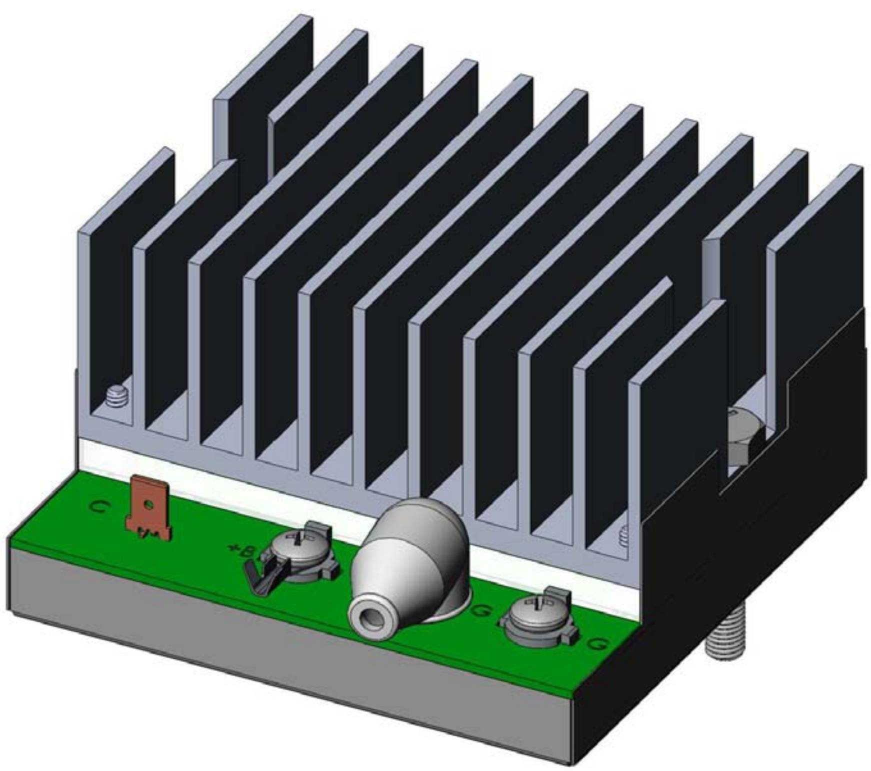
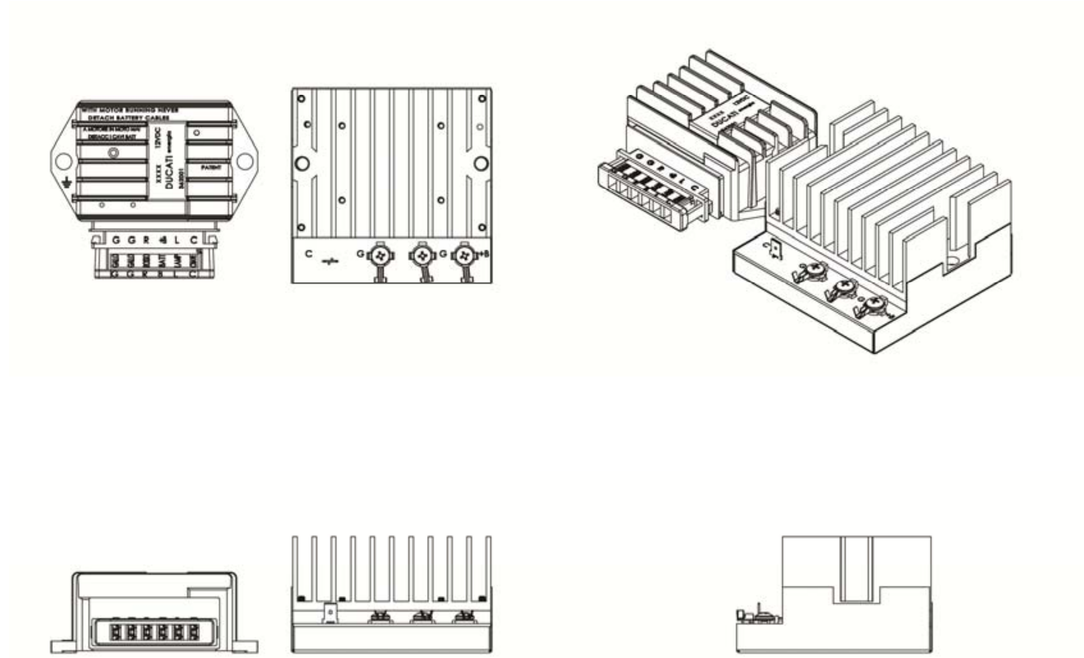
A few weeks ago I scratch built a new voltage regulator to replace the Ducati.

The design goals were;

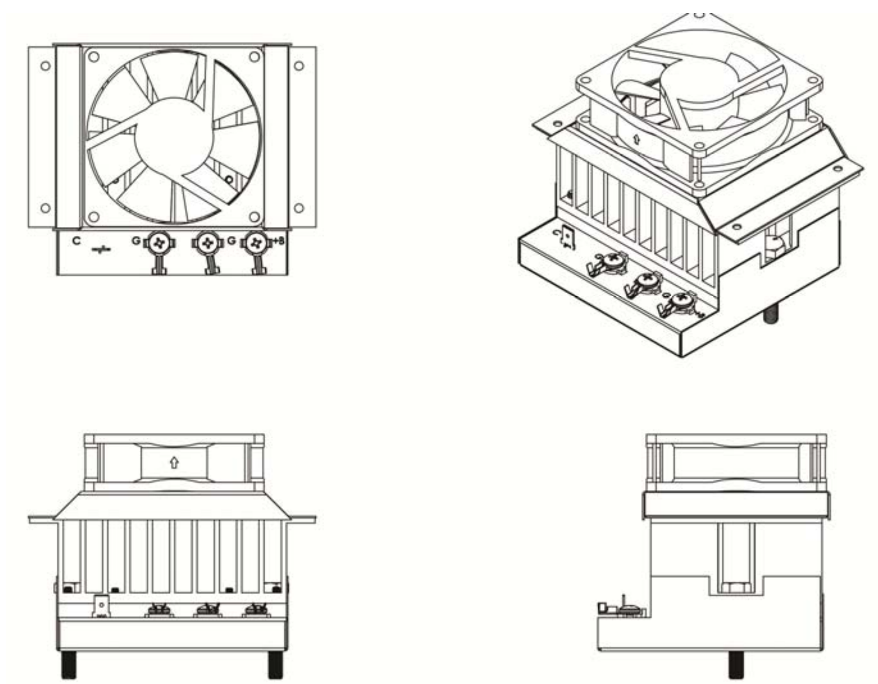
- Low cost “experimental” replacement.
- Repairable.
- All components are off the shelf (no custom extrusions, CNC, or molded parts.)
- No “blind” parts with unknown ratings, all components have data sheets.
- Built with common builders tools.
- Increased heat sink area.
- Eliminate Faston connections for power leads.
- Maintain the Ducati mounting bolt hole spacing.
- Optional cooling fan.

This is what I came up with;





Side by side



With Optional Fan

Temperature Rise

The new version has almost three times the surface area, so it operates cooler.

Temp Rise					
Ducati 362001 ROTAX 965349		New Design V1		New Design V1 w/fan***	
Output Amps	Temp *	Output Amps	Temp *	Output Amps	Temp *
8.5	80°C**	8.5	51°C		
14	107°C				
20	138°C	20	79°C		
22	****	22	83°C	22	40°C

* at 25°C Ambient
** 80°C is the Rotax regulator temp limit
*** 40 CFM fan, Vans PN "ES CPU FAN" (Orion OD8025-12HSS)
**** Not tested at 22 Amps due to elevated temperatures

The Rotax stator is inherently current limited at 22 amps and runs at up to 483 Hz. So this test was never intended to be a real word evaluation of either regulator, but rather a comparison of the two using a common test fixture.

The "Load Test" fixture is a 1000VA 120 volt, 60 cycles, variable Transformer driving a 500VA 240V/12V transformer. This gives us lots of adjustable amps at a very low voltage. The load is a .028 ohm shunt, connected between +B and the case ground. The variable Transformer is used to set the current. Heat generated is a function of the current through the regulator. We don't care about the output voltage for this test. With an output of 22 amps across the shunt, we were supplying ~2 volts AC to the input.

The stock heat sink I selected for the new design is larger than the Ducati, but it will fit on the firewall shelf and clear the rudder pedal support. The parts cost about $60, not including the PCB.

I don't have any issues with the Ducati circuit. So it's only slightly modified.

The Material List and Sourcing

Unfortunately the parts can't be sourced from one vendor. We got it down to four.

Electronics, Digikey spreadsheet
Hardware, Aircraft Spruce spreadsheet
Misc (plastic filler strip), McMaster Carr
PCB Vendor , Eagle(V2.53) .brd format and ordering data

The above spreadsheets have gone through several revisions. They are accurate to the best of my knowledge. The filler strip is only a suggestion. I cut up an anti-static ¼" wide tube used to package TO220 case devices. The PCB board file is the modified Rev-1 board. There were a few minor errors on the Rev-0 board. I did not reorder the Rev-1 board to check it.

Digikey has a nice feature where you can upload an Excel or CSV file directly into your shopping cart so you don't have to manually enter in 23 parts.
For the enclosure I would prefer .032-inch material, but .016-inch 2024-T3 is the only thickness Spruce offers in a 12"x12" sheet. Any thing else and the cost goes up exponentially. We only need a 6" by 6" sheet, so you get four practice runs. Maybe you can do better locally. The ½" long front flange is designed to go under the board to support it. It needs to be strong enough to support the downward force on the PCB when the terminals are tightened.

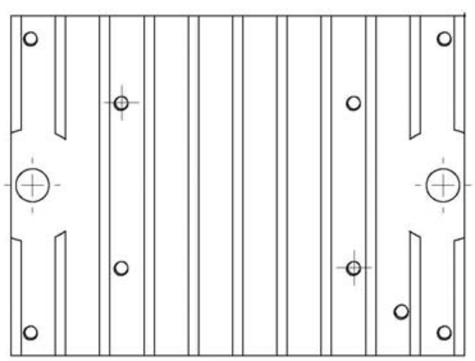
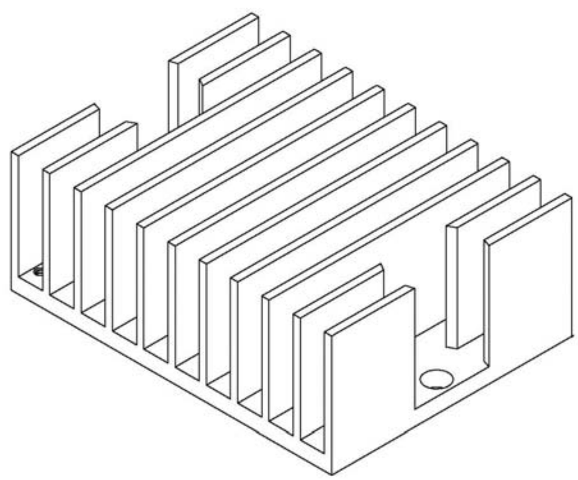
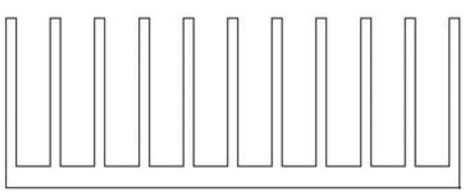
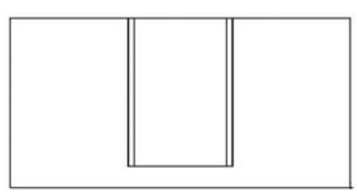
The PCB screw terminals are rated at 30 amps each. The PCB was designed for 22 Amps in the power circuit. With standard 1 oz copper we generate three to four watts of heat along power traces at 22 Amps. A board of three or four ounce copper would be a better choice but, it's not an option for prototypes. For a workaround I omitted the solder mask along the wide power traces on the bottom of the board. We can increase the current carrying capacity with a piece of solid copper wire. This wire can be laid down along the three power traces, from the component lead to the terminal.

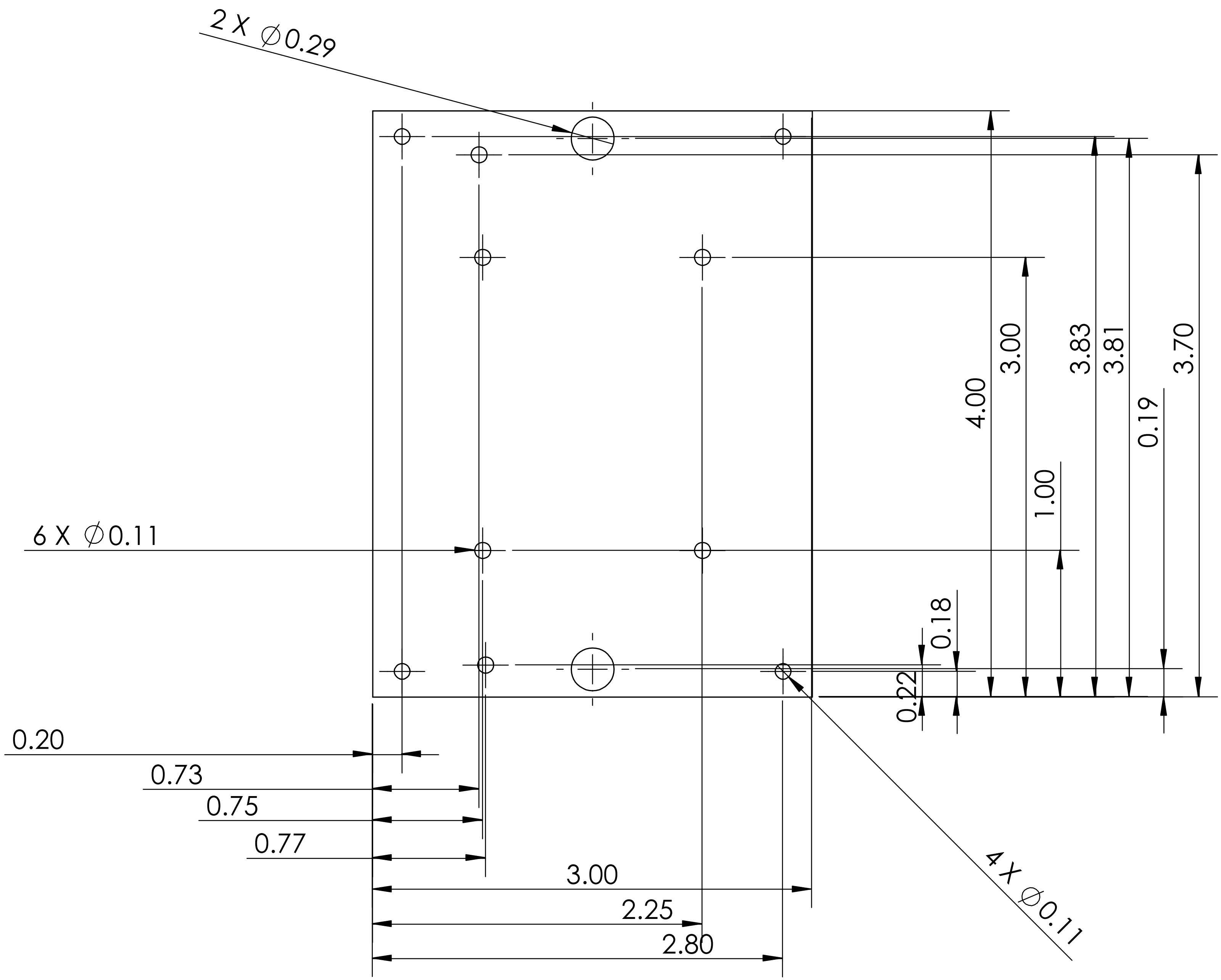
Mechanical Fabrication

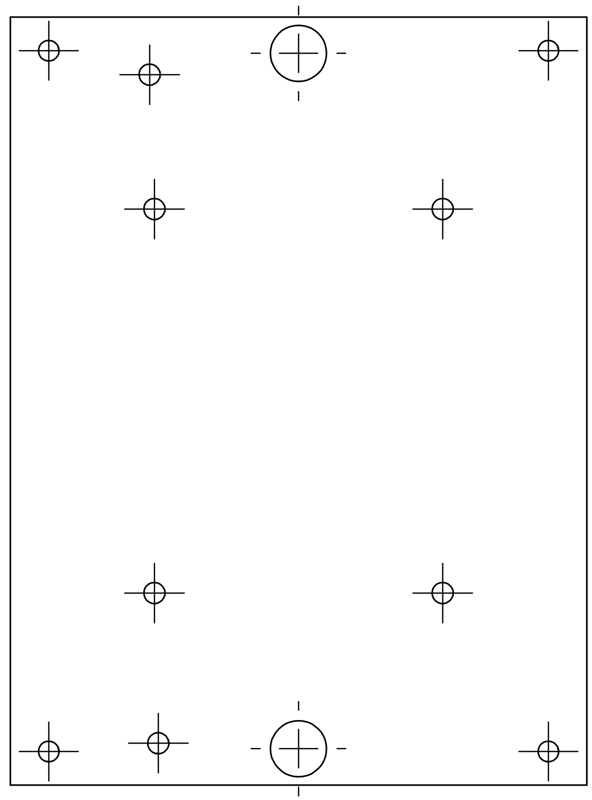
Heat Sink
Caution: protect the machined heat sink surface.

1) There are three ways to mark off the surface of the heat sink
   - Layout and Measure, here are the dimensions
   - Print out this 1:1 scale Heat sink Template and tape it to the face and center punch.
   - Secure the PCB to the face of the heat sink and use a transfer punch to locate the ten holes. You will need to measure the ground wire screw hole.
2) Drill the two ¼" mounting holes.
3) Drill and tap the 6-32 screw holes.
4) The fins need to be cut so we can install the AN4 mounting bolts with clearance for a socket.
   - Clamp a board between both top flanges.
   - Using the two ¼" mounting holes on the machined side, drill through the board.
   - Use the holes in the board to guide the pilot of a ¾" hole saw.
   - Cut to the bottom of the fins, but not into the heat sink base. Snap off the four fins.
   - The AN4 mounting bolt and the large aluminum spacers act as a current conductor from the heat sink to the airframe ground. Finish the fin stubs to a smooth surface. Files can be used, but a 1/2" counterbore with a ¼" pilot will give professional results for under $30.
5) The two mounting flanges can be trimmed or retained as an attach point for a cooling fan duct.

When you are done you should have this.

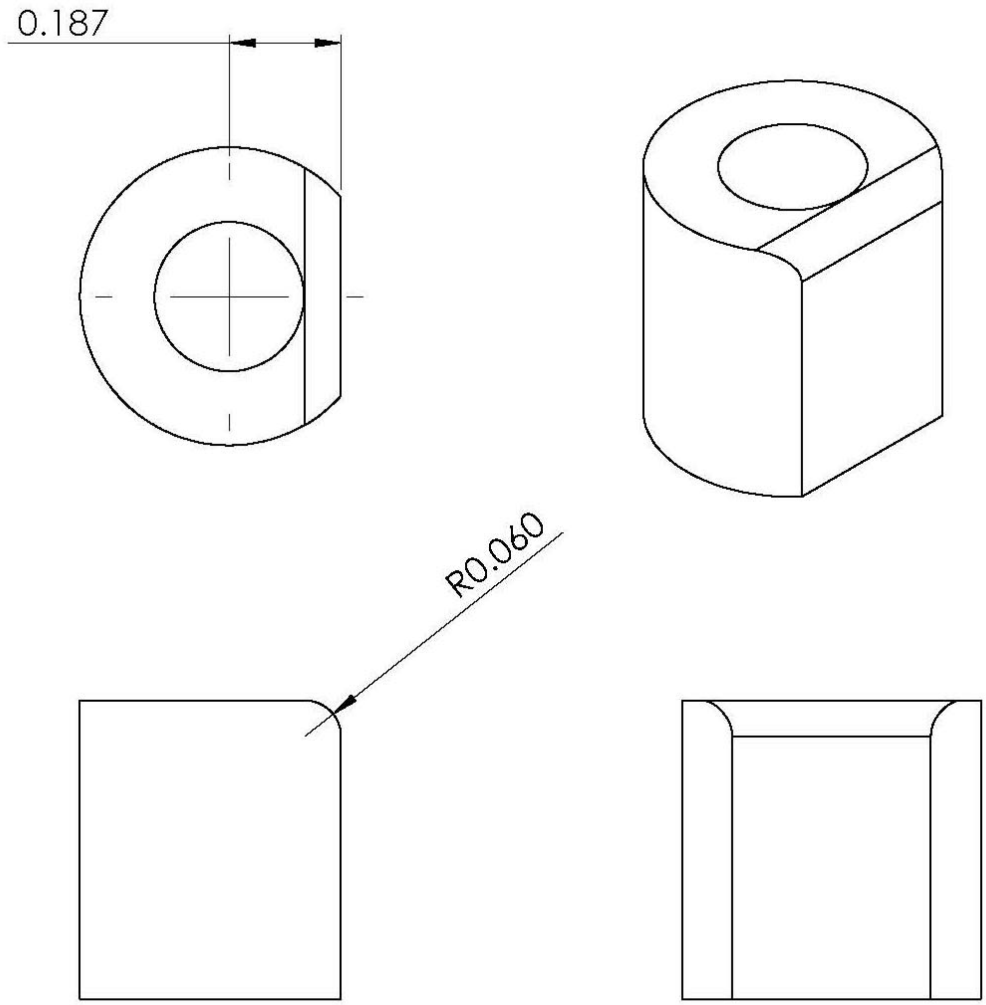






2 X ∅0.29
6 X ∅0.11
4 X ∅0.11
4.00
3.00
1.00
0.18
0.22
3.83
3.81
0.19
3.70
0.20
0.73
0.75
0.77
3.00
2.25
2.80



Large Aluminum Spacers

The PCB is positioned between the Heat sink and Enclosure Cover with aluminum spacers. File one side of the spacers to make a flat edge to clear the enclosure cover. The longer, ½" spacer needs a radius along one flat edge, to nestle into the enclosure bend radius.

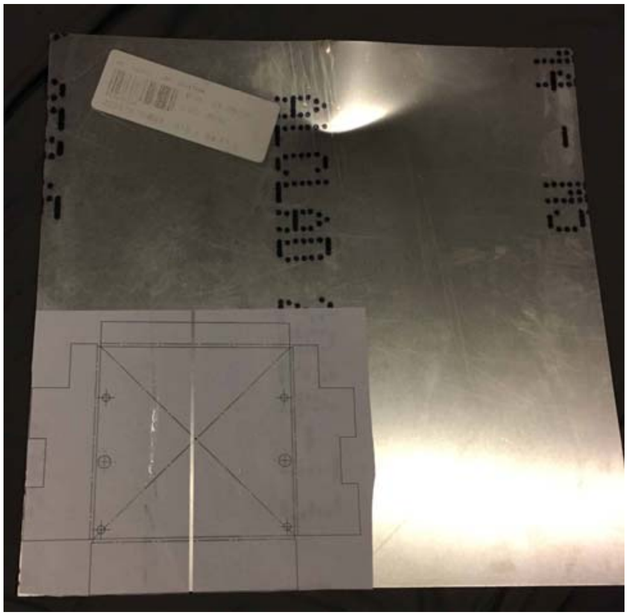


Countersink the Nylon Spacers

Countersink on one end, on each of the four nylon spacers. Remove enough material without shortening the spacer.

Enclosure Cover (* based on .016 material with a .032 bend radius)

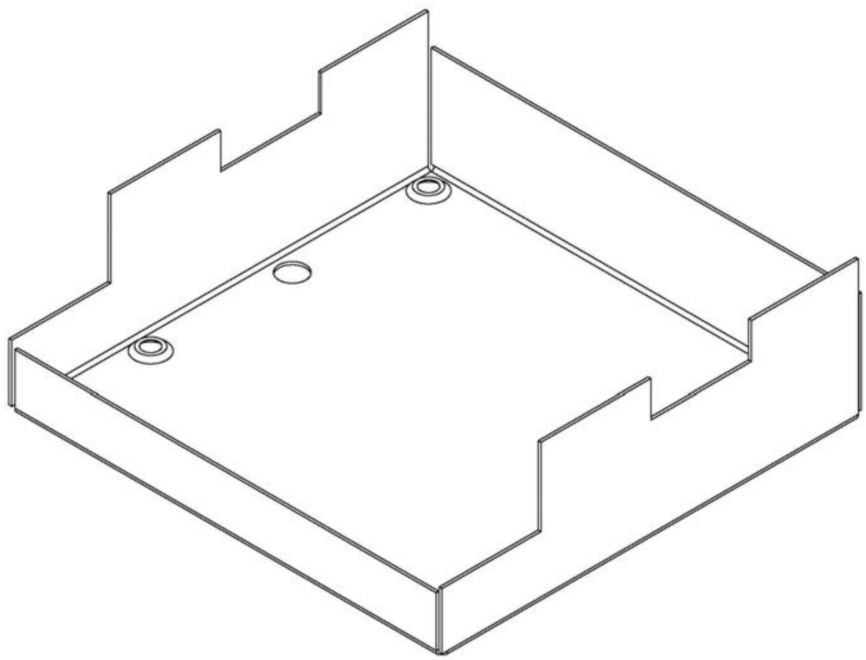
1) The flat sheet can be marked either of two ways
   - Layout and Measure, here are the dimensions *
   - Print out this 1:1 Enclosure template (bend edges)* or Enclosure template (bend lines)* on a label (or print on paper and attach it with spray adhesive) to the protective plastic on the aluminum sheet. Center punch, drill, and cut to size. (Remove the plastic sheet and paper template after the part is bent.)

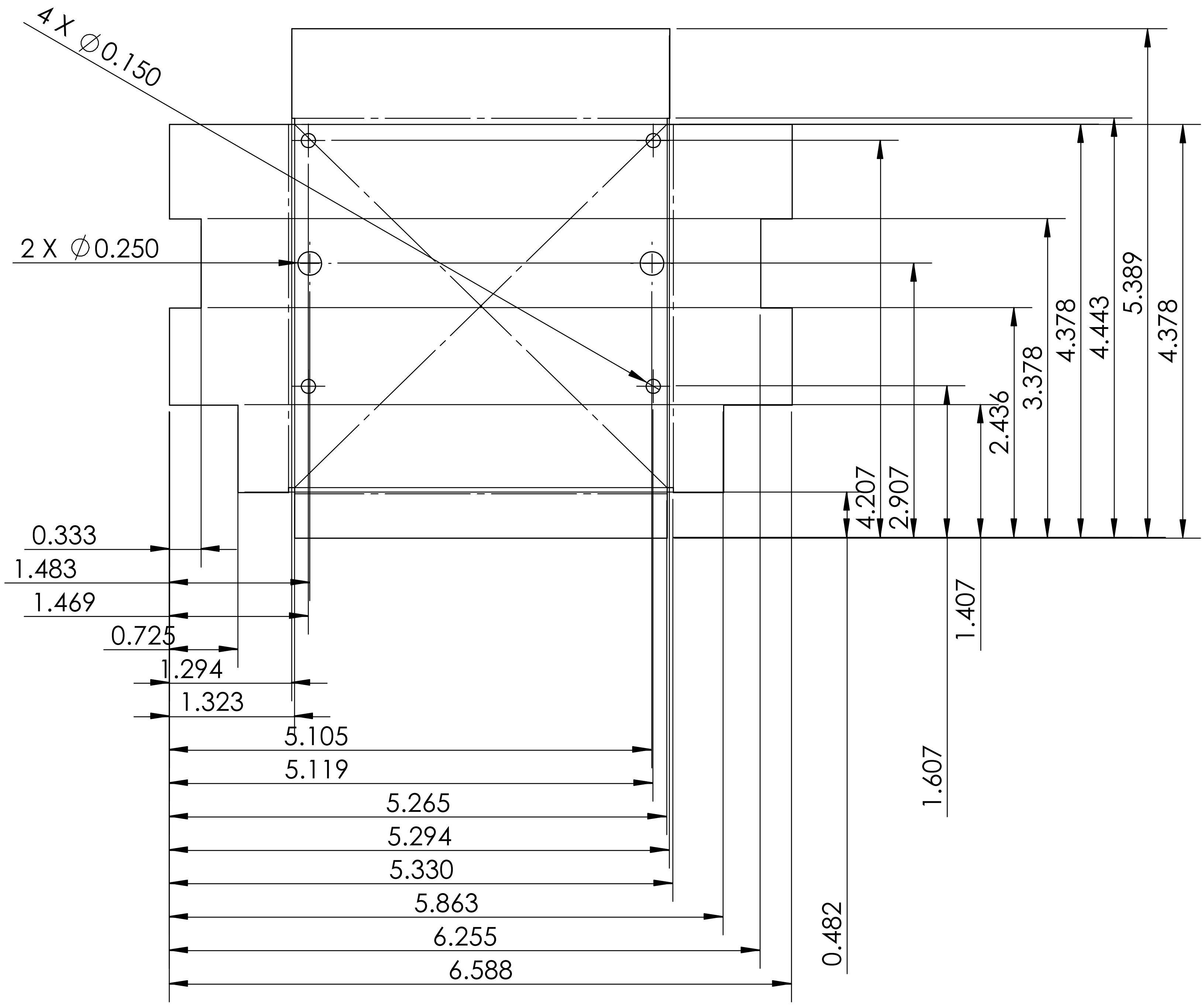


If you don't have a dimple die for a #6 screw your #30 dimple die will give adequate results. The raised part of the dimple should be on the template and bend line side of the sheet. Dimple the four 6-32 screw holes.

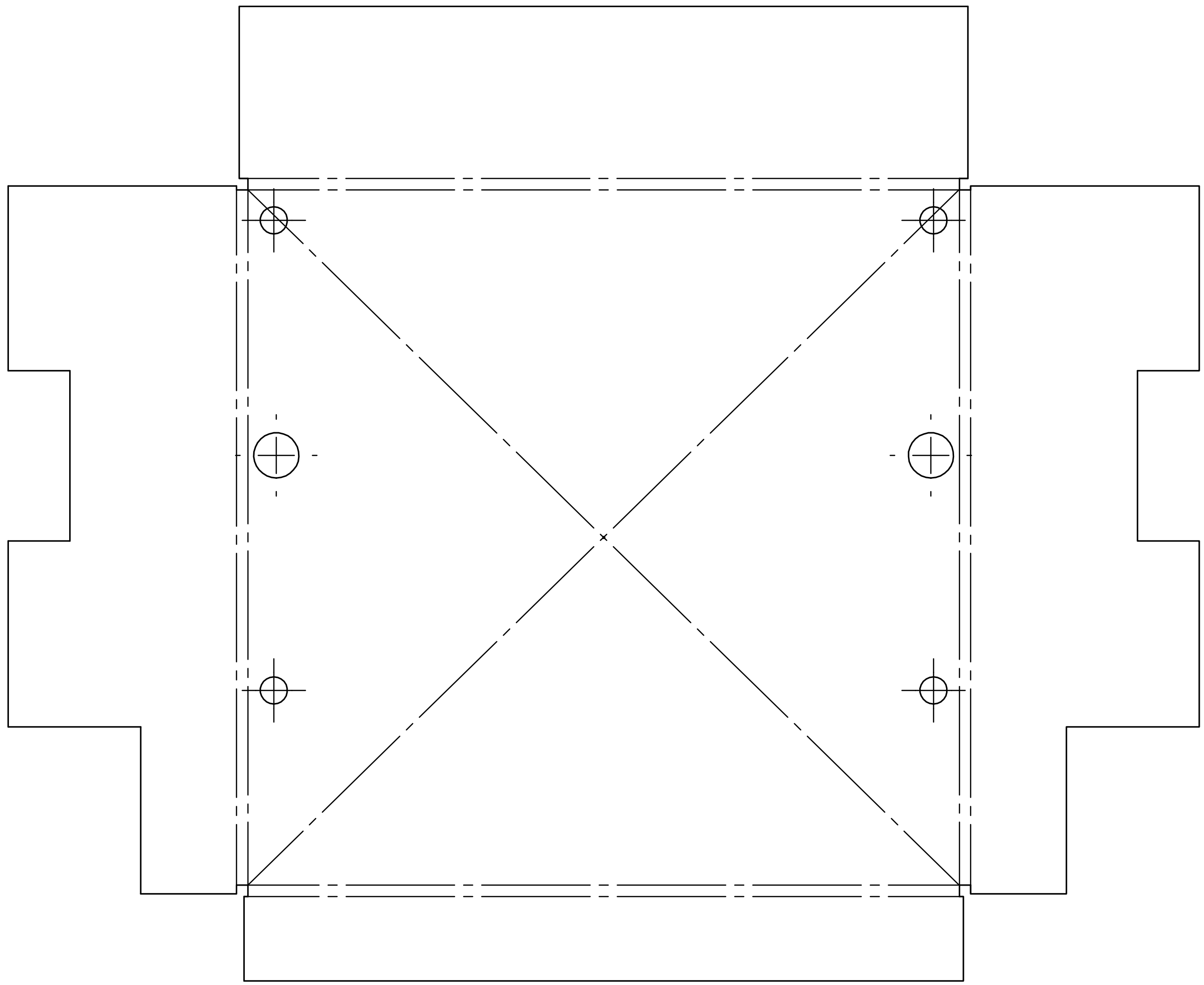
2) Use a sheet metal brake and bend the four sides up.

Your finished part should look like this.

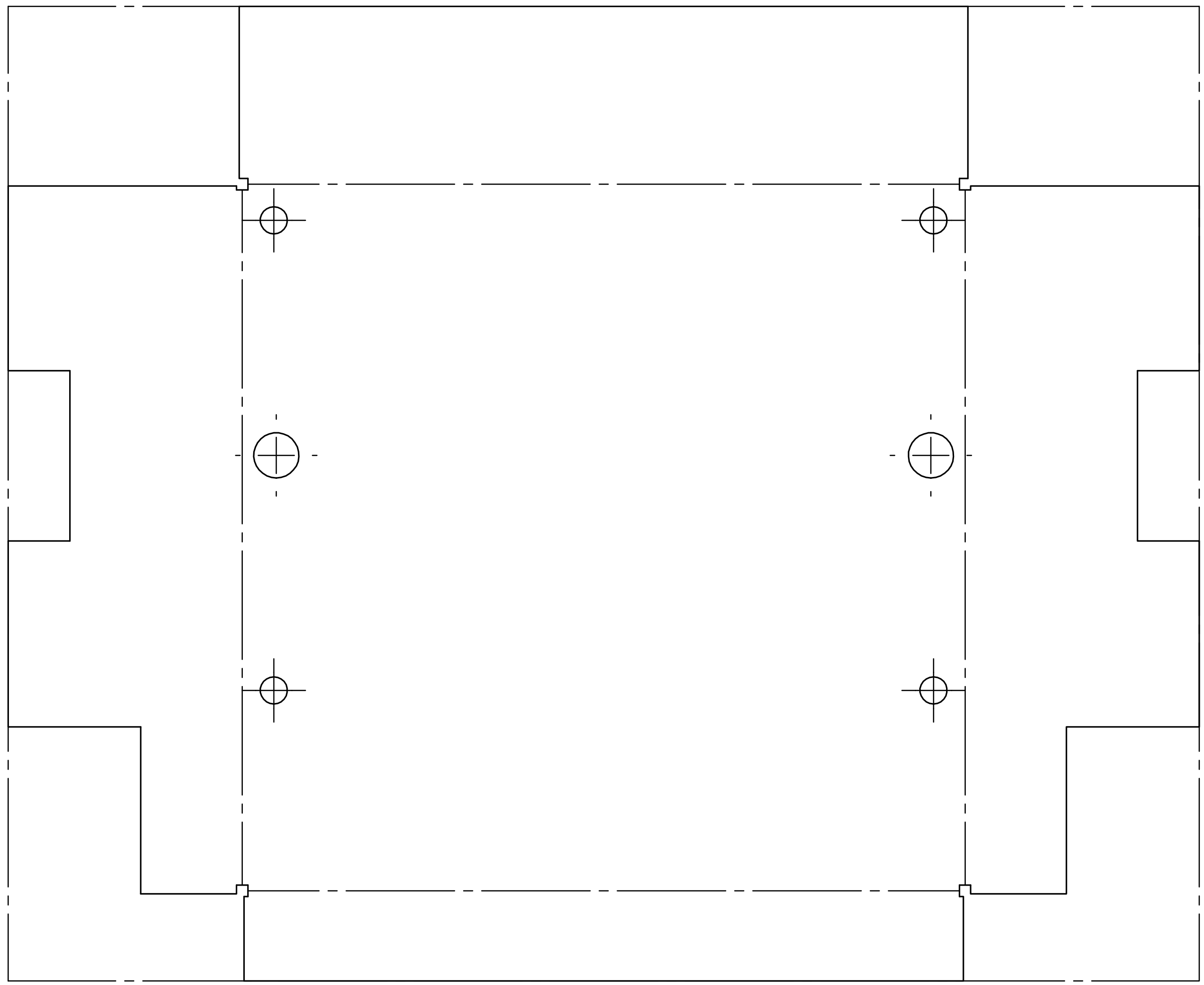



4 X ∅0.150
2 X ∅0.250
0.333
1.483
1.469
0.725
1.294
1.323
5.105
5.119
5.265
5.294
5.330
5.863
6.255
6.588
4.207
2.907
1.407
1.607
0.482
2.436
3.378
4.378
4.443
5.389
4.378

with bend edge lines



bend center lines

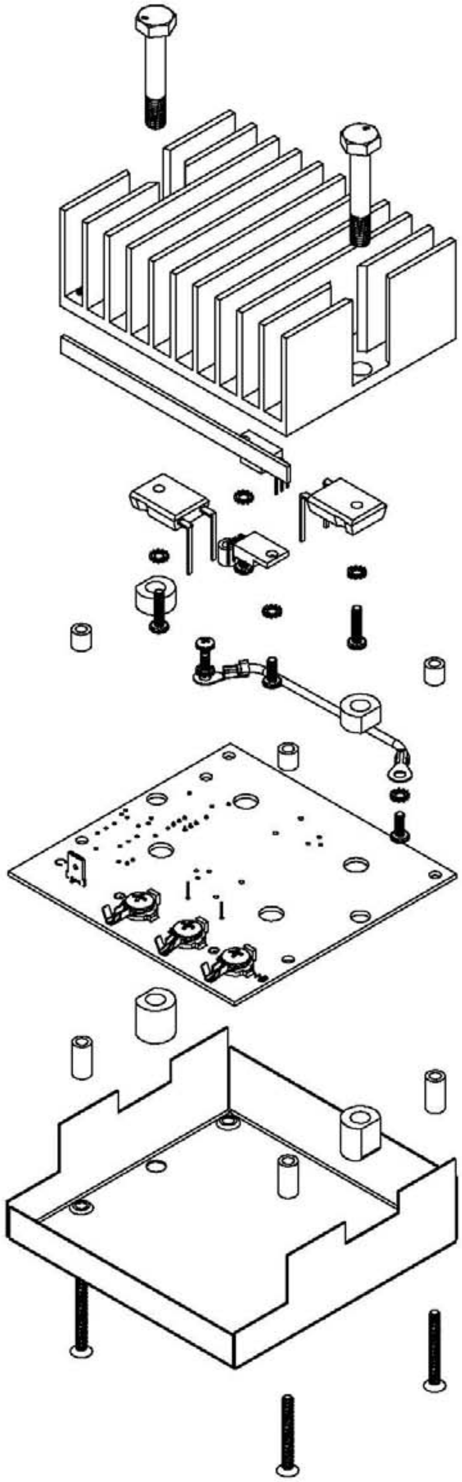


PCB Assembly

1) It's probably been a while since your last Heathkit® project so lets review a few basics;
   - Diodes, zeners and most caps are polarity sensitive. Do not install these backward.
   - The band on the diode case is the cathode end. This corresponds to the line of the arrowhead in the diode symbol.
   - The negative side of an Aluminum Electrolytic Capacitor is marked with a series of minus signs, inside a wide band. On radial packages (both leads on the same end) the longer lead is positive.
   - The PCB silkscreen will show the positive side of a cap with + sign.
   - The large cap in the AC circuit is not polarity sensitive.
   - The board will be installed upside down. So the terminals are installed on the bottom (unmarked side) of the PCB. (The board file includes a bottom silkscreen layer. The only things on this layer are the four terminal markings. For an additional $20 you can get the bottom silkscreened. I used a Sharpie.)
   - The image of the power components is for reference only; these devices connect to the board, but mount to the heat sink.
   - Do not install the power components at this time, they need to be fitted.
   - Use an ohm meter to check values if you drop or mix resistors.
2) Load the components into the PCB. The PCB silkscreen may only have names/IDs for the components. Component values are on a separate layer and the board fabricator may or may not include it in the silk screen. In case the values are not included they can be found here component loading.
3) Solder the components, using an appropriate soldering iron. A good light and magnifier will help.
4) With a set of flush cutters clip the leads flush with the top of the solder joint about 1/32" to 1/16" above the board surface (don't cut into the solder, clip the lead.)
5) Inspection. Are the components in the right locations? Are any backward? Check your work or have someone else inspect it. It's easier to inspect it and fix now than troubleshoot later.

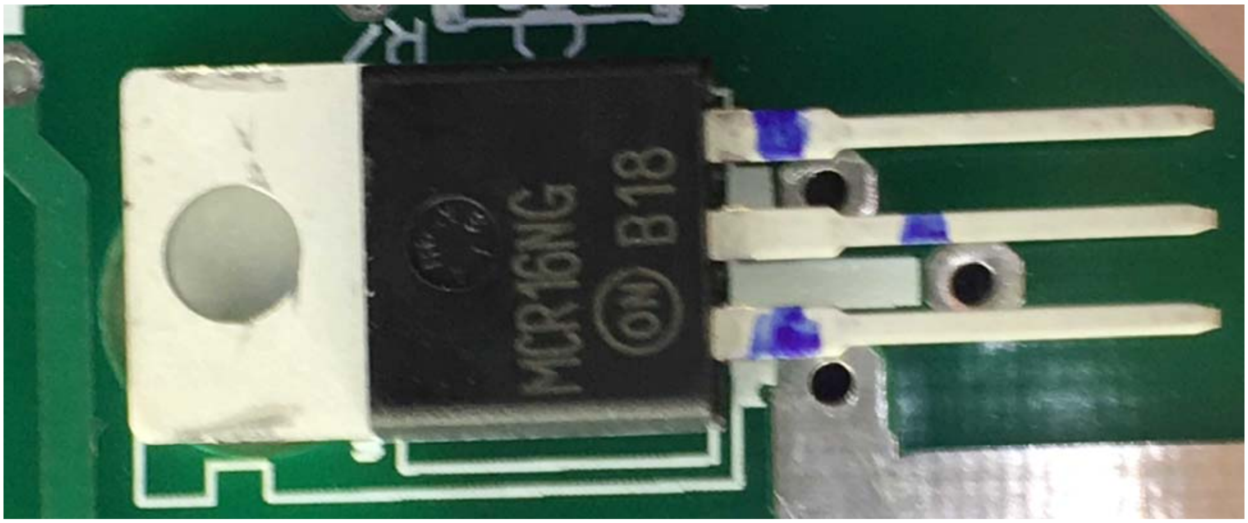
Final Assembly

Here is the assembly overview



I) Fitting the Power Components

1) Use care in bending the leads. This page is cut from STMicroelectronics TN1225, Lead Bending.
2) Align each power component to the silkscreened outline on the PCB.
3) Mark a bend line on each lead referenced to that lead's pad hole.



4) Doing one lead at a time, hold the lead with a pair of needle nose pliers at the bend line. Allow for the bend radius. With your finger, bend the lead 90 degrees up, away from the heat sink side.
5) Repeat on the remaining components.
6) Cut, trim and fit the plastic filler strip between the PCB and the heat sink. Oversized holes can be used to capture the two #6 aluminum spacers.
7) Temporarily install the power components, filler strip, ¼" spacers, and #6 aluminum spacers. Check the fit and adjust as needed.
8) Take it apart.
9) Attach a 3-1/2" long #18 gauge ground wire from the PCB to the heat sink.
10) Apply heat sink compound to each power component.
11) Install the power components into the unmarked side of the PCB, but don't solder.
12) Place the heat sink over the power components and PCB. Carefully turn the assembly over. Do not let the component leads fall out of their PCB holes.
13) Install the filler strip and four #6 aluminum spacers. Temporarily tighten the four PCB attach screws through the spacers securing the board to the heat sink.
14) Slide the two ¼" long large spacers between the heat sink and the PCB. Use an AN4 bolt to center the spacer. Slide the two ½" long large aluminum spacers over the bolts with the radiused side away from the board. Align the flat side of the spacers with the heat sink edge. Temporarily secure with a nut.
15) Install and torque the four power component screws and lock washers.
16) We don't want these metal spaces coming loose during assembly or handling. RTV

the six top spacers and two large bottom spacers to the PCB. Do not put RTV under the large spacers. They need electrical contact through the PCB.

17) Allow the RTV to cure.

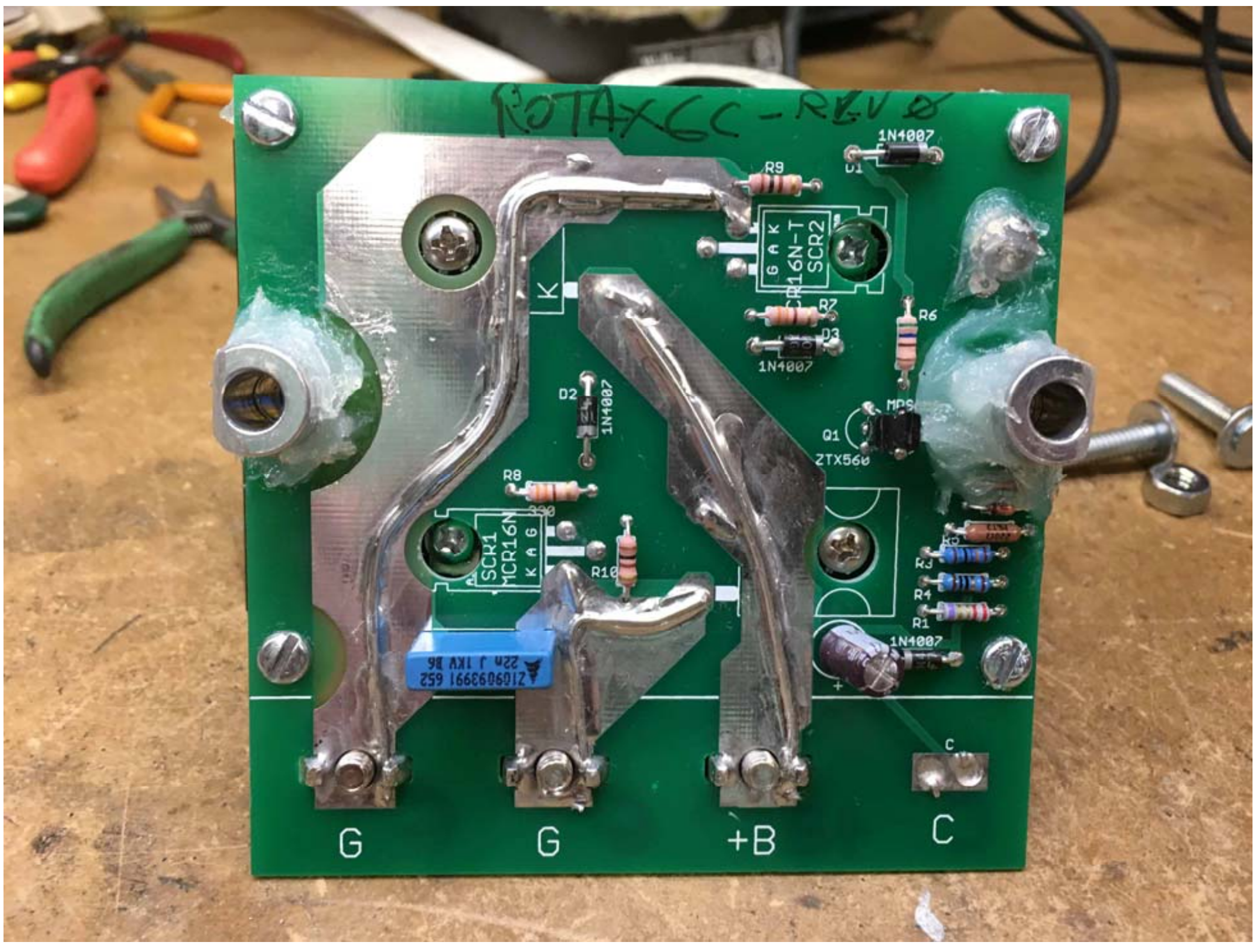
18) Bend the leads of the power components flush with the PCB on the wide traces that have no solder mask. Form the lead as needed to follow the shape of the trace. Only do this on the wide traces without a solder mask.

19) Solder the leads.

20) Trim the leads that were not bent over.

21) Form three pieces of bare, solid copper wire. Use 18 gauge or larger. Run each wire from the screw terminal to the power component lead. Follow the shape of the unmasked trace. Solder in place.

22) Leave the PCB screws in place until its time for final assembly to protect the component leads.



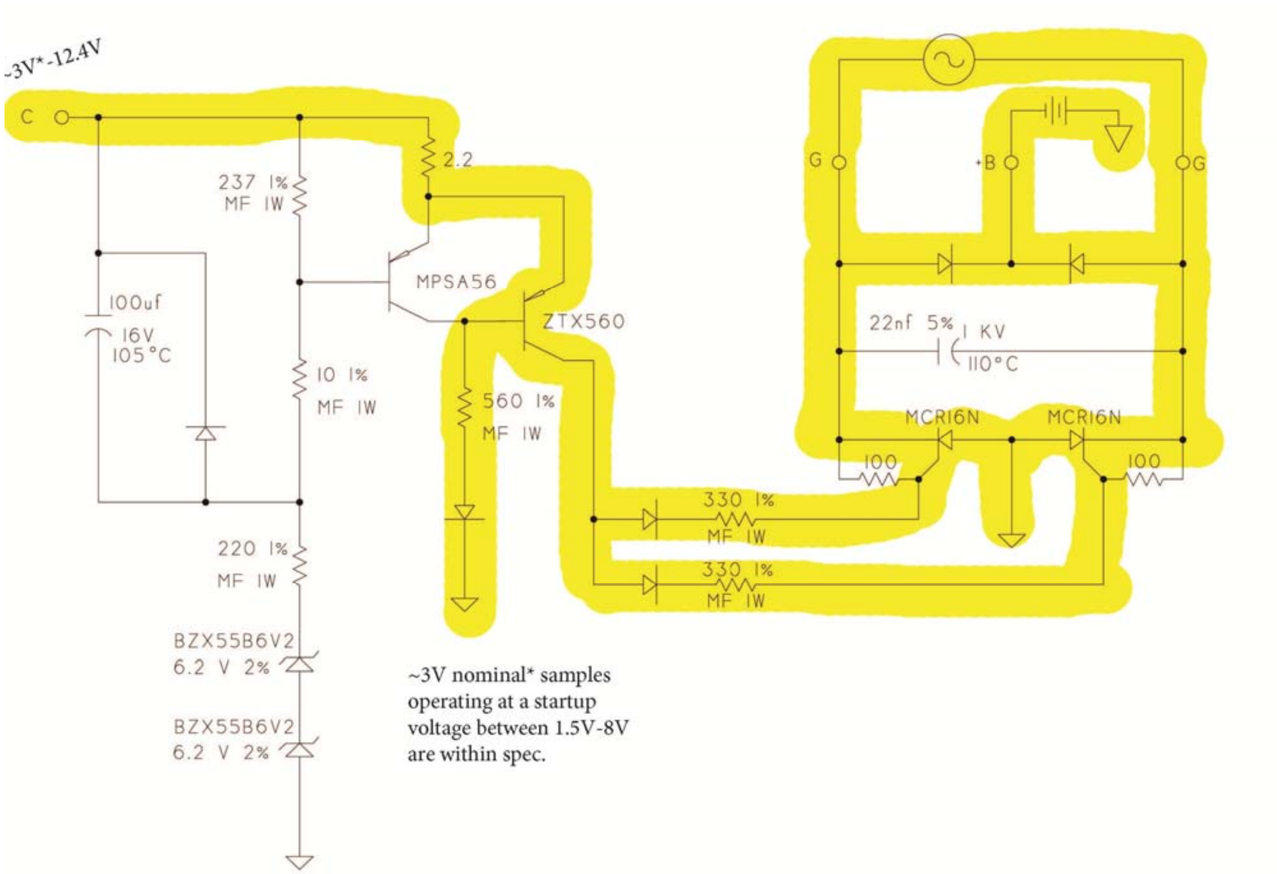
II) Install the Enclosure cover

1) Remove the screws and bolts securing the PCB in place.
2) Install the four screws in the cover
3) Install the four nylon spacers on the screws with the countersunk side toward the dimpled cover.
4) Align the four PCB screw holes to the four cover screws.
5) Flip it over and torque the four cover screws.

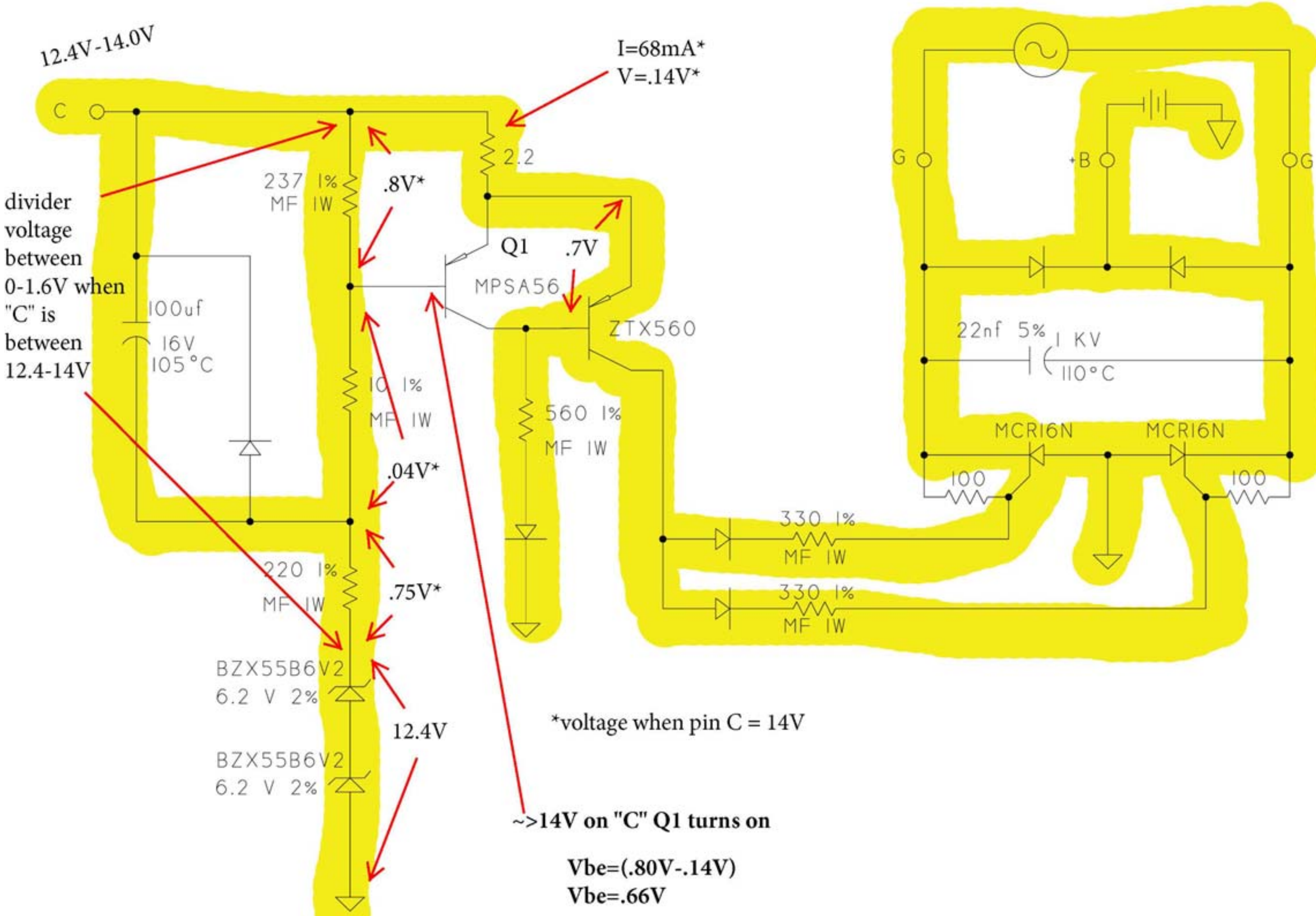
Schematic and how it Works

This regulator uses a switched bridge rectifier. This is simply a full wave bridge to convert AC to DC, except half the bridge uses SCRs so the bridge can be turned on and off. The power to fire the SCR gates comes from the "C" terminal. This input is both control and sense. The operation of the regulator is better understood when the C pin is powered independently. The test voltage applied should be any voltage expected in any normal or abnormal condition. The regulator C pin input is designed to tolerate voltage between -14 volts through +24 volts. There are five circuit paths in the operation of the regulator based on the voltage at the C terminal.

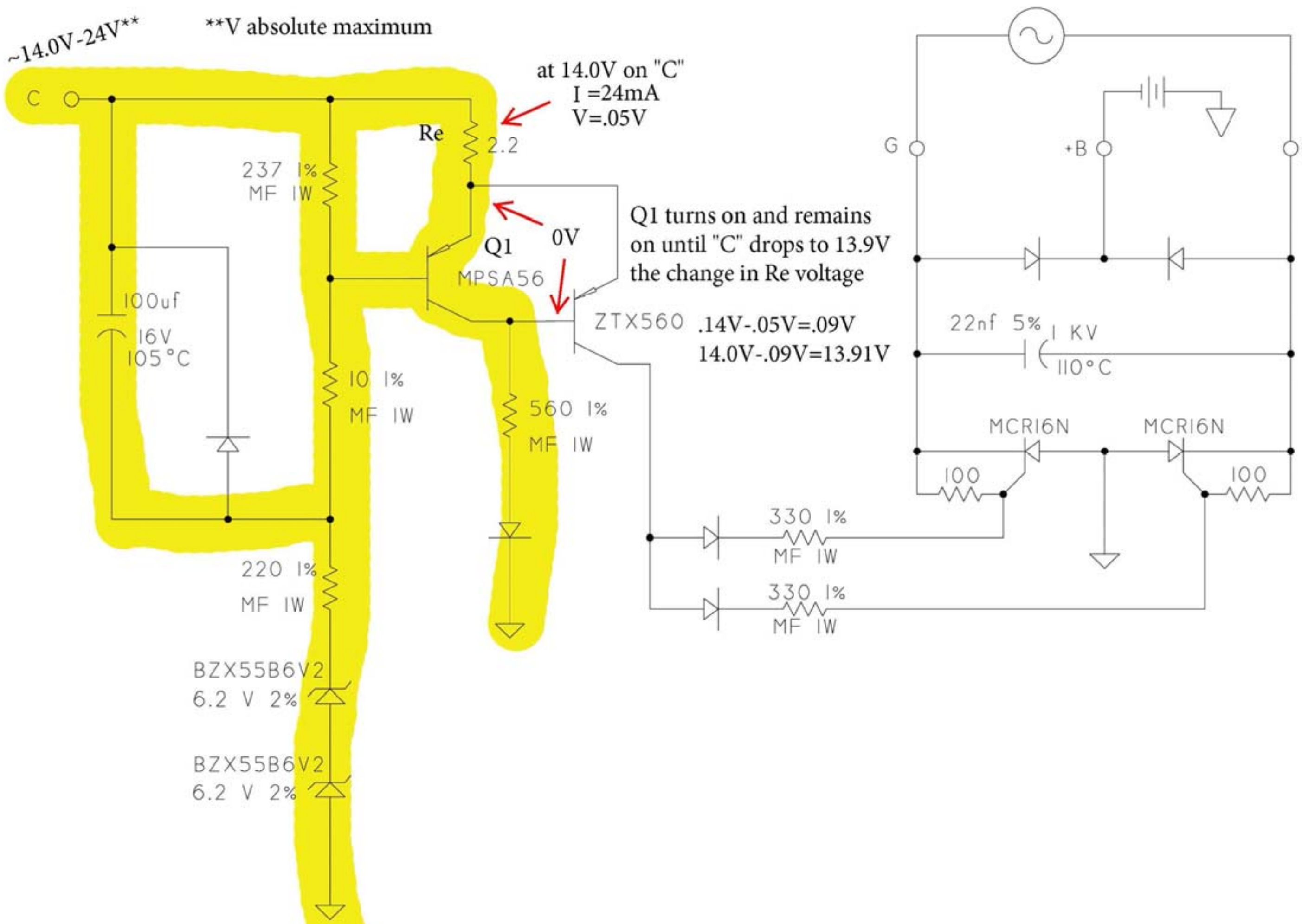
1) Low voltage operation.



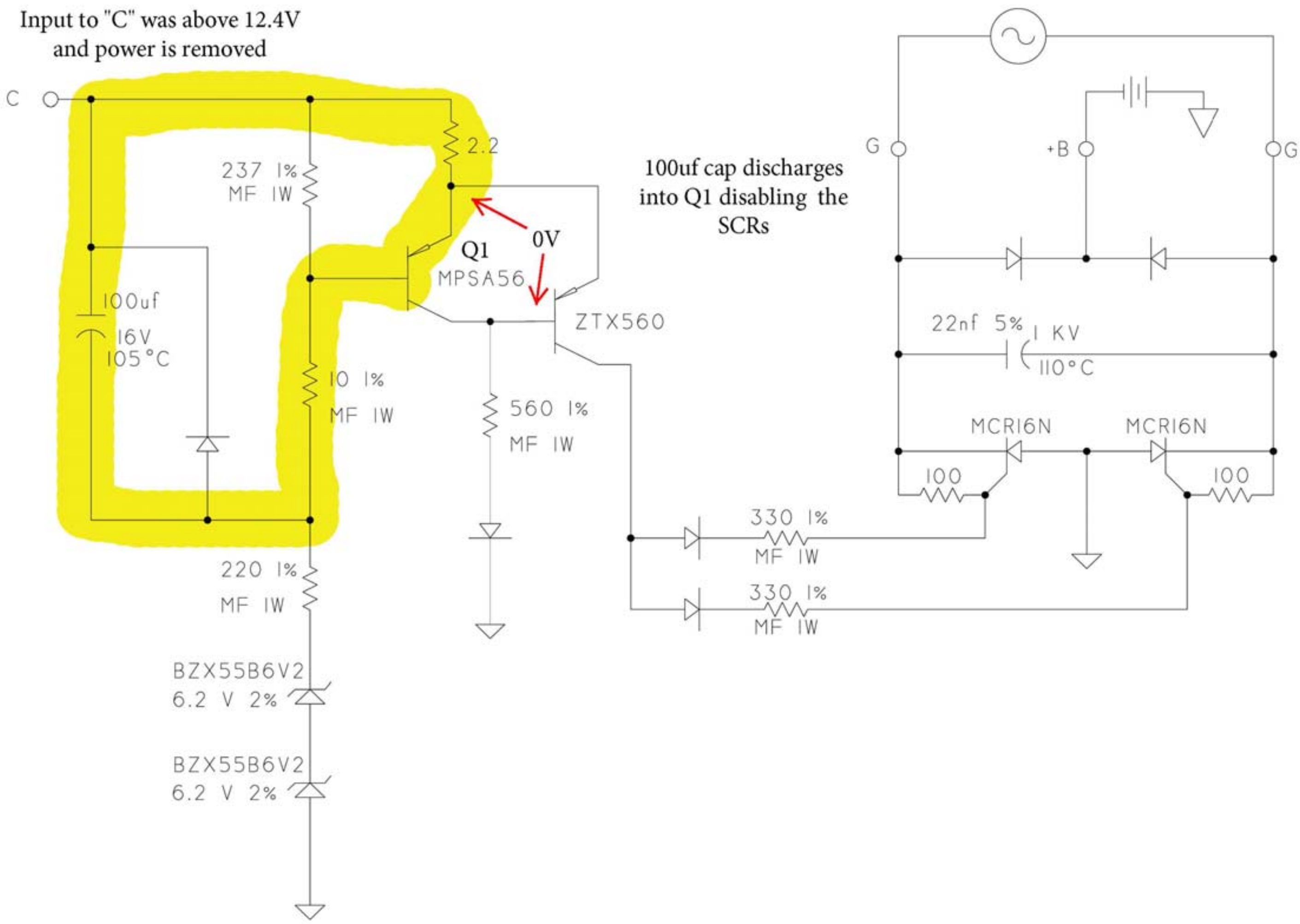
2) Low voltage operation, approaching turn off set point



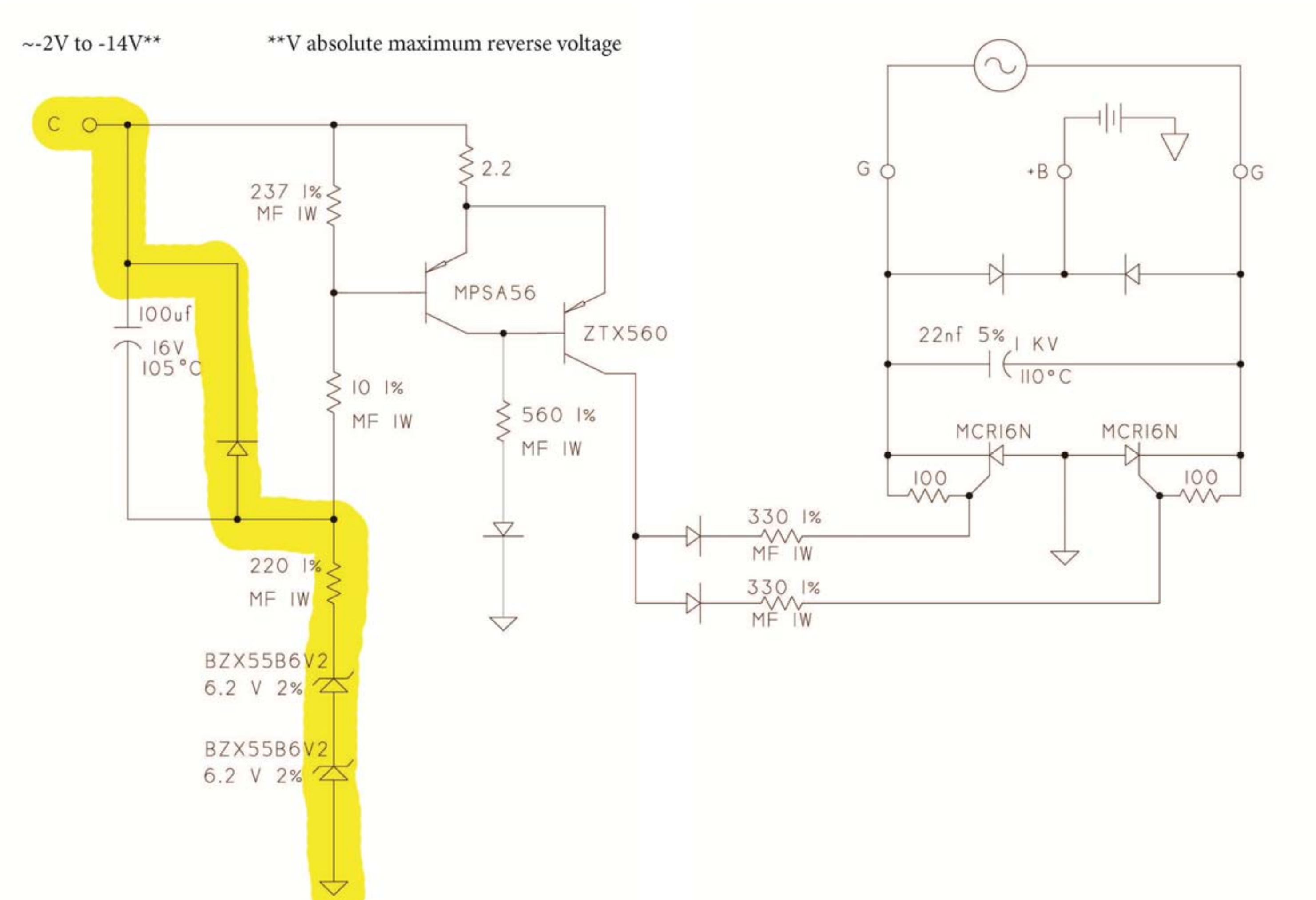
3) Satisfied, approaching turn on set point.



4) Output disable when the regulator is satisfied and power is removed from the C pin. This prevents the regulator from turning on again momentarily as the voltage drops below the turn on set point.



5) Reverse power operation.



Testing

1) Connect the 16 volt secondary of a door bell transformer to the two G terminals.
2) Use a 12 volt automotive bulb as a load. Connect one side of the bulb to the +B terminal and the other side to the heat sink (ground.) Use the AN4 mounting bolt location where the anodized finish has been removed for all ground connections.
3) Using a 9-volt battery, connect the negative battery terminal to the heat sink ground.
4) When the 9-volt battery positive terminal is touched to the C pin, the bulb will light.
5) Connect a second 9-volt battery in series like this to make an 18 volt supply.

NOTE: This is not an ideal way of testing, but it's the easiest workaround for not having an adjustable DC power supply. We won't know the actual "OFF" threshold voltage, but it will confirm the regulator shuts off.

6) When the second 9-volt battery (+) terminal is touched to the C pin, the bulb will NOT light. Do not leave 18 volts on the C pin any longer than necessary to perform the test.

Install it. Because the screw terminals are in an unfused circuit we included electrical terminal nipples to prevent accidental contact. Install the #10 Lock washers under the screw heads of the power terminals to prevent vibration from loosening them. A separate #12 ground wire may be run from under the head of one of the AN4 mounting bolts to the battery/airframe grounding point for improved grounding. The parts list includes the ring terminals for this option. Because the regulator location and wire runs may vary, we did not include a wire length in the spreadsheet. There is enough instrumentation with standard avionics to test this in place for proper operation. The displayed system voltage with minimum load at a moderate RPM should show 14 volts +/- .3 volts once the battery is charged.