOP TALK page

Potentiometer

VR1	10k min. round preset
VR2	22k (or 25k) min. round preset (see text)

Capacitors

C1, C2	10p disc ceramic, 0·5mm pitch (2 off)
C3 to C8	100n disc ceramic, 0·5mm pitch (6 off)
C9, C10	22µ radial elect. 10V (2 off)

Semiconductors

D1 to D60, D73 to D174	red l.e.d., 5mm dia. ultrabright (162 off)
D61 to D72	red l.e.d., 5mm dia, ultra-bright (see text) (12 off)
D175 to D179	1N4148 signal diode (5 off)
D178, D179	1N4001 rectifier diode (2 off)
IC1	PIC16F877-4 microcontroller, pre-programmed (see text)
IC2	78L05 +5V 100mA voltage regulator
IC3	LM317 adjustable voltage regulator
IC4	ULN2004A 7-way Darlington line driver
IC5	L293DN 16-pin Half-H driver
IC6	LM35CZ temperature sensor
IC7	LMC6484 quad op.amp, rail-to-rail

Miscellaneous

S1 to S3	min. push-to-make switch, p.c.b. mounting (3 off)
TB1	1mm pin-header, 4-way (optional)

Printed circuit board, available from the *EPE PCB Service*, code 395; 22s.w.g. tinned copper wire, solid (for link wires); 14-pin d.i.l. socket; 16-pin d.i.l. socket (2 off); 40-pin d.i.l. socket; 1mm terminal pins or pin headers; connecting wire; solder, etc.

Approx. Cost Guidance Only **£45** *excl. batts*

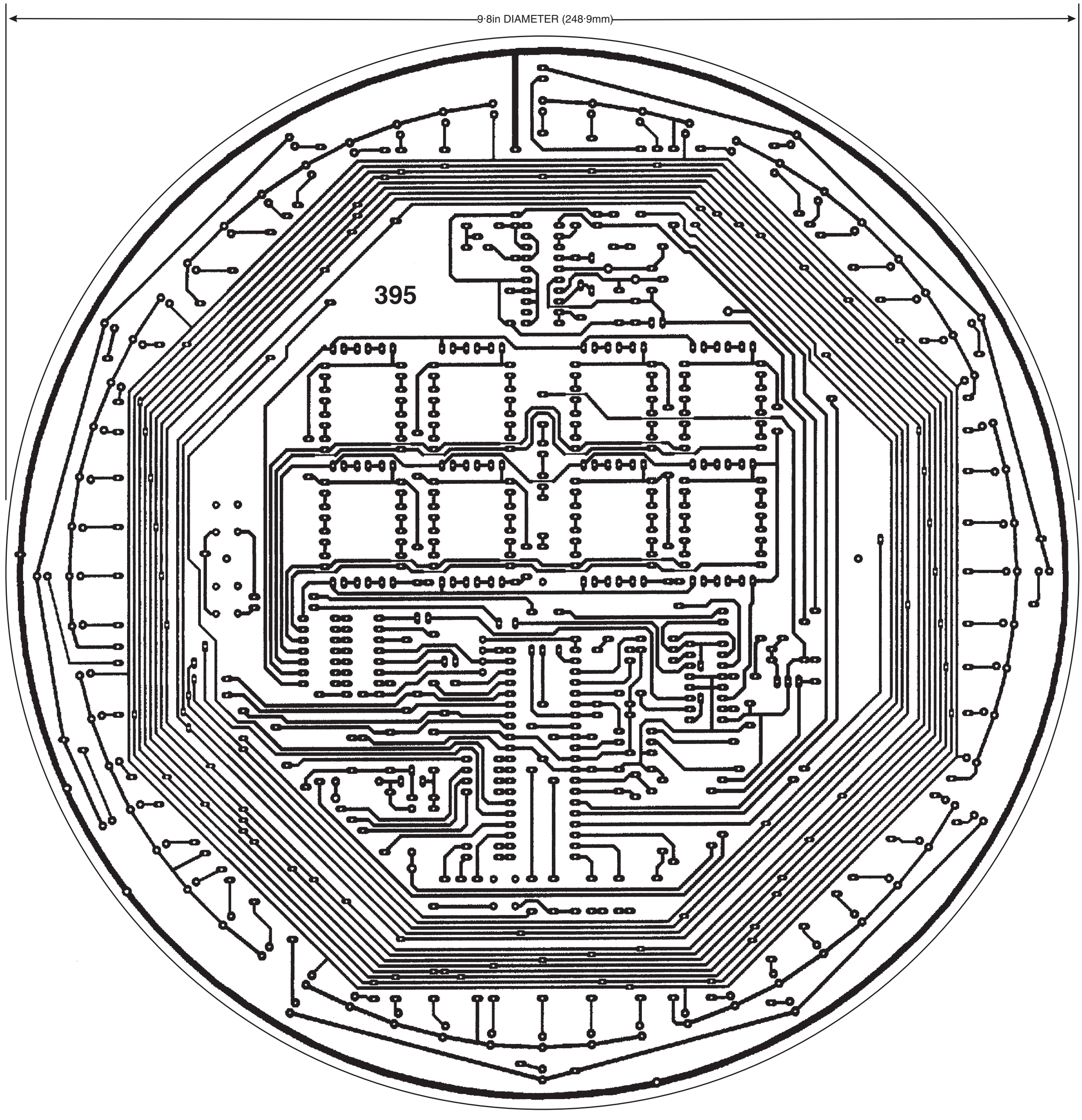


Fig.11. Reduced scale copper foil track pattern for the PICronos L.E.D. Wall Clock. This should be enlarged on a photocopier to 9·8in. x 9·8in. (248·5mm x 248·5mm) or purchase a board from the EPE PCB Service.

to be hardwired as no provision for them has been made on the board. The principle was discussed in *Teach-In 2002* Part 5 (with reference there to Fig.5.6 page 194). The values shown in Fig.9 provide a cut-off frequency of 166Hz.

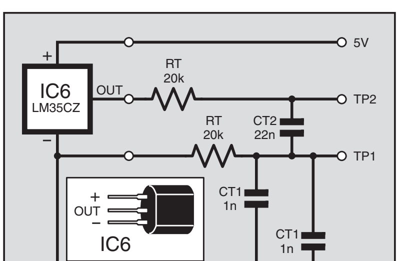


Fig.9. Additional components suggested if external temperature sensing is required.

Between them, IC7a to IC7c form a standard differential amplifier providing a d.c. gain of ×10. Resistors of one per cent tolerance are specified for all resistors except R31 and R32 (which may be five per cent). This close tolerance allows the amplifier to provide an output voltage swing that linearly tracks the output of the sensor by a factor of 10.

By calculation, the gain of the amplifier is actually ×9·9 (×3 via IC7a/b and ×3·3 via IC7c – see *Teach-In 2002* Part 5 for explanation). It was felt that this was close enough to 10 to be acceptable. For those readers who wish to be more precise, resistor R30 should be *omitted*, and resistor R30a plus VR2 should be inserted *instead*, adjusting VR2 to provide the exact gain needed.

Note that software allows the set range width (but not the gain) of the output voltage to be raised or lowered in response to pushswitch control (see later).

CONSTRUCTION

Printed circuit board (p.c.b.) component and track layout details are shown in Figs. 10 and 11. This board is available from the *EPE PCB Service*, code 395.

Both figures are shown to a reduced scale. The full size is 9·8in. × 9·8in. (248·5mm × 248·5mm). If you wish to make your own p.c.b. using Fig.11, the image should be enlarged on a good quality photocopier.

The board supplied by the *EPE PCB Service* is in the round format and has pilot holes drilled for the two mounting holes as shown in Fig.10 and Fig.11.

There are over 130 link wires that need to be made on the board. The cost of producing a plated-through-hole (pth) board was considered to be prohibitive. The use of a double-sided board with interconnecting pins was also felt to be just as taxing in construction as inserting link wires.

Make the link wire connections first, especially noting that some go under d.i.l. (dual-in-line) i.c. positions. The links are best made using solid tinned copper wire of 24 s.w.g. (a roll of which should be part of anyone's toolkit).

Next insert all the d.i.l. i.c. sockets. Do not insert the i.c.s themselves, or the temperature sensor, until the board has been fully checked for poor soldering, incorrect component positioning, and the correctness of the power supply has been determined. Regulator IC3 can be mounted with its back against the board to keep the board's profile low.

Next insert the resistors, diodes (but not l.e.d.s), capacitors and voltage regulators in order of ascending size. Ensure the correct orientation of the semiconductors and electrolytic capacitors.

Finally, insert the l.e.d.s. Note that those in the two "rings" all have their cathodes (k) pointing towards the centre. Those in the horizontal segments all have their cathodes to the right, while the cathodes of those in the vertical segments all face downwards.

To assist in the best alignment of the l.e.d.s, initially just solder one leg of each so that it is easier to re-position a misplaced one by having to unsolder only one lead. The l.e.d.s will have small spigots close to the body end of each lead, allowing their insertion depth to be maintained consistently.

Those who have good quality printed circuit board assembly frames with clip-on foam "lids" will find the entire p.c.b. assembly far easier than those who do not. The author's frame accepts p.c.b.s of 10in × 18in (254mm × 457mm) and the PICronos board was designed to just fit it.

It may be of interest to know that the author has used this frame for over 20 years and it considerably assists in the assembly of all the boards he designs.

It is strongly recommended that if you do not have an assembly frame, you should buy one. But only get a good quality one – those at the cheaper end of the selection may prove more trouble than they are worth, as the author once found to his detriment. Those in the professional class are the best.

Using this frame, assembly of the PICronos board took around four hours.

The author did not provide the clock with an enclosure and no recommendation for using one is offered.

SOFTWARE

The software for the clock is available on a 3·5in disk (Disk 6) from the *EPE* Editorial office (a small handling charge applies), or as a *free* download from the *EPE* ftp site. The easiest way into the latter is via the main *EPE* website page at **www.epemag.wimborne.co.uk**. and click on the ftp site link at the top. Then click on down through folders PUB, PICS and then into the PICronos folder.

There are two files – ASM (source code in TASM grammar) and HEX (in standard MPASM format). The HEX file is the code file to be sent directly to the PIC via a suitable programmer (e.g. *TK3*). It contains embodied configuration and data EEPROM values.

For those whose programmers cannot handle embedded data, the configuration values must be set separately. The values are XT crystal, WDT off, POR on. All other factors should be off. Data EEPROM values can be set by switches during clock adjustment and calibration, as discussed next month. Note that unexpected display results may occur until the values have been set.

Pre-programmed PICs can also be purchased – for details of this and on obtaining the software disk, read this month's *Shoptalk* page.

NEXT MONTH

In the final part next month, the clock's software and setting-up are discussed.