NASA/TM-20230014821

Mark I Silicon Carbide Integrated Circuit Test Oven Assembly and Programming Guide

David Spry, Stephanie Booth, and Philip Neudeck
Glenn Research Center, Cleveland, Ohio

March 2024

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Acknowledgments

This work was conducted by NASA Glenn Research Center in Cleveland, Ohio, with funding from the NASA Science Mission Directorate under the High Operating Temperature Technology (HOTTech) and Long-Lived In-Situ Solar System Explorer (LLISSE) projects and the NASA Aeronautics Research Mission Directorate under the Transformational Tools and Technologies (TTT) project.

Level of Review: This material has been technically reviewed by technical management.

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Summary

This report provides a parts list, with assembly and programming instructions for building first-generation (Mark I) compact test ovens; this oven design is customized for prolonged functional electrical testing of prototype silicon carbide (SiC) devices at temperatures up to 500 °C (932 °F). The general approach of using multiple compact ovens to perform long-term, high-temperature electronics testing efficiently is described in a conference paper (Izadnegahdar, Alain, et al.: Alternative Setup for Long-Duration Low-Duty-Cycle 600 °C Ambient Testing of SiC Integrated Circuits. International Microelectronics Assembly and Packaging Society (iMAPS) HiTECH 2021 Technology Crossover Extravaganza, 2021), available at https://ntrs.nasa.gov/citations/20210011676. The new Mark I oven design described here offers several significant improvements over the compact oven described in that paper. For example, it is constructed from commercial off-the-shelf (COTS) components and requires minimal assembly. Much of the work involves drilling holes in the two aluminum project boxes, which contain the control electronics and the oven itself. The cost of components is less than $200 (USD) per oven, which makes constructing multiple ovens affordable. In addition, the two-box design separates the high-temperature heater from the electronics, which keeps the electronics cool, prolonging the lifetime of these components.

1.0 Mechanical

1.1 Parts Needed

Consult the Bill of Materials (BOM) (Table II in the appendix) for detailed descriptions of all components.

1. (2) Aluminum project boxes
   a. (1) Black (BOM 15) for housing the electronic controls
   b. (1) Silver (BOM 16) for housing the oven/heater
2. (12) Standoffs (BOM 11)
3. (6) Screws (BOM 10)
4. (2) Nuts (BOM 22)
5. (1) Heater block (BOM 8)
6. (1) Silver-colored aluminum plate (BOM 26)
7. (1) Aluminum mounting plate (BOM 3)
8. (1) Power socket/switch (BOM 13)
9. (1) Aluminum kitchen foil (BOM 25)
10. (1) Ceramic insulation blanket (BOM 2)

1.2 Black (Electronic Controls) Box Drill Holes and Cutouts

The upper and lower halves of the aluminum project boxes are designed to slot together via a tongue and groove connection on the side panels. To ensure the halves of the 45- by 45-mm cutout for the proportional integral derivative (PID) temperature controller for the black box indicated in Figure 1(c) will be properly aligned after cutting, mark the square on the outside of the box with the top and bottom halves slotted together.

Always use an appropriate cutting fluid to minimize drill bit and diamond wire saw breakage.

Drill holes in the front and back panels as indicated in Figure 1(c) and (d). The four holes at the corners of these panels are predrilled. Use a 1/8-in. (3.17-mm) titanium-itride-coated tool steel drill bit for drilling holes for the screws that will hold the power switch in place and the holes for the power switch cutout. Use a 1/64-in. (2-mm) drill bit for the vent holes. (To ensure placement consistency if building multiple ovens at the same time, drill one front and one back panel by hand according to the printed template, then use these panels as guides for marking the locations on the other panels of the same type for use with the drill press.)

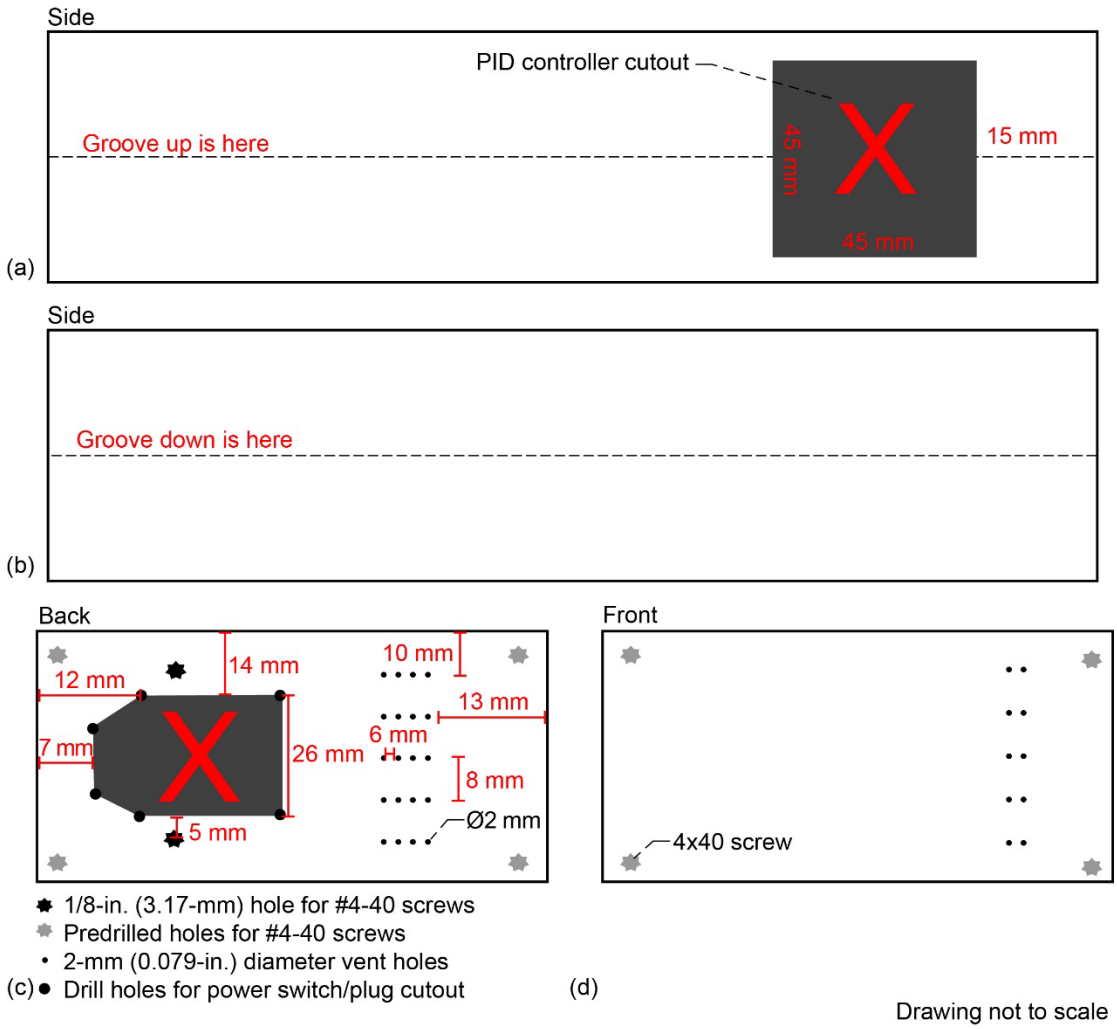
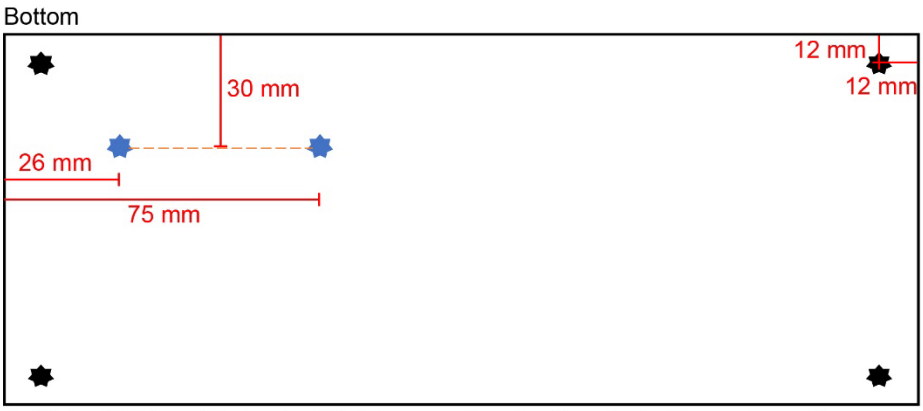
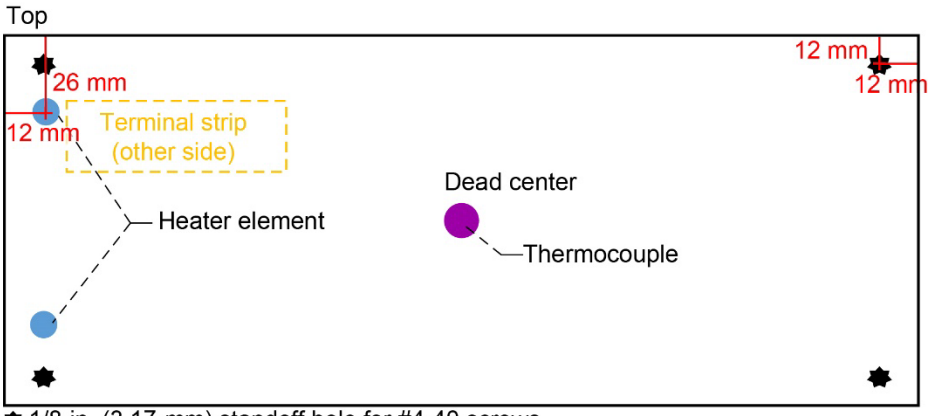


Figure 1.—Black (electronic controls) project box drill holes and cutouts. (a) Side panel with location of PID controller cutout. (b) Side panel with no drill holes or cutouts. (c) Back panel with power switch cutout and screw and vent hole locations. (d) Front panel drill hole locations. (e) Drill hole locations for bottom of black project box. (f) Drill hole locations for top of black project box. Terminal strip will later be attached to inside of top.



1/8-in. (3.17-mm) holes for #4-40 screws for attaching feet with washer and nut
Hole drilled with 5/32-in. (3.97-mm) bit for #6-40 screws provided with the solid-state
(e) relays (SSR) (component of BOM 14)



1/8-in. (3.17-mm) standoff hole for #4-40 screws
3/8-in. (9.52-mm) hole for heater element
(f) 1/2-in. (12.70-mm) hole for thermocouple

Drawing not to scale

Figure 1.—Concluded.

Use a diamond wire saw to cut out the power socket/switch cutout by cutting between the six drilled holes on the back. Use the same saw to remove the PID controller cutout on the two halves of the side panel. File down all sawn edges squarely and evenly. Debur all drilled holes and cuts.

To prevent contact between metal filings and the electronic components, wash each panel thoroughly when drilling/sawing is complete, using plain water (if using a water-soluble cutting fluid) or water and ordinary dish detergent (if using an oil-based cutting fluid). Rinse and let dry.

Place the fuse (included in BOM 13) into the power switch (BOM 13) and attach the switch to the back panel using #4-40 screws (BOM 10) and nuts (BOM 22). Refer to Figure 2 for the correct orientation of the power switch.

Drill 1/8-in. (3.17-mm) holes at points indicated from all four corners of both the bottom (Figure 1(e)) and top (Figure 1(f)) of the box.

Figure 2.—Back panel of black (electronics) project box. Note power switch orientation.

Drill 5/32-in. (3.97-mm) and 1/8-in. (3.17-mm) holes as indicated on the bottom of the black box (Figure 1(e)). Drill ½-in. (12.70-mm), 3/8-in. (9.52-mm), and 1/8-in. (3.17-mm) holes as indicated in the top of the black project box (Figure 1(f)).

1.3 Silver (Oven) Box Drill Holes and Cutout Locations

In the silver project box, drill the back panel vent holes as indicated in Figure 3(c) with a 1/64-in. (2-mm) drill bit. Drill a hole at each end of the front panel cutout (Figure 3(d)), using progressively larger bits to expand the holes gradually (starting with an 1/8-in. (3.17-mm) bit, followed by 1/4-in. (6.35-mm), then 5/16-in. (7.93-mm), and finishing with a 3/8-in. (9.52-mm) bit). Use a diamond wire saw to connect these holes to form the rectangle shown in Figure 4, cleaning up and finishing the edges with a sharp file so the final size is 30 by 12 mm. For the bottom of the silver (aluminum) box (BOM 16), drill 1/8-in. (3.17-mm) holes at points as indicated from all four corners of the bottom of the silver. Drill ½-in. (12.7-mm) holes at points indicated on one side (Figure 3(e)).

The top of the silver box (Figure 3(f)) requires no cutting or drilling.

1.4 Aluminum Plate (BOM 26) Drill Holes

Cut the aluminum plate from BOM 26 to 106 by 120 mm to be the same width and length as the tops and bottoms of the project boxes (BOM 15 and BOM 16).

Drill 1/8-in. (3.17-mm) holes at points as indicated from all four corners of the silver-colored aluminum plate and ½-in. (12.70-mm) holes at points indicated on one side (Figure 3(e)).

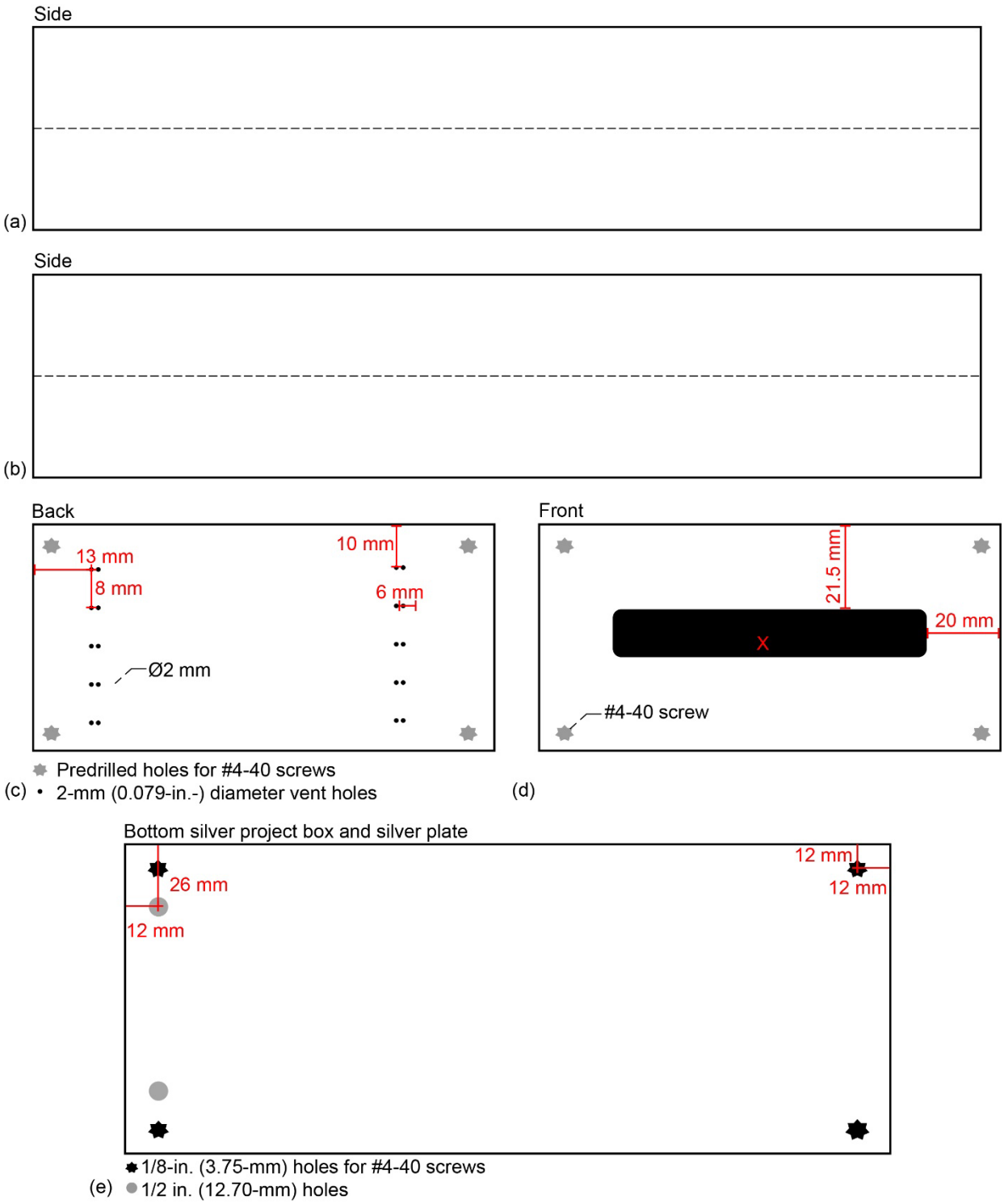


Figure 3.—Silver project box (oven) drill holes and cutout locations. (a) Side panel with no drill holes or cutouts. (b) Side panel with no drill holes or cutouts. (c) Back panel drill hole locations. (d) Front panel cutout location. (e) Drill hole locations for box bottom and silver-colored aluminum plate (BOM 26). (f) Top panel with no cutouts or drilling.

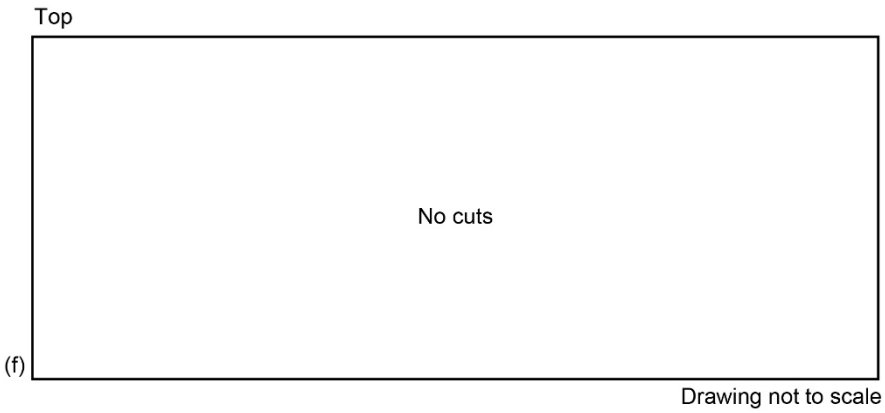


Figure 3.—Concluded.

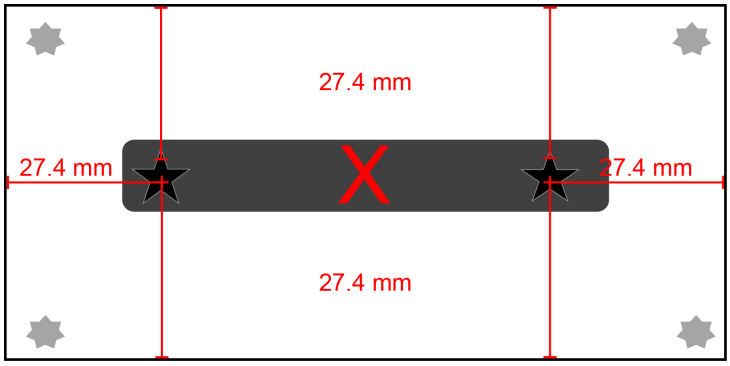


Figure 4.—Dimensions of front panel oven opening.

1.5 Heater Block for Silver (Oven) Box

Prepare the heater block, starting with a 4-in.-long piece of aluminum T-slot profile stock (BOM 8), cutting out the middle part of the profile's cross section with a diamond wire saw, as shown in Figure 5(a) and (b). File down the cut edges smooth.

Next, tap the thermocouple (TC) hole (circled in Figure 5(c)) with a ¼ to 20-in. tapped tap with an 1/8-in. (3.17-mm) deep hole.

Cut, using either a saw or shears, the aluminum mounting plate (BOM 3) in half to make a 4- by 3-in. plate. Place the aluminum mounting plate on top of the heater block and mark the location of the screw holes (Figure 6). Tap with a blind bottom tap for a #4-40 screw at each corner hole. Screw the aluminum plate into each corner of the heater block.

Cut a 90-mm length of 12-in.-wide aluminum kitchen foil (BOM 25), then fold it as shown in Figure 7 to make it 63 mm long. Set the foil aside for later use in assembly of the oven.

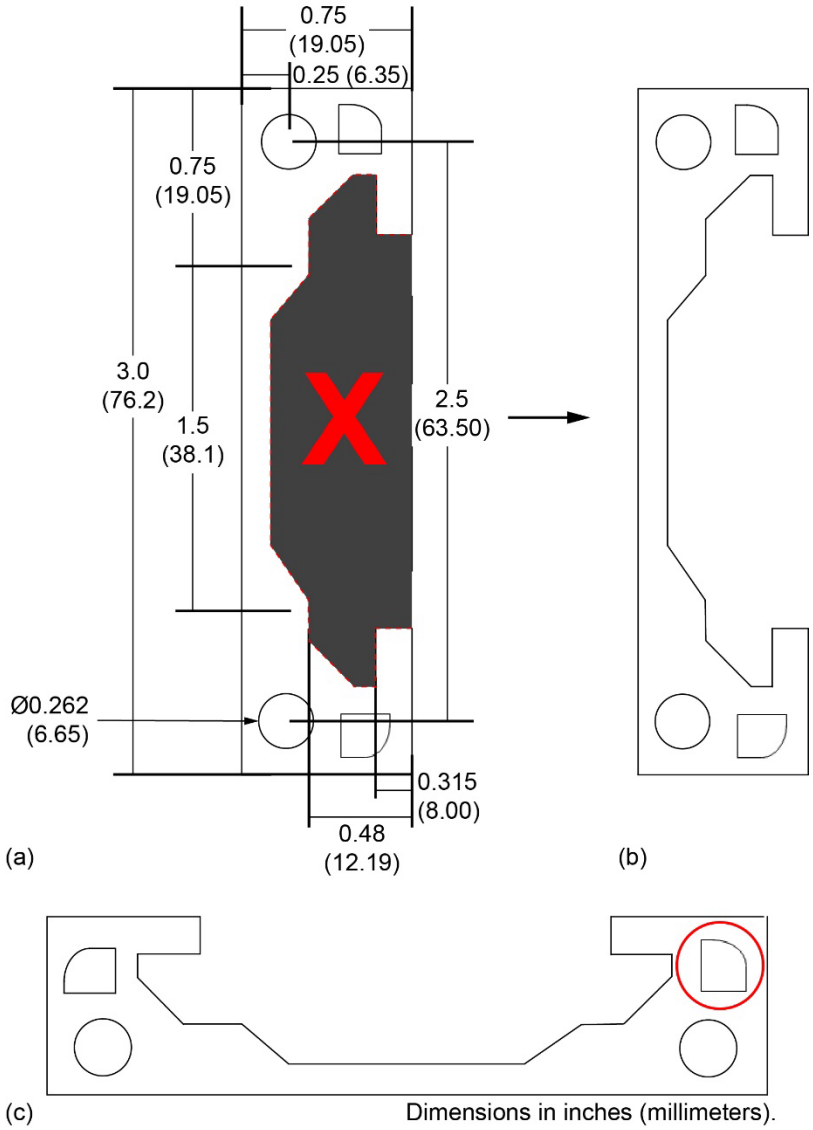


Figure 5.—Cut and file extraneous material away from aluminum T-slot profile stock to form heater block. (a) Original profile with indication of cut lines. (b) After cutout. (c) Tapping TC hole on heater block.

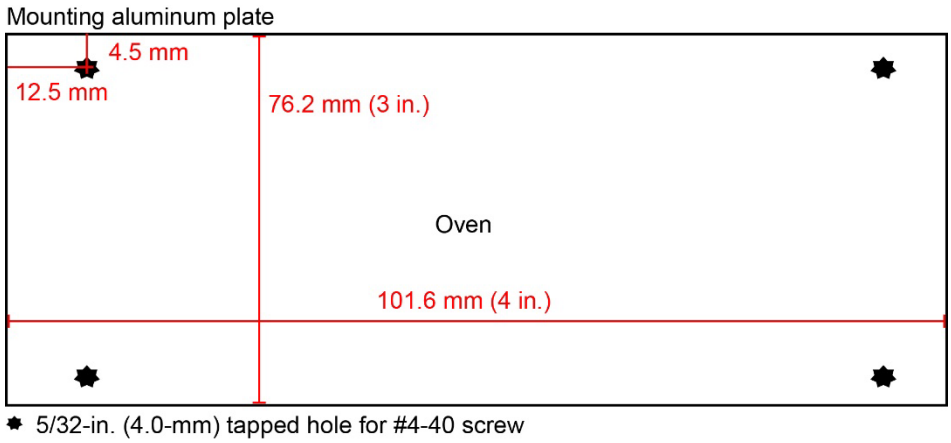


Figure 6.—Locations for tapped holes for 3- by 4-in. aluminum plate (cut from 4- by 6-in., 1/16-in.-thick aluminum plate (BOM 3)).

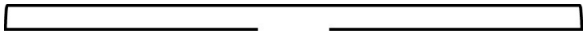


Figure 7.—Aluminum kitchen foil, folded down from 90 to 60 mm in length.

1.6 Thermal Insulation for Silver (Oven) Box

Use sharp, heavy-duty scissors to cut the ½-in.- (12.70-mm-) thick ceramic insulation blanket (BOM 2) into pieces of the following dimensions:

- (1) Top piece (120 by 90 mm)
- (1) Bottom piece (120 by 100 mm)
- (2) Side pieces (100 by 40 mm)
- (1) Substrate piece (95 by 40 mm with 80-mm slit in the middle on one side) (see Figure 8)
- (1) Back piece (120 by 90 mm with two slits, each 20 mm from the 90-mm side and 30 mm deep (Figure 8)

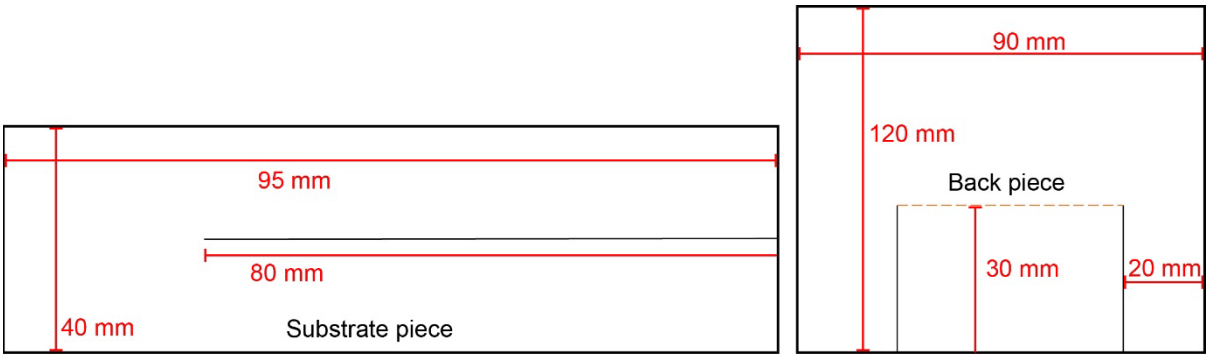


Figure 8.—Slitting locations for substrate and back pieces.

2.0 Electrical Wiring

2.1 Parts Needed

Prepare wires using the following dimensions and connectors (BOM 4, 5, 6, 7, 17, 22, 23, and 24):

- (3) White 16-gauge wire at
  - ~170 mm (C)
    - One end terminated with blue female insulated spade wire connector (BOM 4)
    - One bare straight wire end
  - ~210 mm (A)
    - Bare straight wire end
  - ~80 mm (I)
    - Both ends terminated with blue female insulated spade wire connector (BOM 4)
- (2) Yellow 16-gauge wire at
  - ~220 mm (B)
    - Bare straight wire ends
  - ~220 mm (A)
  - Bare straight wire ends
- (2) Black 16-gauge wire at
  - ~170 mm (E)
    - One end terminated with blue female insulated spade wire connector (BOM 4)
    - One bare straight wire end
  - ~80 mm (H)
    - Both ends terminated with blue female insulated spade wire connector (BOM 4)
- (1) Green 16-gauge wire at
  - ~80 mm (J)
    - One end terminated with blue female insulated spade wire connector (BOM 4)
    - One end terminated with a red ring terminal (BOM 21)
- (1) Blue 18-gauge wire at
  - ~140 mm (K)
- (1) Red 18-gauge wire at
  - ~120 mm (L)
- (1) TC type K (BOM 14)
  - TC wire length should remain as supplied by the manufacturer
- (2) Heater elements (four wire leads) (BOM 1)
  - Lengths stay the same (100 mm)
  - Ends are terminated with red insulated fork spade wire connector (BOM 7)
- Solid-state relay (part of BOM 14)
- Plug with fuse and switch (BOM 13): confirm it is connected to its side of the black project box
- PID controller (BOM 14): confirm the white plastic connector is attached to the controller
- Terminal block (BOM 17)

2.2 Wiring

Figure 9 offers an overview of the wiring connections inside the black project box prior to putting the top and the bottom of the box together. Figure 10 and Figure 11 show the wiring schematic without and with details of the terminal block pins.

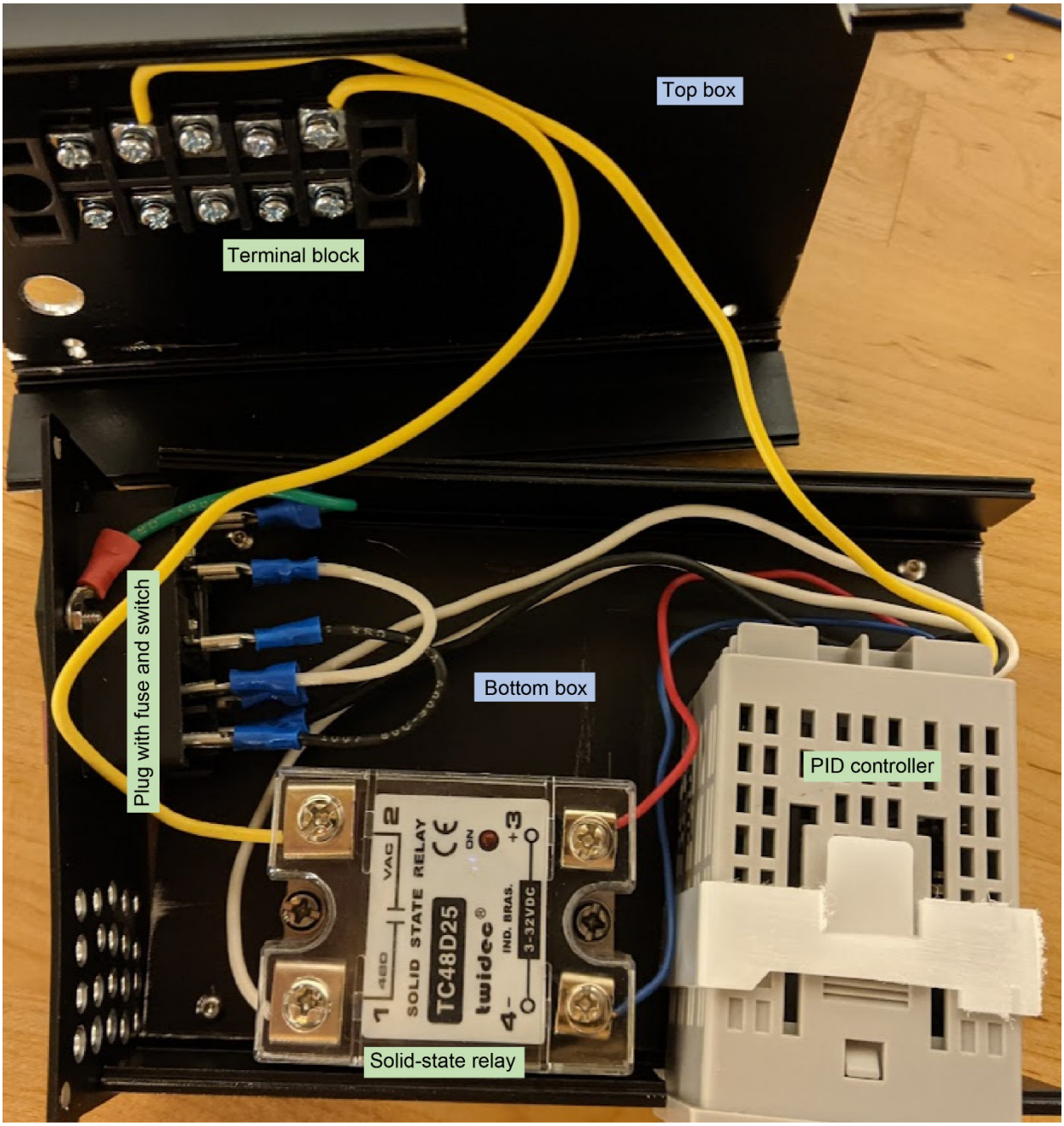


Figure 9.—Black box wiring connections.

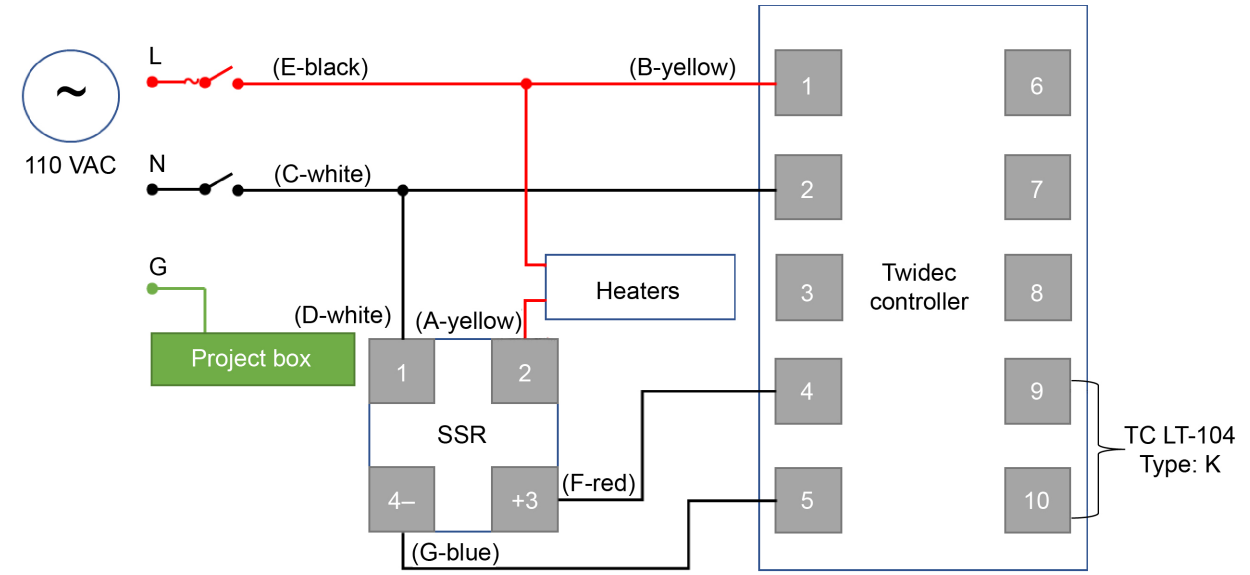


Figure 10.—Wiring schematic for black box (electronics) without details of terminal block pins.

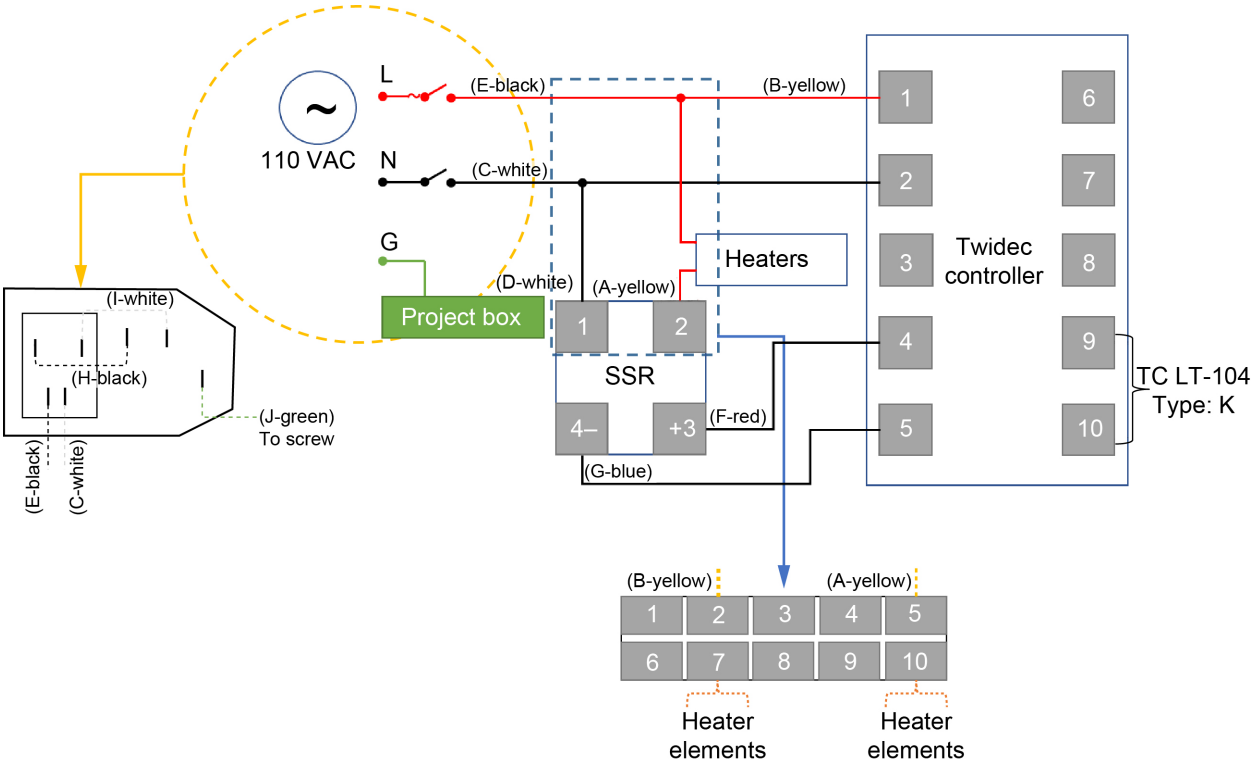


Figure 11.—Black box wiring schematic with details of terminal block pins.

3.0 Assembly

3.1 Step 1: Heat Shield

The oven heater block and heater aluminum plate should already be assembled. If not, please follow the directions outlined in the Mechanical → Heater Block section before beginning the heat shield assembly process.

Start with the bottom of the silver project box (BOM 16).

- At each of the four small corner holes, place a standoff (BOM 11) beneath the box and connect it to a nut (BOM 22) inside the box. Then connect the silver-colored aluminum plate to the standoff with two more standoffs (refer to Figure 12).
- Place heater elements (BOM 1) and the TC (BOM 14) in the slots indicated in Figure 13. The TC hole is the one that was threaded in Section 1.5.
    - Keep a spacer/block under the oven block to avoid bending the heater elements and TC any further than necessary.
    - Loosen one screw on the aluminum plate to insert the TC, then screw it back down, locking the TC in place. Insert the TC in place before placing the heater element because it is a tight fit, but move the bolt out of the way of the heater.
    - Keep heater element cables as unbent as possible when inserting them in the holes.
- Feed the TC and heater element wires through their respective ½-in. (12.70-mm) holes.
- Attach the terminal strip to the inside surface of the top of the black project box (BOM 15) using a hot-glue gun in the location indicated in Figure 1(f).
- Feed the heater element leads through the 3/8-in. (9.52-mm) holes and the TC lead through the center ½-in. (12.70-mm) hole in the bottom of the black box (see Figure 1(f)).
- Attach the top of the black box to the standoffs with #4-40 bolts (BOM 10).

Figure 12.—Location of spacer blocks.

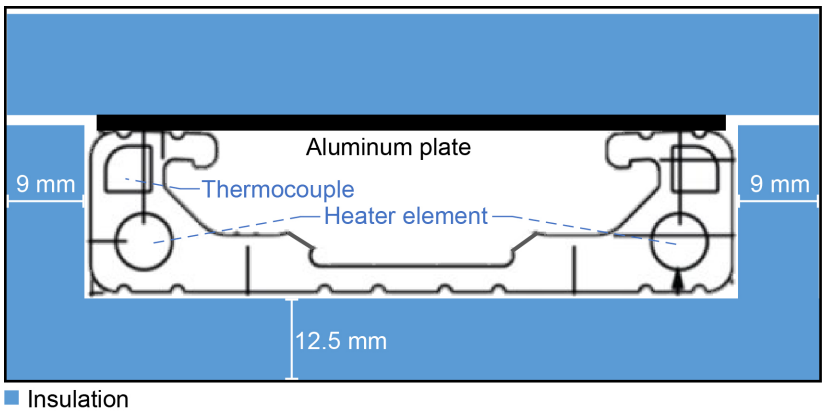


Figure 13.—Locations for TC and heater elements (BOM 1) on aluminum mounting plate.

3.2 Step 2: Oven

- Replace the spacer/block under the oven block with the bottom insulation (refer to Figure 14.)
- Place foil on the oven towards the side with the extra two holes (see Figure 14 and Figure 15).
- Place the side, back, and top insulation around the block (Figure 16).
- Close up the box with the two front and back pieces and the top silver box piece.

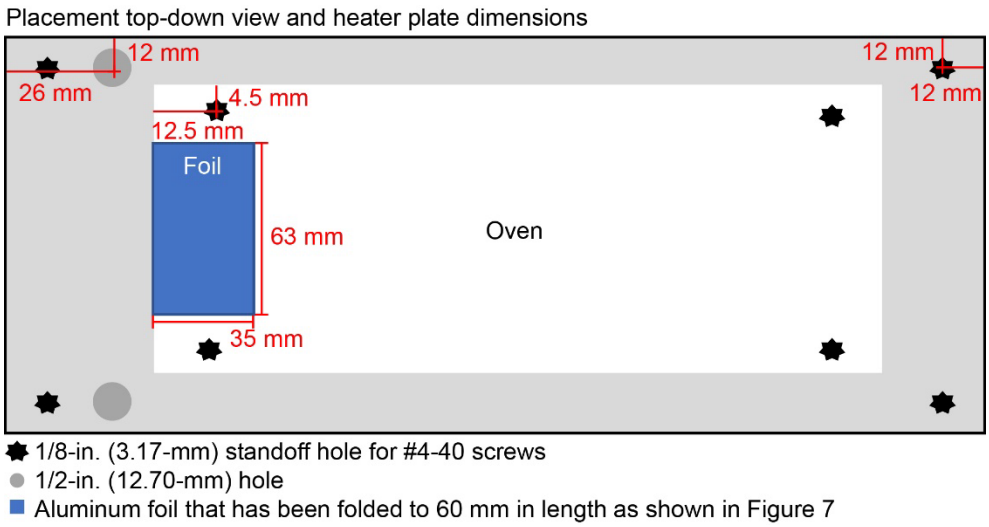


Figure 14.—Oven top-down view and heater plate dimensions.

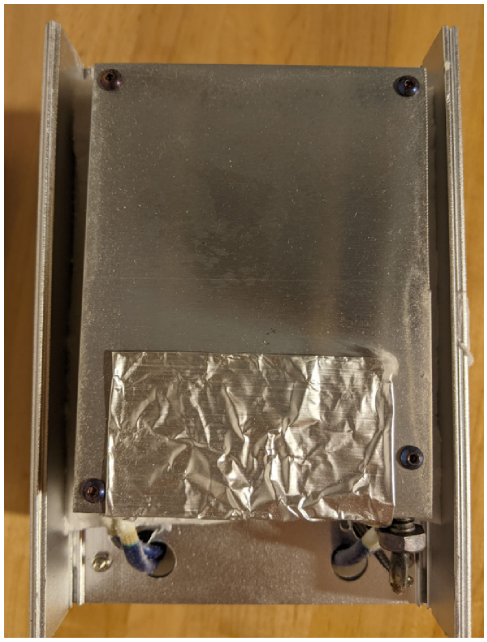


Figure 15.—Aluminum foil placement in oven.

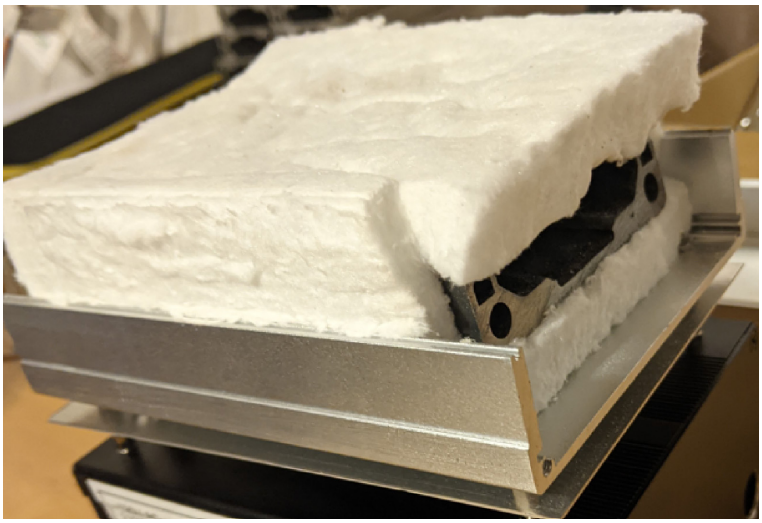


Figure 16.—Installation of insulation on top and sides.

3.3 Step 3: Control Box

At this point, all the components for the black electronic controls box should be wired together outside of the box with the exception of the TC and heater elements. If this is not yet complete, refer to the photos in the Electrical Wiring section (Figure 9 to Figure 13).

- Attach the feet to the bottom of the black project box (BOM 10, 24, 19, 9, 22), assembling components in this order: bolt (#4-40) → box (facing down) → blue Loctite® (Henkel) (BOM 24) on the bolt → washer (#6) → washer (#6) → foot → nut.
- Separate the solid-state relay (SSR) (part of BOM 14) from its provided heat sink. Clean off the paste and keep the bolts, lock washer, and washer.
- Smear a little thermal paste (BOM 23) between the two empty screw holes on the bottom of the black box. Then screw the SSR to the inside surface of the bottom of the black box at the location indicated in Figure 1(e).
    - M4 bolt (comes with SSR) → lock washer (comes with SSR) → washer (comes with SSR) → project box → nut (BOM 20)
- Screw the back panel of the black project box containing the power side to the bottom of the box.
- Move all wires out of the way of the terminal strip and SSR.
- Connect heater elements to the terminal strip. Per each heater element, one lead to each used pins on the terminal strip. Heater element leads are wired in parallel on the terminal strip. One side is wired to the SSR pin 2 and the other to the PID controller pin 1.
- Wind extra TC cord into an oval and secure with three zip ties. Connect leads to PID controller and leave the extra cord behind the PID controller.
    - Make sure to wind the cord into a SMALL oval
    - Move the ends of the zip ties toward the center to be out of the way.
- Fit the PID controller into the cutout square (as shown in Figure 10) and close the black project box.
- Secure the black project box on the side panels with the screws provided with the project box.
- See Figure 17 for the completed assembly.
- See Figure 18 for a top-down view of the oven with dimensions.

Figure 17.—Completed assembly of control electronics and oven.

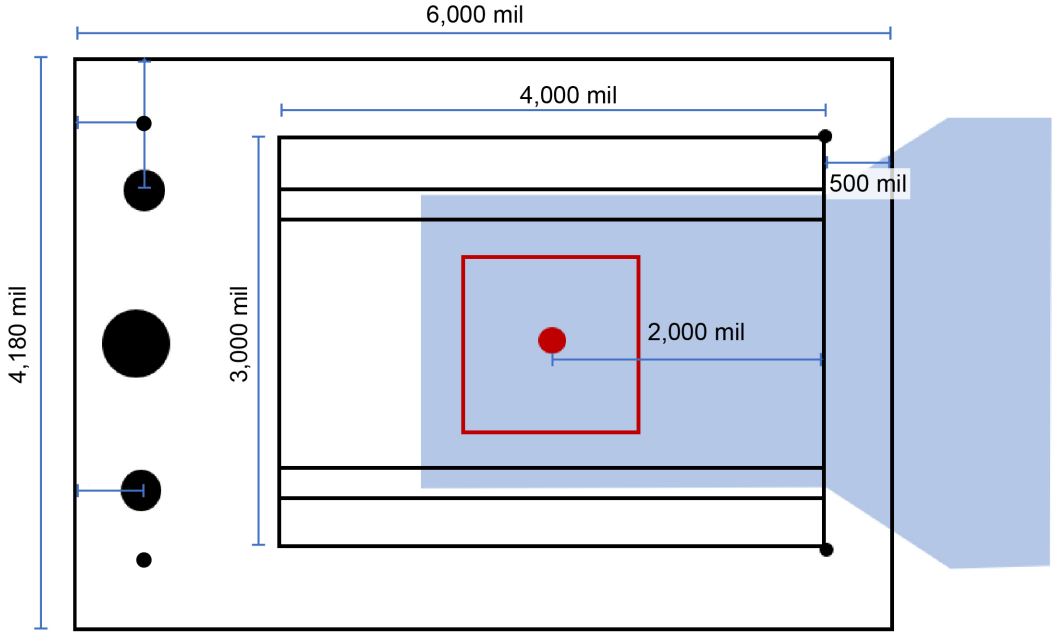


Figure 18.—Top-down view of oven with dimensions. Blue outline represents ceramic substrate for holding prototype devices during testing (not included in this guide).

3.4 Step 4: Final Steps

Program the PID controller (see Table I).

TABLE I.—PID CONTROLLER CAPABILITIES

Parameter	Screen shows	Default value	New value	Adjustable range	Description
AL1		10		DIL-DIH	Alarm value (no display when AC1==0)
AL2		10		DIL-DIH	Alarm value (no display when AC1==0)
ATU	Aru	0		0-1	Self-tuning
P		30	40	0-999	Proportional
OH		2		1-100	Main control return difference (display when P==0)
I		120	24	0-999	Integral (no display when P==0)
D		30	60	0-999	Differential (no display when P==0)
Ar		80		0-100	Integral overshoot suppression (no display when P==0)
T	r	20	2	1-100	Cycle (no display when P==0)
SC		0		–199-199	Corrected value
LCK	LCY	0		0-111(BIN)	Coded lock: 000(bin) All parameters are modifiable, 001(bin) SV AL1 AL2 are modifiable, 011(bin) SV is modifiable, 111(bin) all are not modifiable; all others are not modifiable
Password menu (long press of MODE + shift keys to enter in non-menu state)					
COD		0	1	999	Submenu password: 001-enter submenu 1, 911-restore factory values menu
Submenu 1					
SN		K		B, S, R, T, K, N, J, E, PT, PT.Cu	Scale division no.
SLL		-50		Sensor corresponding measurable range	Display lower limit
SLH		999		0-1	Display upper limit
Oud		0		0-1	Control mode: O-heat-up 1-refrigerating
Ouk		0		0-1	Output mode: O-switch 1-continuous (1 to 5 V or 4 to 2mA requires corresponding module support)
OHN		1		0-6	Return difference control mode set when stepping control 0-underside return difference Closed when PV≥SV; Open when PV≤SV–OH; 1-bilateral return difference Closed when PV≥SV+OH; Open when PV≤ SV–OH
AC1		1		0-6	Al1 alarm mode: O: no alarm; upper deviation alarm; lower deviation alarm; alarm beyond upper and lower deviation; alarm within upper and lower deviation; process value upper limit alarm; process value lower limit alarm
AC2		0		1-100	Al2 alarm mode: O-no alarm; Upper deviation alarm; Lower deviation alarm; Alarm beyond upper and lower deviation; alarm within upper and lower deviation; Process value upper limit alarm; Process value lower limit alarm
AH1		2		1-100	Alarm 1 return difference
AH2		2		0-1	Alarm 2 return difference
Unt		0		0-100	Unit: 0: °C, 1: °F
DF		65		0.00-10.0	Filter coefficient
Cot		5		0-50	Display suppression
Fun		0			Over-temperature display suppression: 0-Turn-off function; For other values, if the value exceeds the set value, the excess part will be displayed proportionally; display value=SV+(measured value-SV)/FAC
Fac		0			

3.4.1 Change the Set Value (SV)

1. Power cycle the heater/PID.
2. Use the arrow buttons to increase/decrease the SV to the desired temperature.

3.4.2 Set PID Settings

It should only be necessary to enter these settings once for each unit.

In PID parameter setting mode, each time the MODE key is pressed, the next parameter will be displayed.

To access the PID parameters:

1. Hold down the MODE key for about 5 sec.
2. Change only LCK (looks like LCY) parameter to "1" to modify the PID internal parameters.
3. Change parameters to the following values (some do not require changing):
   a. AL1 (alarm 1) → 10
   b. ARU (self-tuning) → 0
   c. P (proportional) → 40
   d. I (integral) → 24
   e. D (derivative) → 60
   f. Ar (integral overshoot suppression) → 80
   g. T or backwards 7 (cycle) → 2
   h. SC (corrected value) → 0
4. When all entries have been made, press and hold the MODE key for about 5 sec. to store the parameter values.
5. To change temperature units:
   a. Press and hold MODE and SHIFT («) keys.
   b. COD → 001 to enter submenu 1
   c. Continue to press either the Up or Down arrow button until Unt (unit) appears: 0 for Celsius; 1 for Fahrenheit.

3.5 Notes

If it becomes necessary to add or replace oven components, the process of opening the oven is slightly counter intuitive. Opening the top and bottom of the oven requires unscrewing the outer screws and all the screws on the side where the plug is located. The bottom of the silver box, the silver-colored plate, and the top of the black box cannot be disassembled without disassembling the entire oven.

4.0 Concluding Remarks

The design of the Mark I compact test oven is customized for prolonged functional electrical testing of prototype silicon carbide devices at high temperatures. The Mark I oven design offers several significant improvements over earlier compact ovens, including the use of commercial off-the-shelf components and minimal assembly requirements. The cost of each oven is less than $200 (USD), which makes constructing multiple ovens affordable. The oven's two-box design separates the heat-producing components from the electronics, which keeps them cool, prolonging their lifetime.

Appendix—Bill of Materials

TABLE II.—BILL OF MATERIALS (BOM)

BOM item no.	Description	Manufacturer
1	Cylinder cartridge heater elements, 110 V, 150 W, 6 by 100 mm, model no. JND-HEATER6100	Twidec
2	Ceramic insulation blanket, PO810013, 19 by 14 by 1/2 in., model no. 2675E	Lynn Manufacturing
3	1/16- by 4- by 6-in. aluminum mounting plate, 5052 aluminum, 16-gauge	2TwentyTwo Steel Designs
4	Blue female insulated spade wire connector electrical crimp terminal 16-14 AWG, 4.8 by 0.5 mm (quantity 100)	Baomain
5	Hookup wire kit, UL1007 solid wire, 16 AWG gauge solid, rated 300 V, model no. 16UL1007SLDKIT	Remington Industries
6	#2-64 hex machine screw nuts, grade 2, zinc-plated steel and clear finish (quantity 100)	Fastenere
7	Red female insulated spade wire connector electrical crimp terminal 22-16 AWG 4.8 by 0.5 mm (width 0.2-in.) (quantity 100)	Baomain
8	Light T-slotted profile, 3034-Lite, 15 series, 3 by 0.75 in., 72 in. long	80/20 Inc.
9	50 small round rubber feet with screws (cutting board feet)	Otrestodyl
10	#4-40 by 5/16-in. stainless steel button head socket cap screw (quantity 100)	FullerKreg
11	#4-40 6+6 mm F/M brass hex standoff spacer screws PCB pillar nickel-plated (quantity 100)	Uxcell
12	UL approved, 6-ft. universal computer monitor power cord, 18 AWG NEMA 5-15P to IEC13, model no. LYSB01J4M3QDW-CMPTRACCS (5 pack)	Aurum Cables
13	Inlet module plug male and power socket with 5 A fuse switch, 10 A 250 V, 3-pin IEC320 C14 plug type (quantity 6)	Antrader
14	MV100-B10 Digital Display PID temperature controller, thermostat regulator 85 to 265 V_{AC} with K thermocouple sensor plus heat sink and solid-state relay (SSR 25 DA)	Twidec
15	Aluminum project box, black, 106 by 55 by 150 mm, part no. LKHZ012	JIUWU
16	Aluminum project box, silver, 106 by 55 by 150 mm, part no. LHKZ011	JIUWU
17	Terminal block set, includes: 5 pieces 6-position double row screw terminal strip blocks with cover, 5 pieces black and red pre-insulated barrier jumper strips, 60 pieces insulated fork wire connectors. part no. G-882	Glarks
18	Red insulated fork spade wire connector, electrical crimp terminal 18-22 AWG (quantity 100)	Baomain
19	#6 flat washer, 18-8 (304) stainless steel (quantity 100)	Instockbolts
20	M4-0.7 stainless steel 304 (18-8) hex nut (quantity 100)	Instockbolts
21	Ring terminal connector M6 stud circular 16-22 AWG crimp	TE Connectivity
22	Stainless #4-40 hex nut, 18-8 304 stainless steel (quantity 100)	Fullerkreg
23	Thermal grease G104	GENNEL
24	Cyanoacrylate Adhesive Instant Glue	Loctite
25	12-in.-wide aluminum kitchen foil, standard weight, uncoated	Reynolds Wrap
26	1/16- by 5- by 6-in. silver-colored aluminum plate, 5052 aluminum, 16-gauge	2TwentyTwo Steel Designs