DIY SOLDER REFLOW OVEN WITH PID CONTROL

When we left off last month, we'd finished assembling the PCBs and the hardware required. Now all that's left is to put it all together – and get it going!

Part II – by Phil Prosser

Just in case you missed the first instalment last month, let's briefly recap:

We're taking a bog-standard "toaster oven" (we bought ours at KMart) and making a controller for it, which allows it to be turned into a reflow oven for soldering PCBs with lots of (or even a few) SMD components.

We do this without any modifications to the Toaster Oven at all – in fact, there is only minimal mains wiring to be done within the controller. What's more, we've made it very safe to use.

If you want more details than that, we'd suggest you look up the first part in the April issue (siliconchip.com.au/Article/13802).

Now, let's get on with the show!

Putting it together

Everything mounts inside a commercial plastic case, with the components mounted on a baseplate made from 1.5mm-thick aluminium. Cut it to 200x115mm and drill all the required holes as shown in Fig.8. Deburr all the holes and clean it up.

We haven't shown a cutting/drilling diagram for this simply because of its size but we have prepared one; it can be downloaded from the Silicon Chip website and printed out at 1:1 size.

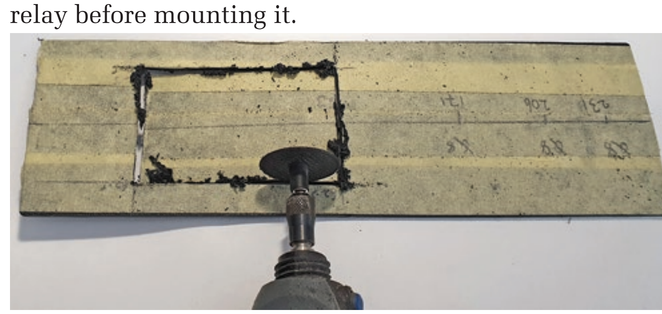
Similarly, drilling diagrams for the front and rear panels, along with a cutting and drilling diagram for the Presspahn safety shield can also be downloaded. Now would be a good time to get those diagrams and cut/drill the components.

We applied masking tape to the front and rear panels and marked cuts and holes on this. For the LCD and the IEC connector, we used a Dremel with a cut-off wheel to cut just inside the marked cut lines, then used a file to neaten the holes. This gave a neat result.

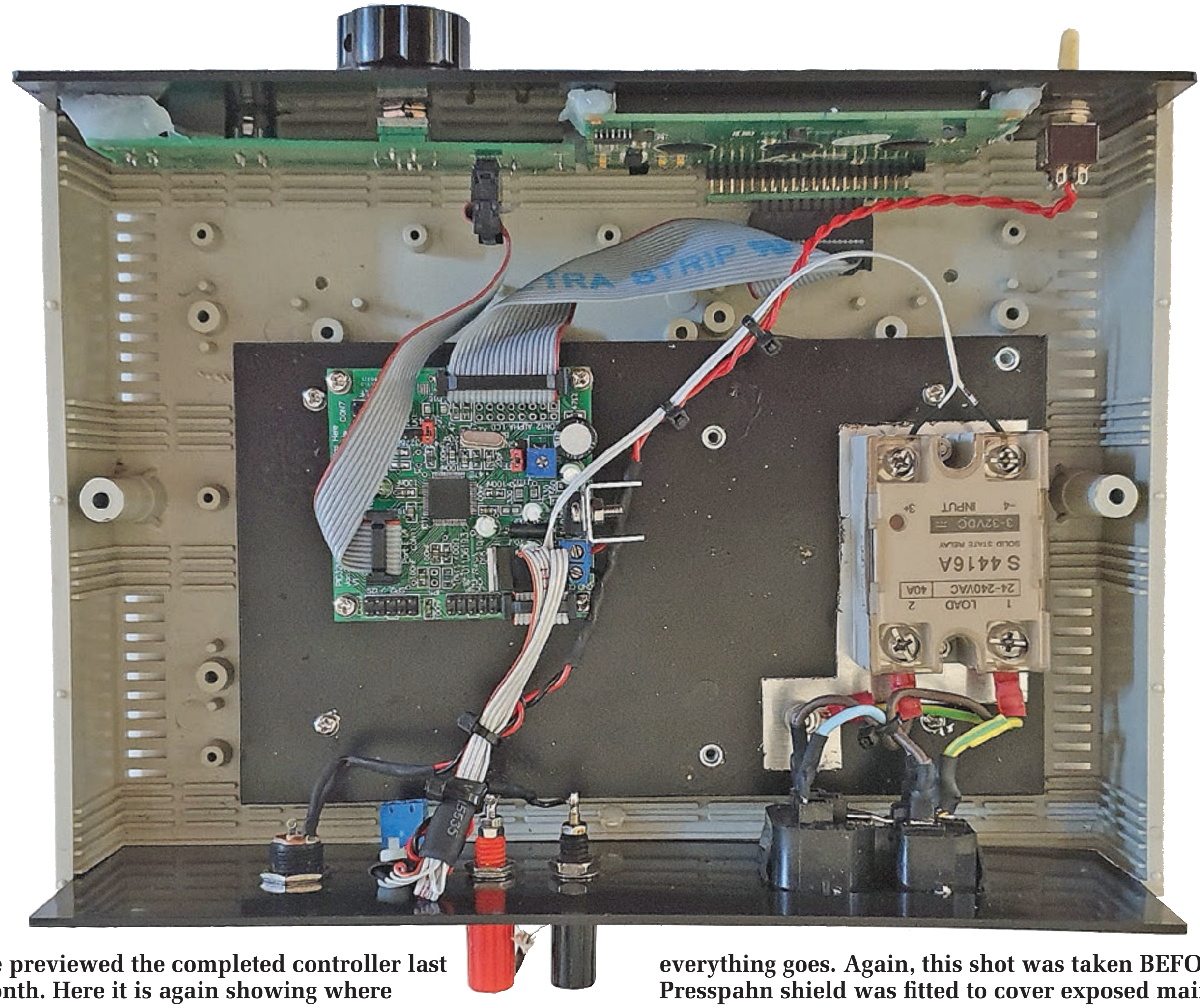
Use the aluminium plate as a template in the bottom of the case, to mark out and drill the holes which will be used to attach the plate to the base.

Be careful to leave a minimum of 40mm of room to the front panel for the LCD connector.

Now you can start to fit the components to the baseplate. Apply a small dollop of heatsink paste under the solid-state relay before mounting it.



Covering the panel with masking tape before cutting out the display window has two benefits: (a) you can much more easily mark the position on the tape (along with other hole locations) and (b) it tends to make the waste stay in place, resulting in less mess!

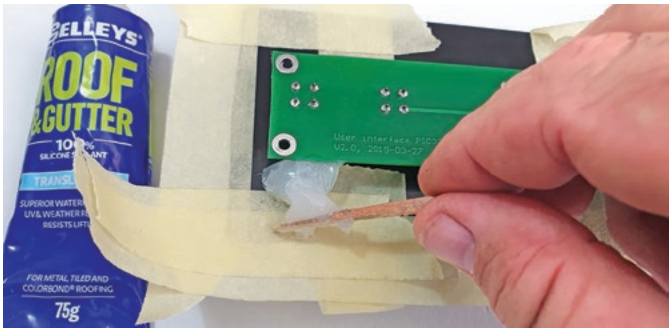


We previewed the completed controller last month. Here it is again showing where everything goes. Again, this shot was taken BEFORE the Presspahn shield was fitted to cover exposed mains.

Mount the PIC32MZ PCB using 15mm Nylon standoffs. These ensure that the board is well insulated, with sufficient creepage distance from the base plate. Do not substitute metal standoffs. You can then attach the metal plate to the bottom of the instrument case and move on to the front and rear panels.

For the rear panel, attach the dual IEC connector, binding posts and DC socket securely. We can solder wires to these in-situ later.

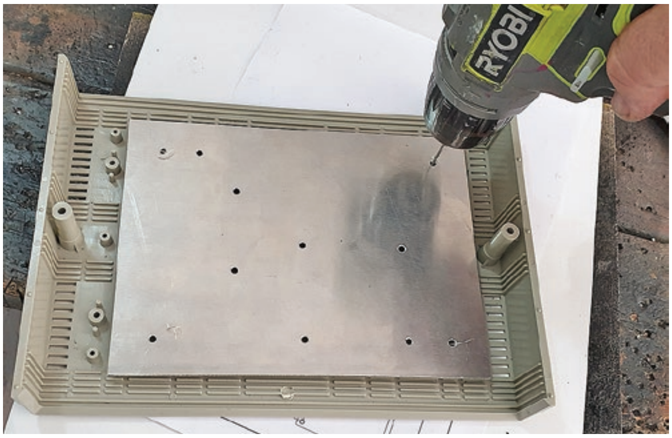
It is now time to mount the LCD screen and front panel PCB. We used glue (actually, silicone sealant) to avoid messy screws through the front panel, and makes it bombproof. You just need to be a bit careful in application. Start with the LCD.



To avoid screw heads protruding from the front panel, we glued the LCD to the rear of the panel using silicone sealant. The masking tape showed us where the glue was to go.

If your cut-out leaves a gap around the LCD screen, you may be able to see the white of the backlight assembly through the gap. So use a black marker to colour in the white backlight around the edges of the LCD panel before mounting it.

Put masking tape across the front panel cut-out and temporarily mount the LCD, making sure that the connectors are on the bottom. The tape should hold the LCD pretty well flush with the front panel.



Once you've drilled out the baseplate (download the PDF from siliconchip.com.au) it can be used as a template for drilling the four required holes in the case (these align with four of the pillars moulded into the case).

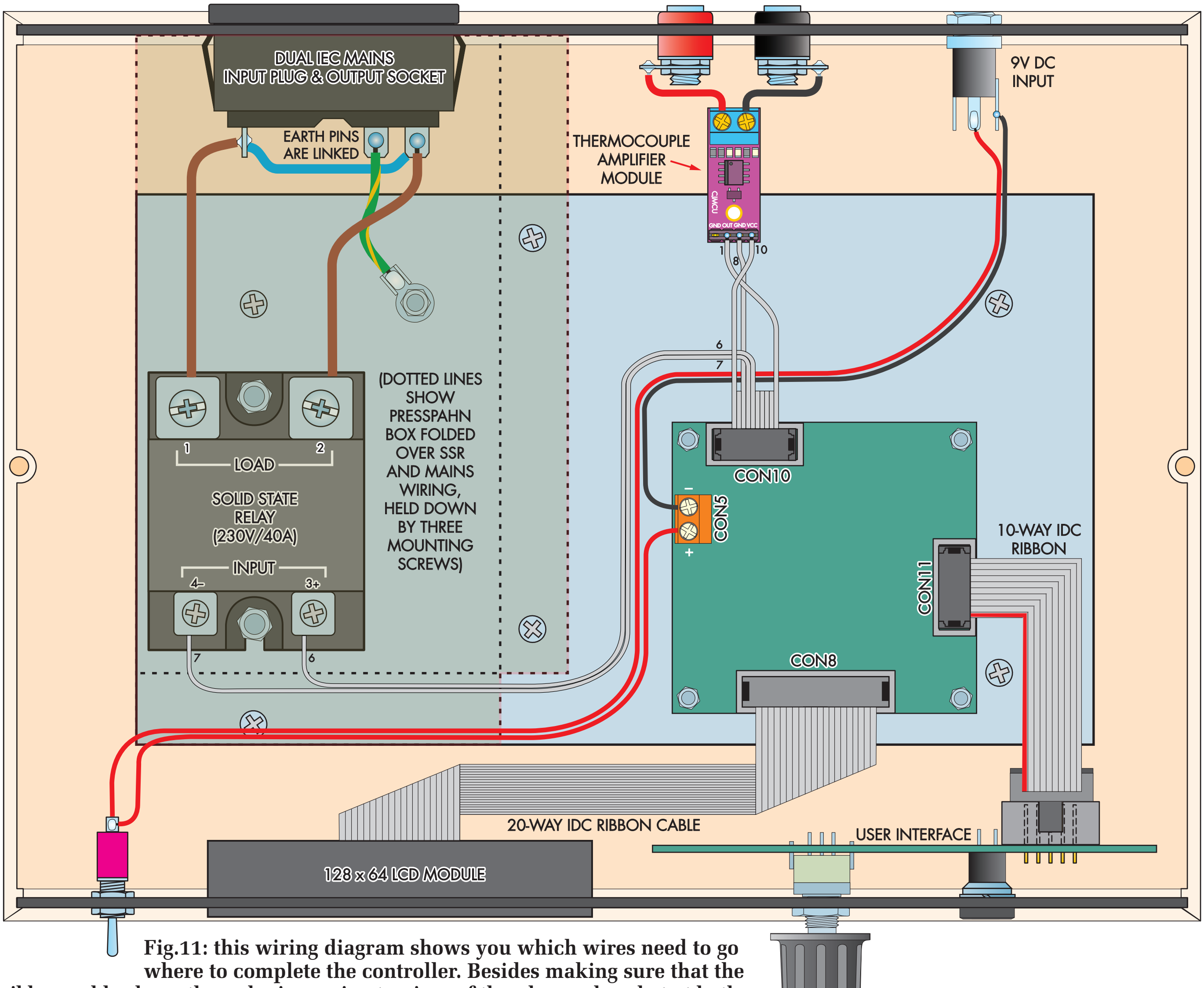


Fig.11: this wiring diagram shows you which wires need to go where to complete the controller. Besides making sure that the ribbon cables have the red wires going to pin 1 of the plug and socket at both ends, and that the IDC connectors are correctly crimped, the main thing to note is the way that the 10-wire ribbon cable from CON10 is split up and routed to two places. Only five wires in this cable are used; the other five should be cut short. When finished, use cable ties to tie all the bundles of wires together, so nothing can move around, and don't forget to add the Presspahn barrier.

Also, apply masking tape around the LCD edges to facilitate tidying up the silicone after you have applied it. Refer to the accompanying photo.

Next, attach the front panel control board. Put one nut (or several washers) over the rotary encoder shaft to set a minimum depth, then mount it to the front panel using the supplied nut. Check the pushbuttons operate properly and do not get stuck on the front panel. If they do, carefully file the holes a bit larger with a round file.

Once it is all good, tighten up the nut on the rotary encoder and check that everything is sitting neatly. Adjust if necessary.

Then, using a matchstick or small timber offcut, build up a dollop of silicone at either corner of the LCD. Do the same with the control board, at the end far from the rotary encoder. Watch out for the pushbutton; do not get silicone onto this, or it will stop it working. You do not need to use a lot of silicone – a dollop at either corner is more than enough. We used far more than necessary.

Once the silicone has set, attach the on/off toggle switch in the usual manner, and push a knob onto the rotary encoder. You are now ready to start the wiring.

Wiring it up

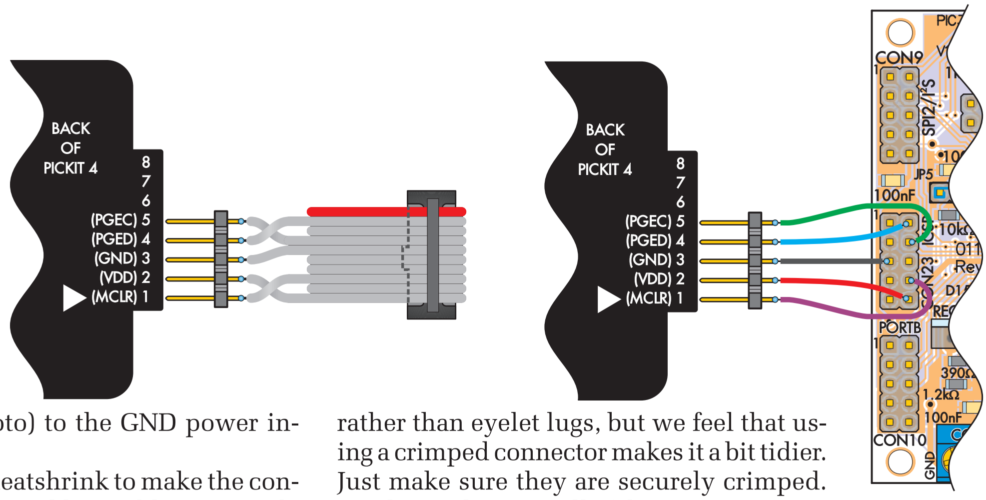
Fig.11 shows the wiring that's needed to finish the controller. As you do the wiring, keep in mind that twisting pairs or bundles of wires together and/or covering them in heatshrink tubing will keep the whole thing neat.

Importantly, this also contributes to the safety, as it stops wires that might break off from moving around and contacting other parts of the circuit.

See our photos for an idea of what it should look like when you've finished.

Start by running light-duty red hookup wire from the middle pin of the barrel connector to the front panel on/off switch, then from the other terminal of the on/off switch to the + power input of the PIC32MZ controller board. Run light-duty black wire from the DC socket ground (outer

Fig.12: PIC32s purchased for this project from our online shop come pre-programmed, but if you're using a blank micro or there is a firmware update, here is how to connect a PICkit 3/4 or similar to the board to reflash the chip.



connector, as shown in the photo) to the GND power input of the PIC32MZ.

Twist these together and use heatshrink to make the connections tidy. Then plug in the two ribbon cables you made earlier, one from the CON11 on the CPU board to CON2 on the front panel, and the other from CON8 on the CPU board to the DIL header on the back of the LCD adaptor board. In each case, make sure the red stripe side of the cable goes towards the pin 1 side on the connector.

Hopefully, when you soldered the LCD adaptor to the LCD screen earlier, you connected pin 1 on that board to pin 1 on the LCD. If not, rotate the IDC connector plugging into the LCD adaptor by 180° to compensate.

The specified dual male and female IEC connector allows a conventional IEC mains power cord to supply power to the unit, and also makes it easy to connect up to the oven.

Strip out a length of 10A mains flex or an unused 10A-rated mains power cord to get the brown, light blue and green/yellow striped wire that you will need to wire this up to the SSR.

For the following mains wiring, keep all the wires as short as possible to maximise safety (the Earth wire is less critical, but it's still better to keep it short if possible.)

Use a short length of the light blue wire to join the two Neutral connectors on the socket together. These are both marked with an "N". Then crimp an eyelet lug onto one end of a short length of green/yellow striped wire, solder the free end to the Earth connector on the mains socket and attach the eyelet to the baseplate using a machine screw, a shakeproof washer (under the eyelet) and two nuts.

Cut two lengths of brown wire and crimp eyelets to one end of each, then solder the free ends to the incoming and outgoing Active terminals on the mains connectors. It doesn't matter which wire goes to which load terminal on the SSR - this is AC after all, so current must be able to flow in both directions.

Note that you could connect to the SSR using bare wires rather than eyelet lugs, but we feel that using a crimped connector makes it a bit tidier. Just make sure they are securely crimped. Apply insulation to all of these connections, and double-check them, then cable tie them all together, so that if one comes loose, it can't go anywhere.

Thermocouple input wiring

The two binding posts are mounted 20mm apart, allowing the Jaycar QM1284 thermocouple to be plugged straight in. This provides a professional-looking solution. However, as mentioned earlier, if you run the thermocouple wire through a grommet in the rear panel and connect them directly to the screw connectors on the thermocouple amplifier board, the temperature readings will be more accurate.

The downside is that you now have a captive thermocouple wire, so changing the thermocouple is a tedious job.

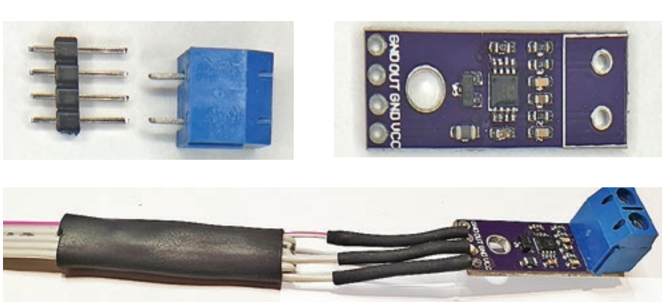
The thermocouple and also the Solid State Relay signals connect to CON10 (PORTB) on the PIC32MZ board. We suggest that you crimp an IDC connector onto one end of a length of 10-way ribbon cable. This can then be plugged into CON10 and the wires at the other end separated and stripped to make the required connections. Make sure that the red striped wire goes to the IDC terminal marked as pin 1.

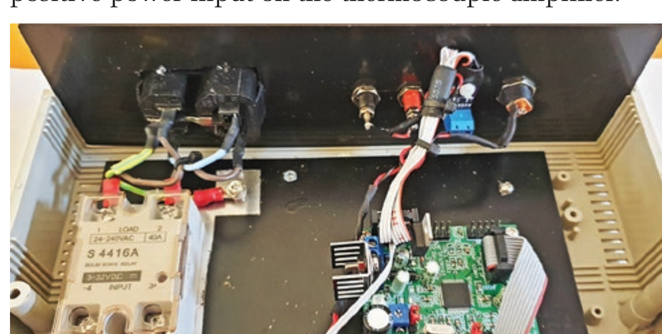
With this cable, some fiddling is required. We couldn't think of an easier way for this short of adding a PCB, which seemed over the top. Pull the wires apart to separate out wires 1 (red), 6 & 7 (together), 8 and 10. Snip the other wires off short as they are not needed. Mark wires 7 and 8 as "-" with some heatshrink or colour it with a permanent marker.

Connect wire 6 to the solid-state relay input + terminal, and wire 7 to the SSR – input. These can be wedged under the screw terminals; do them up tight.

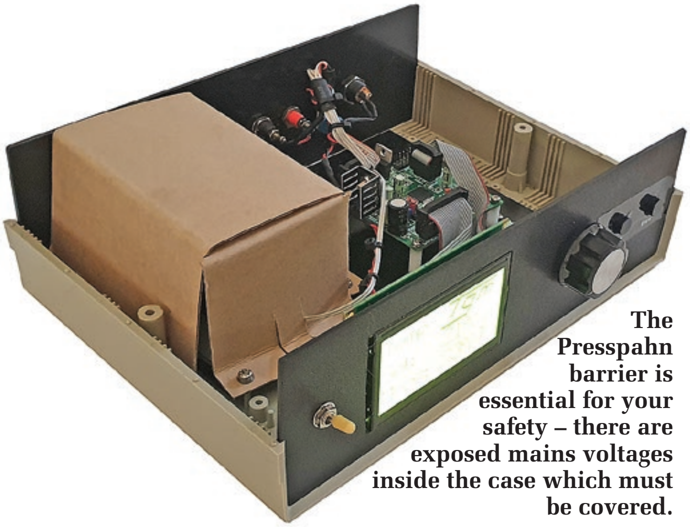
Connect wire 1 to the "Out" connection of the thermocouple amplifier, wire 8 to its ground and wire 10 to the positive power input on the thermocouple amplifier.

The thermocouple amplifier we used has a purple PCB. If you search ebay or AliExpress for "AD8495", then you should be able to find one which looks like ours.





A view of the rear panel connections – again, this is before the Presspahn insulation barrier is installed. Don't forget it!



The Presspahn barrier is essential for your safety – there are exposed mains voltages inside the case which must be covered.

A male IEC plug to female mains socket (such as this on from Jaycar) means no modifications are required for the toaster oven.

We arranged the cable lengths so that it is possible to encapsulate the thermocouple amplifier in heatshrink tubing and zip tie it to the binding posts. This places the thermocouple amplifier in reasonable contact with the thermocouple plugs. Remember that this amplifier has correction circuitry that accounts for the temperature of the thermocouple plug, so the closer it is to this plug, the better.

If you've purchased the recommended thermocouple amplifier with purple PCB, there will be a mounting hole. You can use this to mount it to the rear panel with a Nylon machine screw and nut, close to the binding posts/banana sockets.

Tidying it up

Once you've finished all the wiring, use cable ties to tie each bundle of wires together. This is especially important for the mains wiring, which must all be tied together securely, and also the red and black wires from the DC socket to the front panel on/off switch and to CON4 on the control board.

Make sure that these wires are tied so that they can't move around inside the case (eg, by tying them to the nearby ribbon cables) and that if one breaks off at either end, it can't go anywhere.

Now is also a good time to attach the Presspahn insulation barrier to the bottom plate using machine screws, shakeproof washers and nuts. Refer to the photos to see where it goes. Once the lid is on the case, it should isolate the mains section from the rest of the controller.

Initial testing

For the following tests, do not connect the mains lead. Use only the 9V plugpack. Make sure that jumper JP5 on the CPU board is inserted. There must also be a jumper on LK2 in the position shown in Fig.4. You don't need a jumper on LK1; if there is one there, it doesn't matter which position it is on.

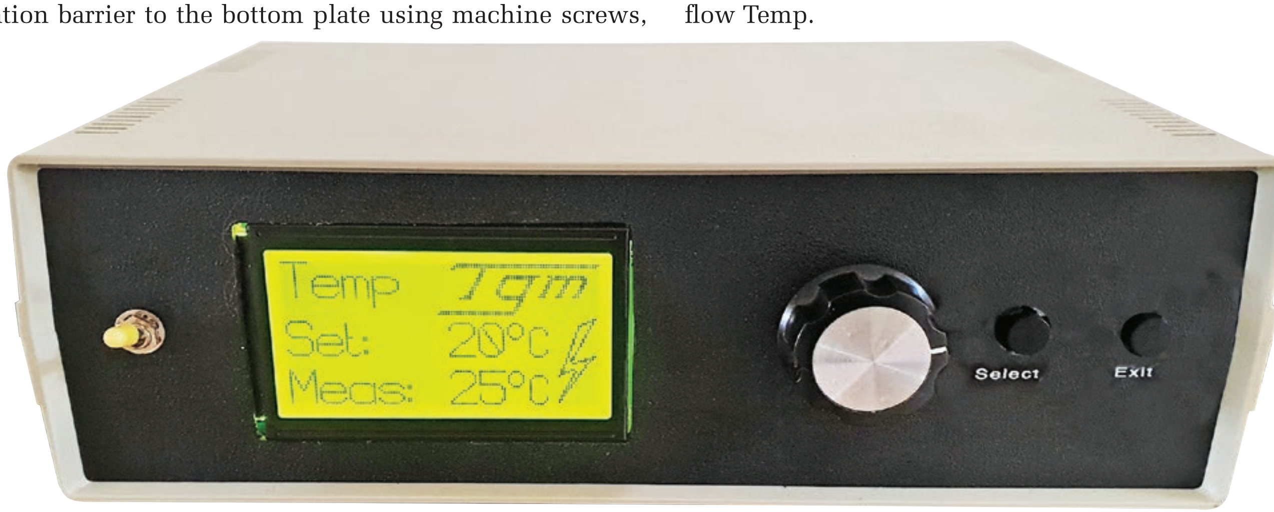
Now switch the device on and check the LCD. Adjust the LCD bias voltage using trimpot VR1. This may require some experimentation; the LCD will initially show no image or a washed-out image. Adjust the bias from one end toward the other until you get a good image.

Next, check that the user controls work by press the right-hand button (EXIT); a screen with four boxes should appear. Rotate the encoder knob; you should see each of the four quadrants be highlighted in turn.

Now we set the initial PID coefficients. Pressing the left-hand button/rotary encoder knob (SEL) when the "adjust PID settings" screen is highlighted. You will be presented a screen asking if you are sure. Rotate the dial to "Yes" and click SEL. Enter 100 for P, 0.5 for I and 670 for D.

This configuration is super critical – if you do not do this, the thing will most likely show 0° C, and definitely not work.

Next, set the reflow settings by pressing SEL when the "Setpoints" screen is highlighted. You will be presented a screen asking if you are sure. Rotate the dial to "Yes" and click SEL. Enter 150C for Preheat Temp and 225C for Reflow Temp.



Four holes must be drilled in the front panel (follow the drilling diagrams on siliconchip.com.au) but there is also a cutout required for the display. We used a Dremel to cut out the rough hole then finished it off with a fine file. The same system can used for the IEC mains socket cutout on the rear panel.

Pin	Role	Connect to
1	Analog input	Thermocouple amplifier output
6	Heater control	SSR input 3+
7	GND	SSR input 4-
8	GND	Thermocouple amplifier GND
10	+3.3V	Thermocouple amplifier power supply

Table 1 – CON10/PORTB connections (other pins not used)

Then set the Sensor TEMPCO settings by pressing the left button (SEL) when the "Tempco and Offset" screen is highlighted. You will be presented a screen asking if you are sure. Rotate the dial to "Yes" and click SEL. Enter 0 for OFFSET (this is in °C), and 0.161 for TEMPCO.

Check that the home screen now shows approximately the right ambient temperature. Boil a jug of water, insert the thermocouple and check that the home screen shows something close to 100°C. Remember that thermocouples are not super precise devices, and an error of a few degrees is OK.

To check that the SSR drive is working, use the following steps:

1) Reset the system by cycling the power

2) Set the target temperature a bit above ambient temperature

3) Watch the LED on the solid-state relay (it is next to the input). This should light up every few seconds, in time with the lightning bolt on the screen going from an outline to a full lightning bolt

4) Turn the set temperature down to around 20°C, and hold the tip of the thermocouple between your fingers, so the measured temperature is above the set temperature

5) Check that after a few seconds, the lightning bolt and red led on the solid-state relay stop lighting.

Note that with a PID controller, there can be a lag in its response to changes in temperature and settings.

Live testing

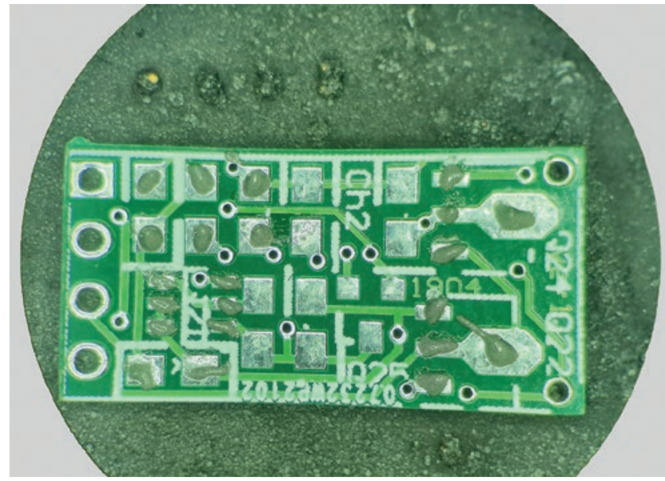
You can now switch off the power and connect the oven to the IEC mains output socket on the controller via the IEC/mains socket adaptor.

Before connecting the mains input IEC lead, double-check your wiring, and ideally have a friend triple check it. Check that:

- no daggy wires are poking out of crimps, terminals and insulation
- there are no wires stripped too far, leaving lots of exposed copper that could contact something.
- the IEC "N" connector goes to the other IEC "N", diagonally across the connector.
- the Earth connector is solidly connected to the base plate.
- one wire from each of the IEC "A" pins goes to one SSR "LOAD" terminal.

Close the case and securely screw it together; make sure there are no exposed mains wires. Turn the oven to its maximum temperature setting, and switch on all elements. Dial the timer for 20 minutes or so, plug the oven into the controller, power up the controller and set the temperature to 20°C. Plug the controller into the mains and switch it on.

The oven should not be on yet, unless your house is particularly cold. Turn the dial on the controller for a setting of 40°C. You should soon see the lightning bolt on the controller coloured in, indicating the hearer is on. If your oven is like ours, you should see a light on the oven indicate it is switched on. After a few seconds, you should see the measured temperature start to creep up.



The board used during reflow test, showing solder paste applied to pads. The amount shown here is more than enough!

The rear panel sports the 9V DC input socket (left) with the polarised thermocouple terminals alongside. At the right end is the twin IEC mains output/input socket which is the raison d'etre for this project: mains comes in to the right-hand (male) socket; controlled mains to the toaster oven comes out of the left-hand (female) socket.

Help, it's not working!

Nothing on the LCD screen

- Check that the LCD bias pot is set correctly. Turn it fully anti-clockwise, then slowly turn it clockwise until you see something on the display.
- Check that the microcontroller is running
- Check your parts and soldering, especially looking for bridges across the microcontroller pins.
- Check the output of the 5V and 3.3V regulators.

My oven is going crazy

- Have you used an oven with a smart controller? This project won't work with it!

The temperature readings are very wrong

- Is the thermocouple connected backwards
- Are the tempco and offset in the software right for your amplifier
- Use a DVM to check the voltage on the thermocouple amplifier output. It should be about 1.25V. If not, read the panel on thermocouple amplifiers
- Put the thermocouple tip in a cup of hot water. Watch to see if the voltage increases.

The temperature readings are slightly wrong

- Is your thermocouple in the oven next to your workpiece
- Check the thermocouple tempco and offset is correct for your thermocouple
- Try putting the sensor tip in iced water and boiling water. If the readings are off by more than a few degrees, check for construction errors

The oven won't heat

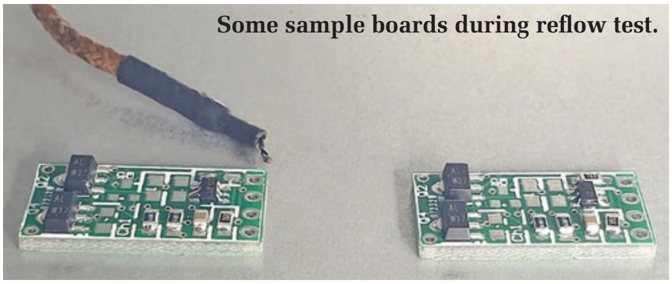
- Ummm - you did check that the oven worked normally before making any modifications, didn't you? (!!)
- Check that your oven's temperature is set to maximum and that it is switched on and both heating elements are selected.
- Is the thermocouple reading the right temperature?
- Set the temperature on the controller for say 100°C and watch the SSR. It has a red LED that indicates when it is on.
- Watch your oven power light. Is it switching on in unison with the SSR light?

The oven is running too hot when set for fixed temperatures

- At low temperatures, even with the optimisations we made, the thermal mass of the oven means that there is still a lot of overshoot. Also, the thermal mass of the elements and oven means it takes a long time to cool down.
- Try starting it up in advance and give it time to settle before using it.

Settings are lost at power-off

- Use the save option after making changes.
- Check the PIC microcontroller pins for shorts on the side close to the EEPROM
- Check the orientation and soldering of the EEPROM chip.



Some sample boards during reflow test.

The thermal inertia of the oven will cause a delay of 20 seconds or so; the temperature will likely overshoot the target. As explained above, our controller is optimised for high temperatures, and you will see overshoot in the order of 15°C or so at low temperatures. Just watch to see that heating switches off before it reaches the target temperature.

Try setting the controller to 60°C, and watch the controller switching on and off. Once heated, the oven takes quite a while to cool down. Remember that when reflowing, you must open the door at the end of the cycle.

Reflowing

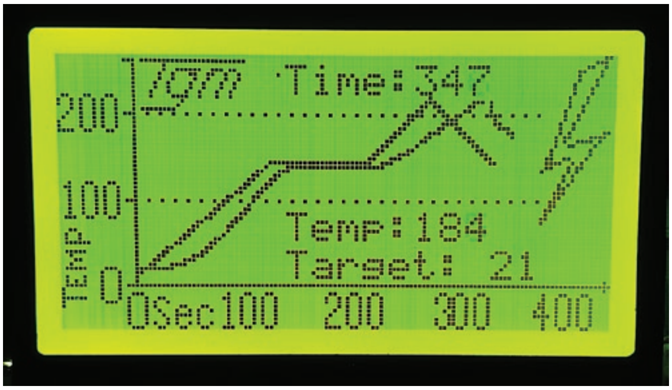
We reflow soldered a couple of boards with SMD components to demonstrate the operation of the oven. As shown in the pictures below, if you are applying solder paste by hand, use a syringe and put less than you think it will take! The biggest mistake most people make when reflow soldering parts is to add too much solder paste.

We stuck the thermocouple to the edge of the oven using tape, and fiddled it until the thermocouple was close to the test PCBs. You need the sensor to be as close as possible to the boards (maybe even touching), to ensure the temperature profile achieved is right in the vicinity of your board.

The temperature profile that the oven ran is shown below. You can see that the temperature fell after we opened the door a crack. We left it like that for about 20 seconds, then opened it fully to allow the board to cool. Don't move the board until it cools, as the solder will still be liquid for a while!

At about 180°C, the flux activates and the solder starts to reflow. By the time the oven hit 225°C, and we opened the door, the board had fully reflowed and settled down. Ideally, you should give your oven a trial run on a less-critical PCB before soldering anything really expensive.

But if you have a hot air rework station, you can probably fix anything that goes awry on the first couple of tries, until you get it fully dialled in. SC



Reflow display showing target and actual temperature profiles.