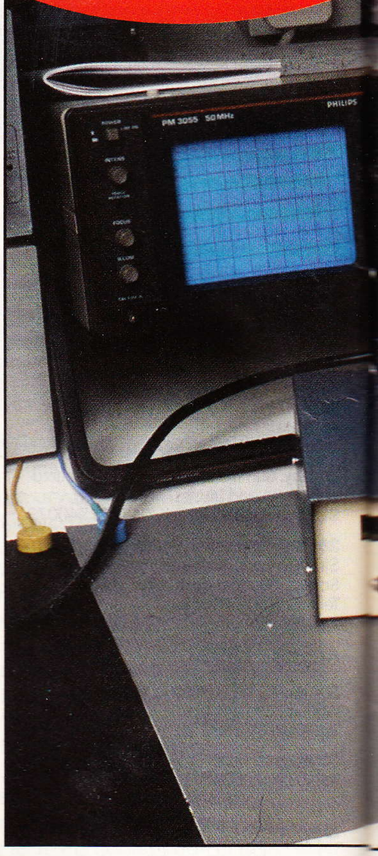
PROJECT

Digital SOLDERING IRON CONTROLLER



by Dr Mike Roberts

This project provides the opportunity to build a top quality, low voltage soldering iron controller at a fraction of the cost of a commercial unit, with the added features of showing you the measured temperature and the power being applied as well as the set temperature.

FEATURES & SPECIFICATION

- Close temperature control in range 60 to 450°C.
- 50W power available when needed.
- Digital display of set temperature, measured temperature and level of power being applied.
- Low noise circuit.
- Very fast warm up time (30 to 40 seconds).
- Temperature can be adjusted for the solder/task being performed.
- Able to tackle larger jobs.
- Iron can be used for melting/sealing plastics or other low temperature duties.
- Iron element and bits last longer.

Once you have used a temperature controlled iron, you will never want to use a conventional iron again! The fast warm-up and consistent temperature control is fantastic. When you want to do a job, just switch on the controller and by the time you have got the solder out and the wires prepared, the iron is ready to use. If you have a large job, this controller can push out 50W of power, so you can tackle a job needing the equivalent of two 25W XS irons. If you have something more delicate to do like cutting/joining bubble-wrap or applying heatshrink film to tight corners on a model aircraft, just turn the temperature down to what you need.

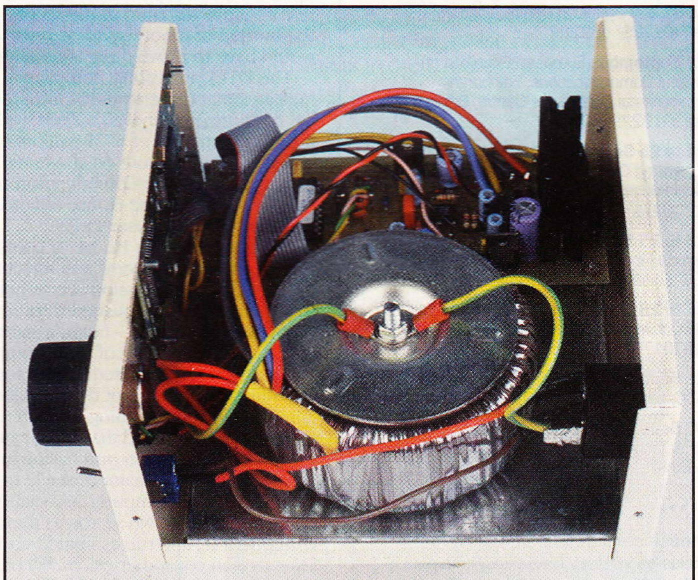
This controller is designed for the Antex TC50 low voltage (24V 50W) iron. It drives the iron with 24V 50Hz power using a zero-crossing switch to apply full half cycles of power with minimum noise.

How it Works

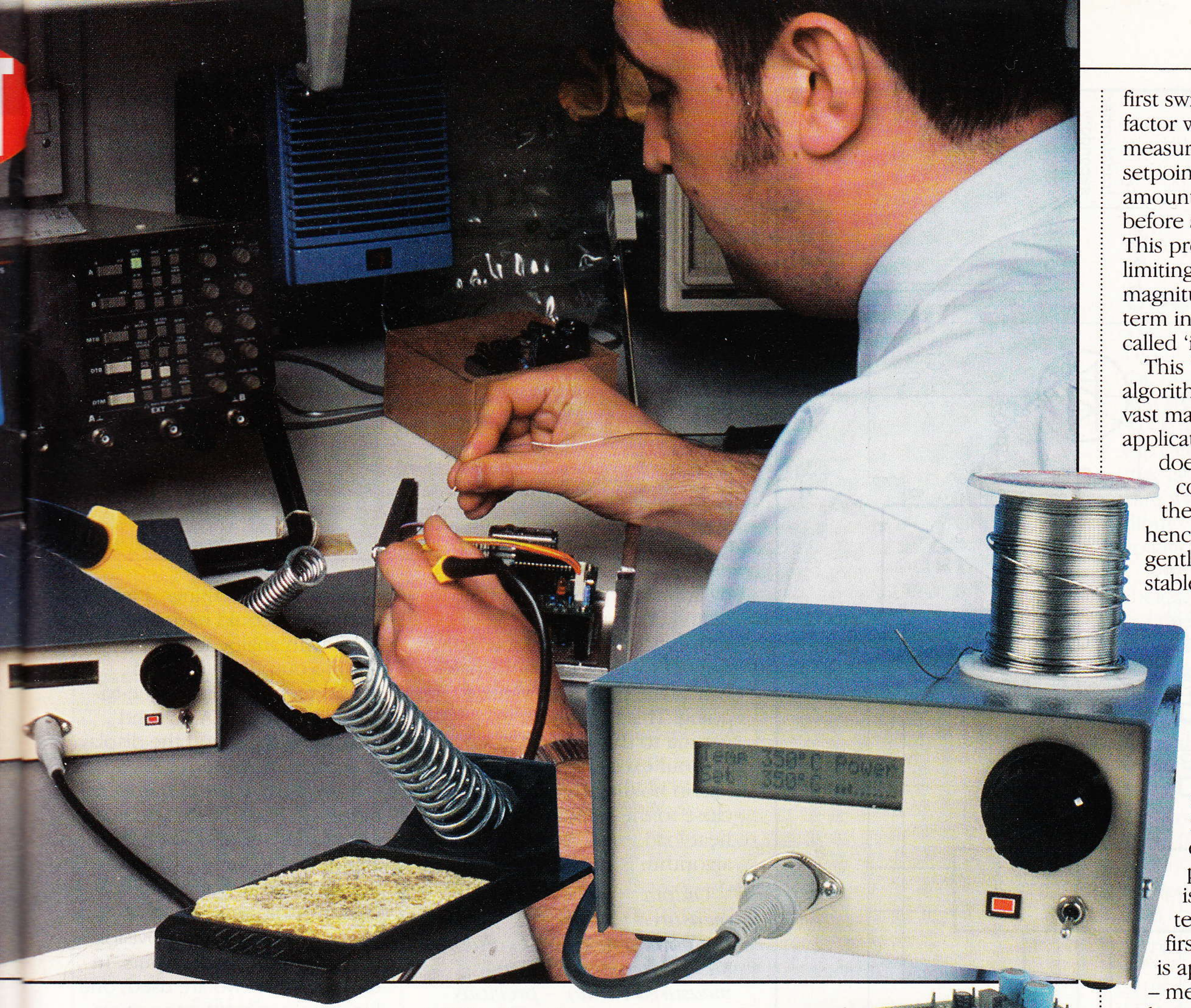
The principle of operation is simple. The iron has a thermocouple in the tip in addition to the heating element. Hence, power can be applied until the measured temperature reaches the desired temperature.

This principle is used in simple temperature controllers such as the Maplin Project from Issue 59 of *Electronics* in November 1992. A limitation, however, with these basic controllers is that the power is either full on or off. With the delay in heat getting to the sensor, the bit temperature continues to rise after the set temperature has been reached and then does the same in the other direction when the power is turned off. The net effect is a temperature which oscillates over about 20-30°C.

The route to close temperature control is to use a range of output powers and to continuously apply the level of power needed for the current situation. The controller then needs an algorithm to decide what level of power is needed. Industrial plant controllers typically use what are called 2- or 3-term proportional controllers. The same technology is applied here as a sophisticated 3-term controller (proportional, integral and derivative action with integral desaturation). These terms are much simpler to understand than they sound, so please read on.



Inside view of the Digital Soldering Iron Controller.



One can have a 'proportional only' controller. The algorithm is of the form:

Output = Kp × (set point – measured value)

Where 'Kp' is the proportional gain.

This will work to a degree (no pun intended). Take, for example, a case where the output and the set point/measured values are in the range 0 to 1·0 and the value of 'Kp' is, say, 10. You will see that in order to apply a full output of 1·0, the value of the (set point – measured value) will be 0·1, i.e., 10% of the range. In our temperature controller case, this would lead to an offset of up to 45°C (range 450°C). This offset can be reduced by increasing the gain. For the same reason, operational amplifiers have high gain. Unfortunately, we cannot make the gain too high as the system has a low frequency response due to the thermal lags. With too high a gain, the system will oscillate. Again, there is an analogy with operational amplifiers which also need high frequency response or they too will oscillate. So, proportional only control will not meet our needs.

Integral action to the rescue. All this does is add up the offsets (set point – measured value) and adds this sum to the proportional factor. The effect is to gently add more power until

the offset is driven to zero. The algorithm is:

Output = Kp × (set point – measured value) + Ki × sum (set point – measured value)

Where 'Ki' is the integral gain.

The integral action gain, Ki, has to be tuned to give the best control. If it is a low value, it is slow to bring the offset to zero. If it is too high, it makes the system unstable. Integral action can also cause problems when the difference between the set point and measured values is large for some period of time, for example, when the iron is first switched on. The integral factor would try to drive the measured value above the setpoint for about the same amount of time as it was below before settling to zero offset. This problem is solved by limiting the maximum magnitude of the integral action term in the algorithm. This is called 'integral desaturation'.

This '2-term' control algorithm is satisfactory for the vast majority of control applications. Unfortunately, it does not do anything to compensate for the thermal lag in the iron and hence, has to be a slow gentle control in order to be stable. The fastest and tightest control is achieved by adding 'derivative action'. This looks at the rate of change of the difference (set point – measured value), hence its name. It works by adding a compensation into the algorithm based on how fast the (set point – measured value) is changing. In practical terms, when the iron is first turned on, full power is applied and the (set point – measured value) is reducing fast. The derivative action recognises this and forces the power to be reduced before the set point is reached. Derivative action enables the controller to predict how much the temperature will increase after the power is removed, hence compensating for the thermal lag. With good tuning, it will turn the power off completely about 20°C before the setpoint is reached and as the heat dissipates, the measured temperature comes up close to the set value leaving the integral action to finish off the job.

The derivative action also speeds up the response when you tackle a heavy heat load. When it sees the temperature falling rapidly, it compensates

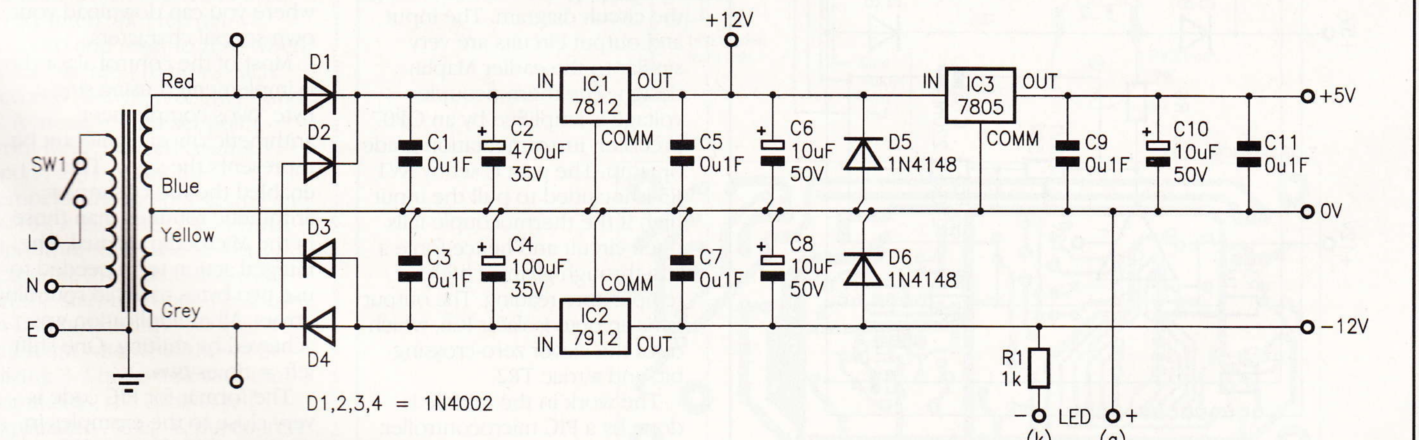


Figure 1. Circuit diagram – Power supply section.

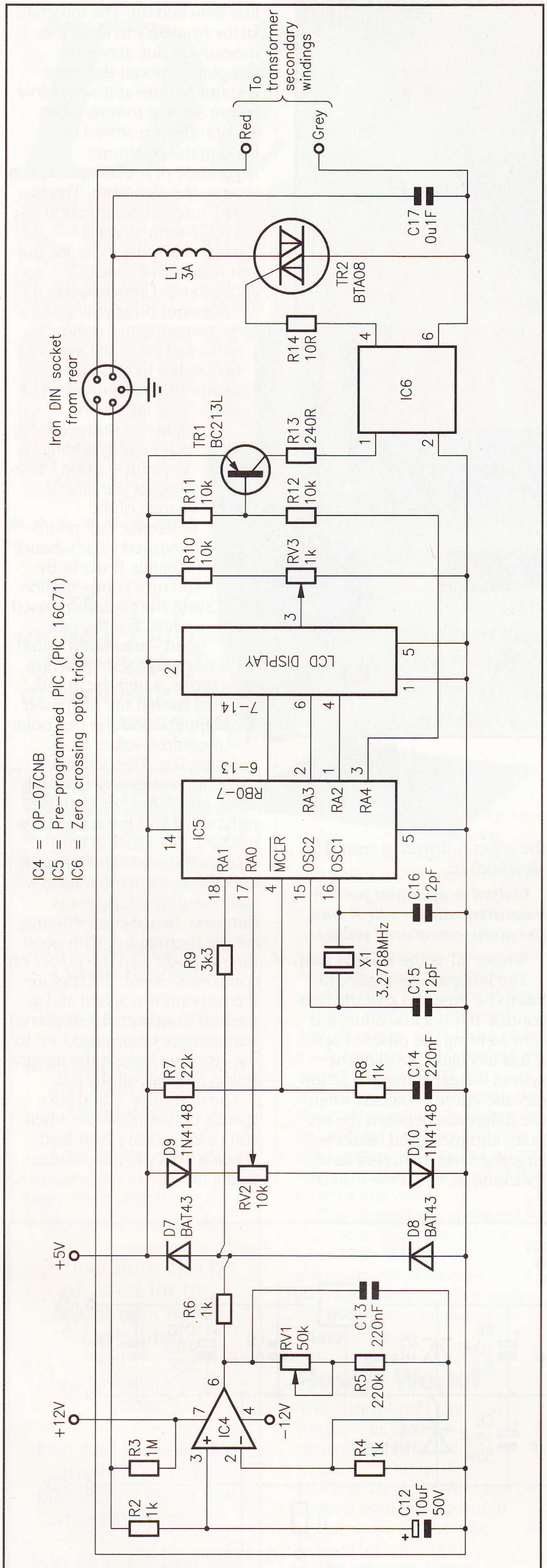
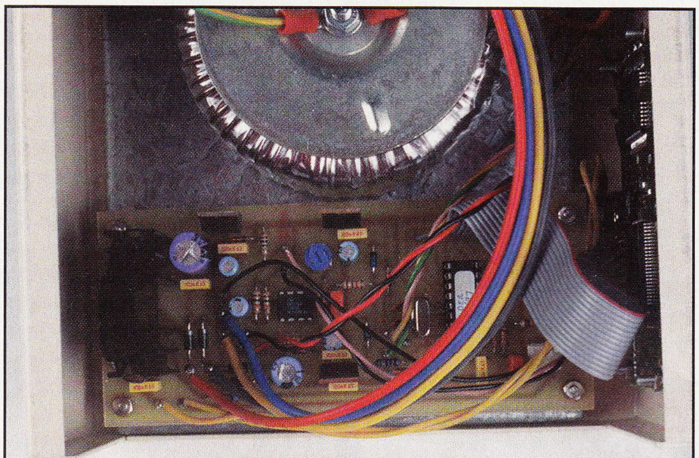


Figure 2. Circuit diagram – Control section.



Close-up of the assembled PCB.

by applying more power than would be applied by proportional action alone. So, the derivative action anticipates where the measured value is going. This helps both in getting to the setpoint fast without excessive overshoot and in holding the temperature close to the setpoint when the heat load varies. The full algorithm is then:

Output = Kp × (set point – measured value) + Ki × sum (set point – measured value) + Kd × [current (set point – measured value) – previous (set point – measured value)]

Where 'Kd' = derivative gain.

The soldering iron controller uses this 3-term algorithm. The values of Kp, Ki & Kd have been tuned to give fast stable control. The controller calculates what output power to apply 10 times per second. This is convenient as there are 100 half cycles per second, so it can apply somewhere between 0 and 10 half cycles of power in every tenth of a second.

The controller also has a software safety trip. If the measured temperature exceeds 460°C, it will shut off all power. This can only be reset by switching the controller off.

Circuit Description

Refer to Figures 1 & 2, showing the circuit diagram. The input and output circuits are very similar to the earlier Maplin design. The thermocouple voltage is amplified by an OP07 precision instrumentation grade op-amp. The gain is set by RV1. R3 is included to pull the input high if the thermocouple fails open circuit and hence force a trip-through giving a high temperature reading. The output is via an opto-isolator IC6, which does the clever zero-crossing bit, and a triac TR2.

The work in the middle is done by a PIC microcontroller. Sorry, I have said the dreaded 'PIC' word. One just cannot get away from these things. I guess the control could have been done with analogue circuitry – but the output conversion would require an analogue-to-digital converter (ADC) and associated logic, and the display of set and measured temperature would require two more ADCs, and then you need display drivers, and so on. I am afraid the PIC simply provides the most elegant and cost-effective solution.

The PIC16C71 has provision for up to 4 analogue inputs. In this case, just two are used, one for the measured temperature and one for the set temperature (RV2). PORTB (8 digital lines) sends data to the alphanumeric display with two of the unused PORTA pins for the display control logic. The last available PORTA pin drives the output. The programme uses the principles described in the earlier 'Putting PICs to Work' article in Issue 113. A 3·2768MHz crystal is divided down to give interrupts at 100Hz. The code executed at the interrupt is used to drive the output and collect the analogue data. Every 10 interrupts, it evaluates the control algorithm and updates the display. The power is shown on the display as a mini bargraph. This is achieved using the feature on the Hitachi displays where you can download your own special characters.

Most of the control algorithm is implemented using single byte 'twos complement' arithmetic (most significant bit represents the sign). This enabled the use of simpler arithmetic routines than those in the Microchip manual. The integral action term needed to use two bytes to avoid rounding errors. All multiplication was achieved by shifting. One shift left = times two.

The format for PIC code is very close to the examples in the Issue 113 'Putting PICs to Work' article. An additional

```
        bsf              STATUS,RP0         ;bank 1
        movlw b'00000010'
        movwf ADCON1                        ;porta 0,1 analogue rest digital
        movlw b'00000011'
        movwf TRISA                         ;porta bits 2-4 out, bits 0,1 in
        bcf              STATUS,RP0         ;bank 0
```

Listing 1. Additional code on the start-up routine.

```
        incf             csec,F             ;increment counter
        movlw d'10'
        subwf            csec,W             ;w=csec-10
        btfsc            STATUS,Z           ;skip if csec<>10
        clrf             csec               ;csec=0
        movlw d'7'
        subwf            csec,W             ;w=csec-7
        btfsc            STATUS,Z           ;skip if csec<>7
        goto             gset
        movlw d'8'
        subwf            csec,W             ;w=csec-8
        btfsc            STATUS,Z           ;skip if csec<>8
        goto             gtemp
        movlw d'9'
        subwf            csec,W             ;w=csec-9
        btfsc            STATUS,Z           ;skip if csec<>9
        goto             calc
        retfie
gset    movlw b'11000001'
        movwf ADCON0                        ;start adc sample, ch0 (set), RC osc
        call             DELAY
        bsf              ADCON0,adgo        ;start new sample
        bsf              STATUS,Z
        retfie
gtemp   movf             ADRES,W            ;w= result = setp
        movwf setp
        movlw b'11001001'
        movwf ADCON0                        ;start adc sample, ch1 (temp), RC osc
        call             DELAY
        bsf              ADCON0,adgo        ;start new sample
        bsf              STATUS,Z
        retfie
calc    movf             ADRES,W            ;w= result = temp
        movwf temp
        code for controller calculation
        retfie
                                            ; sample delay
DELAY   movlw d'3'
        movwf tempr1
del     decfsz           tempr1,F
        goto del
        return
```

Listing 2. Interrupt routine key code.

feature used here is the analogue-to-digital converter, which is available in the PIC16C71. One can take advantage of the interrupt routine which runs every 10ms to simplify the code. An analogue-to-digital conversion will be easily complete in the time from one interrupt to the next. The controller only needs to measure the set point and the temperature once each tenth of a second or every 10 interrupts. It uses a software counter which is incremented every interrupt (100 per second) and reset to zero when it reaches ten (10 times each second). Between counts 7 and 8, it measures the set point from RV2, between counts 8 and 9, it measures the temperature and between 9 and 10 (0), it evaluates the control algorithm to set the power required. The additional code on the start-up routine is shown in Listing 1 and the code in the interrupt routine is shown in Listing 2. I hope that with the comments, the code is self explanatory: 'csec' is the counter of centi-seconds; 'tempr1' is a temporary register used in the 'DELAY' subroutine which allows time for the input voltage to settle before starting the analogue-to-digital conversion; 'setp' holds the value of the setpoint and 'temp' holds the value of the temperature.

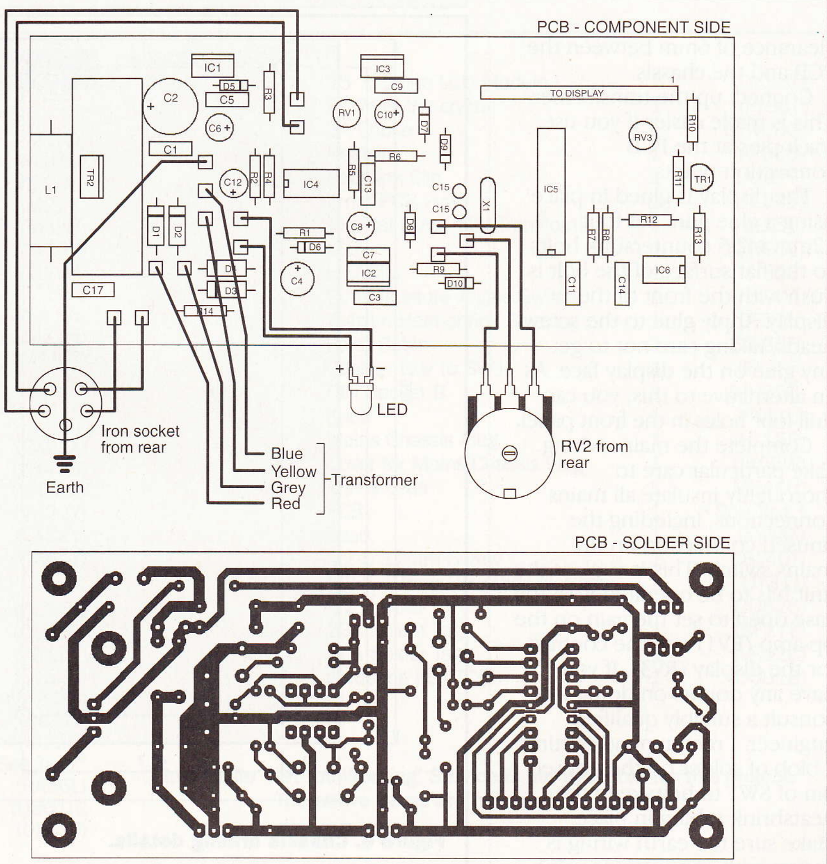
Construction

The PCB layout is shown in Figure 3. I suggest starting with the lower profile components first (resistors and diodes) and work up to the IC socket, with capacitors, voltage regulators and triac last. Please take particular care with the orientation of the diodes, capacitors, ICs and voltage regulators.

With the board complete (before installing the PIC or connecting any of the leads), it is no harm to test the current consumption (if you have a bench power supply). First, apply +18V to D1 with respect to earth. The consumption should be 11mA. Then apply -18V to D3 with respect to earth. The consumption should be 7mA. If these measurements are widely out, check again for component orientation and PCB shorts. If you don't have a PSU, just do the checks anyway.

Next, connect the display, the setpoint potentiometer RV2, the LED, the socket for the iron and install the PIC. Use 3A hook-up wire for the power to the iron. Again, check the power consumptions. These now should be 28mA and 18mA, respectively. Also, with power

Figure 3. PCB legend, track and wiring.



applied to the positive rail, the display should function and the set temperature should change in response to RV2. The measured temperature will not be correct as IC4 needs the negative rail.

The box drilling requirements for the display, RV2, SW1, PCB mounts, transformer, and mains inlet are shown in Figures 4 to 6. The PCB holes in the chassis are best marked using the PCB as a template. It is also necessary to move the chassis rearwards 5mm to give space for the iron socket. The new hole locations are best marked using the case as the template. The chassis self-tapping screws need 2mm diameter holes.

Mount the PCB using 12mm M2·5 bolts fed from underside the chassis, using either a spacer or two nuts 6mm apart to give a clearance of 6mm between the PCB and the chassis.

Connect up the transformer. This is made easier if you use track pins at the PCB connection points.

The display is glued in place using a glue gun. Set four 12mm M2·5 countersunk bolts so the flat surface of the bolt is flush with the front of the display. Apply glue to the screw heads, taking care not to get any glue on the display face. As an alternative to this, you can drill four holes in the front panel.

Complete the mains wiring. Take particular care to thoroughly insulate all mains connections, including the unused connection on the mains switch. This is vital, as the unit has to be operated with the case open to set the gain on the op-amp (RV1) and the contrast for the display (RV3). If you have any doubts on doing this, consult a suitably qualified engineer. I recommend putting a blob of solder on the unused pin of SW1 to help keep the heatshrink tubing in place. Make sure the earth wiring is secure with connections using 10A cable both to the bolt on the transformer and to the panel on one of the bolts on the iron socket. Additional earth wires are needed both to the middle pin of the iron socket and to the 0V connection on the PCB.

Check that the bolt holding the transformer does not touch the top of the case. This would provide a short round the transformer.

With the construction complete, double-check all the wiring, set RV1 & 2 midrange, plug in the iron, and turn on. The display should show the measured temperature, rising from 20°C with the power

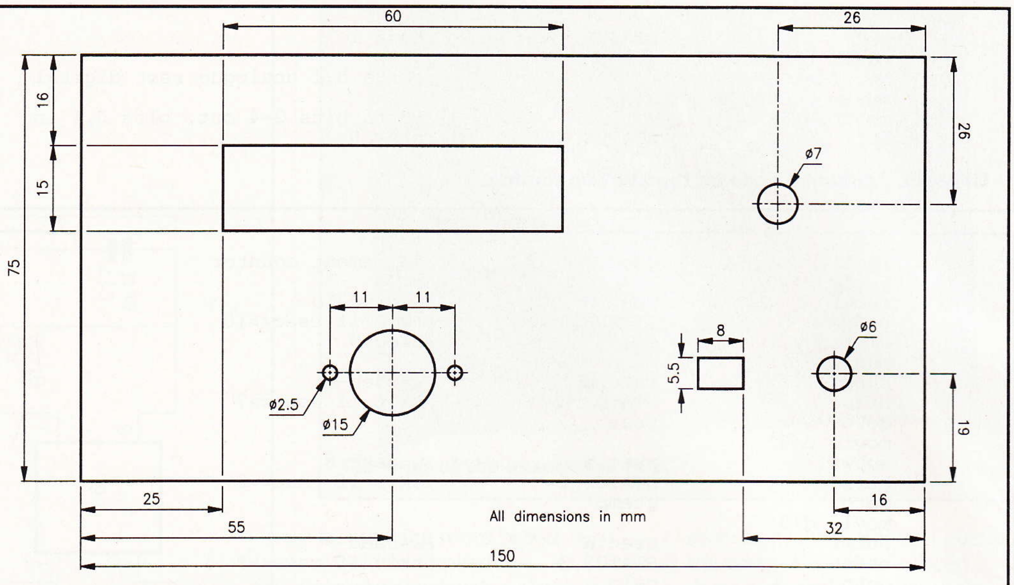


Figure 4. Front panel preparation.

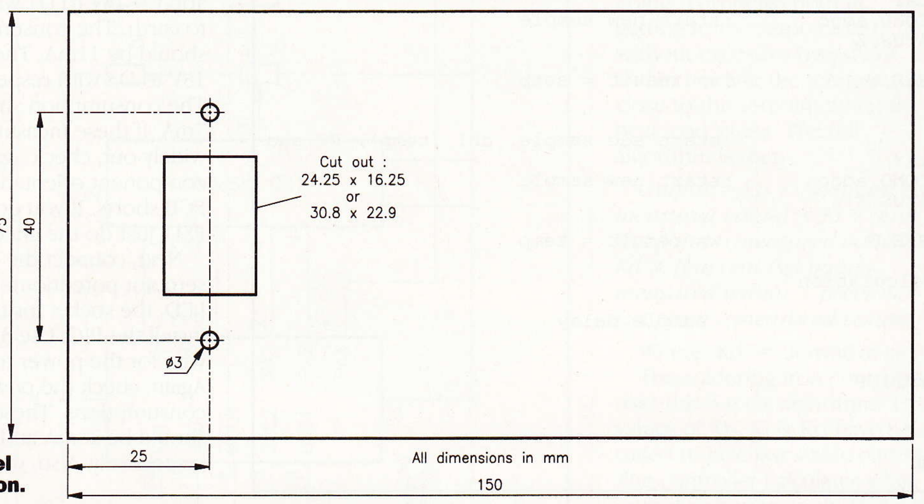


Figure 5. Rear panel preparation.

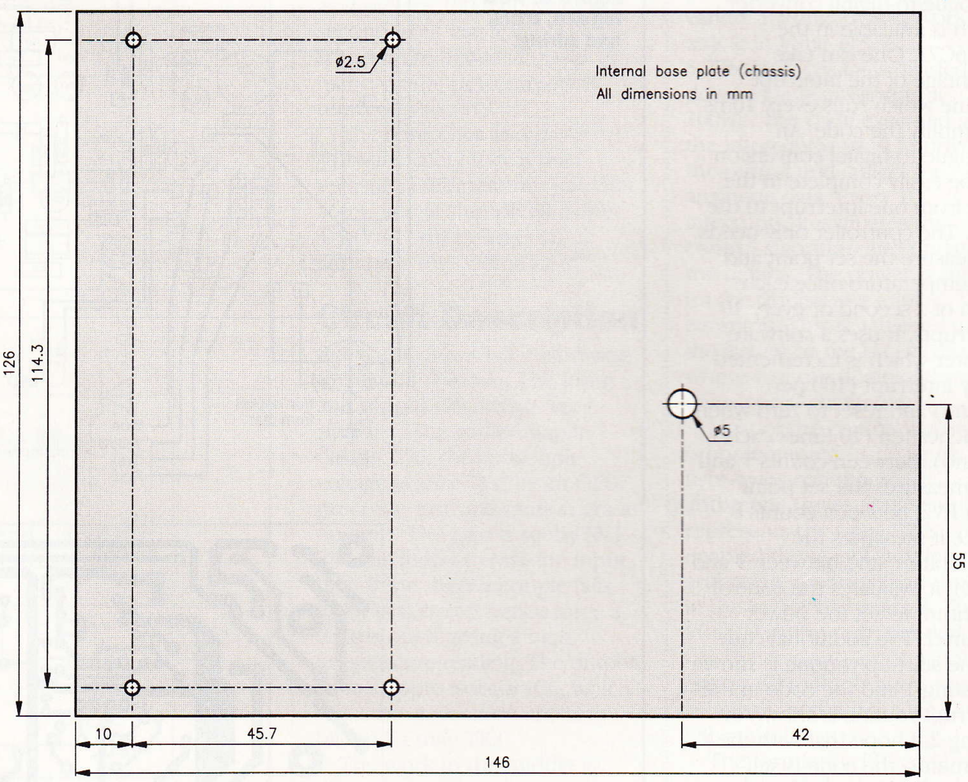
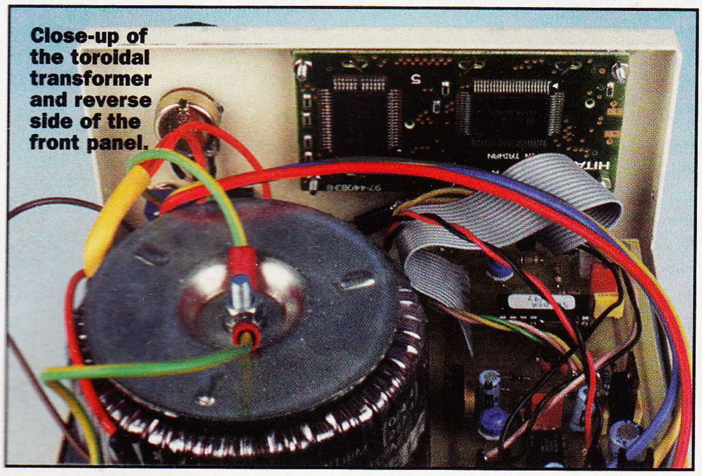
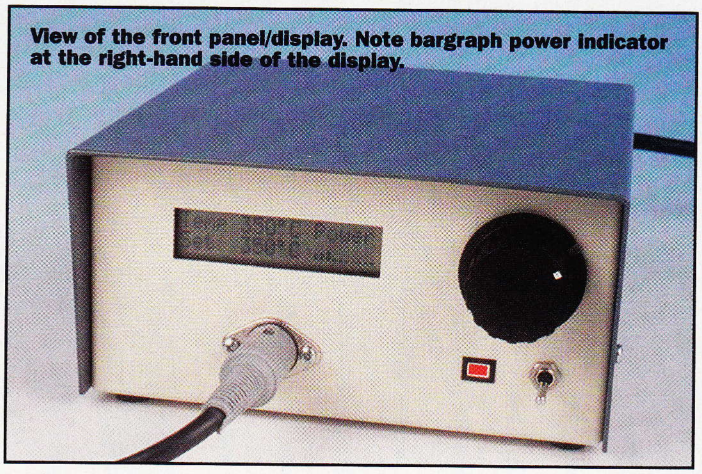


Figure 6. Chassis drilling details.



Close-up of the toroidal transformer and reverse side of the front panel.



View of the front panel/display. Note bargraph power indicator at the right-hand side of the display.

bargraph at full power. As the set temperature is reached, the power should be reduced. If there is any deviation from this, switch off immediately, disconnect from the mains and start looking for faults.

Important Safety Note

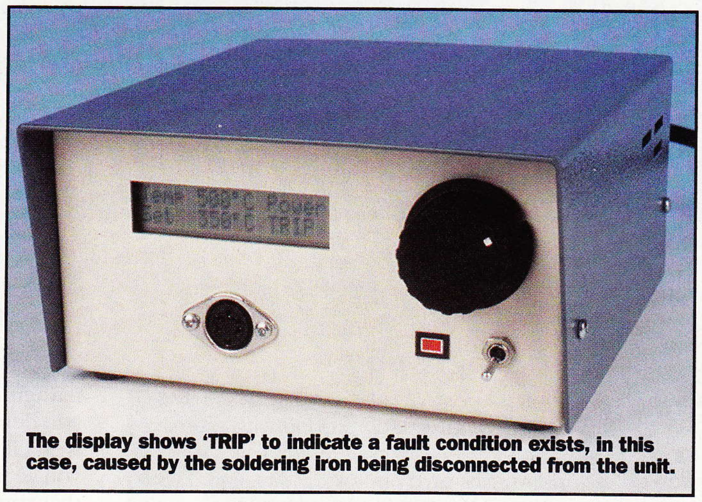
It is important to note that mains voltage is potentially lethal. Details of mains wiring connections are shown in this article, and every possible precaution must be taken to avoid the risk of electric shock during maintenance and use of the final unit, which should never be operated with the box lid removed (with exception of during the initial setting-up – see below). Safe construction of the unit is entirely dependent on the skill of the constructor, and adherence to the instructions given in this article. If you are in any doubt as to the correct way to proceed, consult a suitably qualified engineer.

Operation and Calibration

The power required to keep the iron at a typical 370°C is about 10W (two bars showing in the power bargraph). You can see the power increase as you tackle a big job.

Calibration is not essential as the key thing is to find the temperature setting that suits each job. I calibrated the prototype using Aluminium solder (FY71N), which melts at 270°C. I adjusted RV1 until the solder went mushy with this temperature setting. Please take extreme care when making these adjustments, even with all your mains wiring insulated. Use one hand to adjust RV1 and only use an insulated adjuster.

Adjust RV3 to give the best contrast for the display, again observing the precautions above.



The display shows 'TRIP' to indicate a fault condition exists, in this case, caused by the soldering iron being disconnected from the unit.

Printed Circuit Board and Pre-programmed PIC

A PCB and Programmed PIC are available from the author at £20 including postage.

Contact: Dr. M. P. Roberts, 4 Thames Avenue, Guisborough, Cleveland, TS14 8AD.

ELECTRONICS

PROJECT PARTS LIST

RESISTORS: All 0·6W 1% Metal Film (Unless Stated)

R1,2,4,6,8	1kΩ	5	(M1K0)
R3	1MΩ	1	(M1M0)
R5	220kΩ	1	(M220K)
R7	22kΩ	1	(M22K)
R9	3k3Ω	1	(M3K3)
R10-12	10kΩ	3	(M10K)
R13	240Ω	1	(M240R)
R14	10Ω	1	(M10R)
RV1	50kΩ	1	(WR43W)
RV2	10kΩ	1	(JM71N)
RV3	1kΩ	1	(WR40T)

CAPACITORS

C1,3,5,7,9,11,17	0·1μF	7	(CX21X)
C2	470μF 35V	1	(VH47B)
C4	100μF 35V	1	(VH38R)
C6,8,10,12	10μF 50V	4	(VH22Y)
C13,14	220nF	2	(CX22Y)
C15,16	12pF	2	(WX45Y)

SEMICONDUCTORS

D1-4	1N4002	4	(QL74R)
D5,6,9,10	1N4148	4	(QL80B)
D7,8	BAT43	2	(VR19V)
IC1	7812	1	(QL32K)
IC2	7912	1	(WQ93B)
IC3	7805	1	(QL31J)
IC4	OP-07CNB	1	(RA73Q)
IC5	Pre-programmed PIC16C71	1	* See Text *
IC6	Zero-crossing Opto Triac	1	(RA56L)
TR1	BC213L	1	(QB61R)
TR2	BTA08-600B Triac	1	(UK54J)

MISCELLANEOUS

Display	16 × 2-line LCD Module	1	(DK53T)
X1	3·2768MHz crystal	1	(FY86T)
L1	3A Choke	1	(HW06G)
	Heatsink	1	(AX95D)
	Heatsink Clip	1	(AX97F)
	1mm PCB Pins	1	(FL24B)
T1	Toroidal 50VA 12V Transformer	1	(YK15R)
	LED	1	(QW96E)
	LED Clip	1	(HY62S)
SW1	Sub-Miniature Toggle Switch	1	(FH00A)
	2·4mm Heat-shrink Sleeving	1	(BF87U)
	Earth Cable	1	(XR38R)
	Cable – Live to SW1	1	(FA28F)
	DIN Socket B	1	(HH35Q)
	Knob	1	(FK41U)
	Mains Chassis Plug	1	(HL15R)
	Cover for Mains Chassis Plug	1	(JK66W)
	Mains Lead	1	(MK41U)
	PCB	1	* See Text *
	Case	1	(XY44X)
	M2·5 12mm Screw	1	(BF40T)
	M2·5 12mm Countersunk Screw	1	(JY31J)
	M2·5 Nuts	3	(JD62S)
	2BA Solder Tag	1	(BF27E)
	6BA Solder Tag	1	(LR02C)
	Soldering Iron TC50	1	(DQ01B)

The Maplin 'Get-You-Working' Service is not available for this project. The above items are not available as a kit.