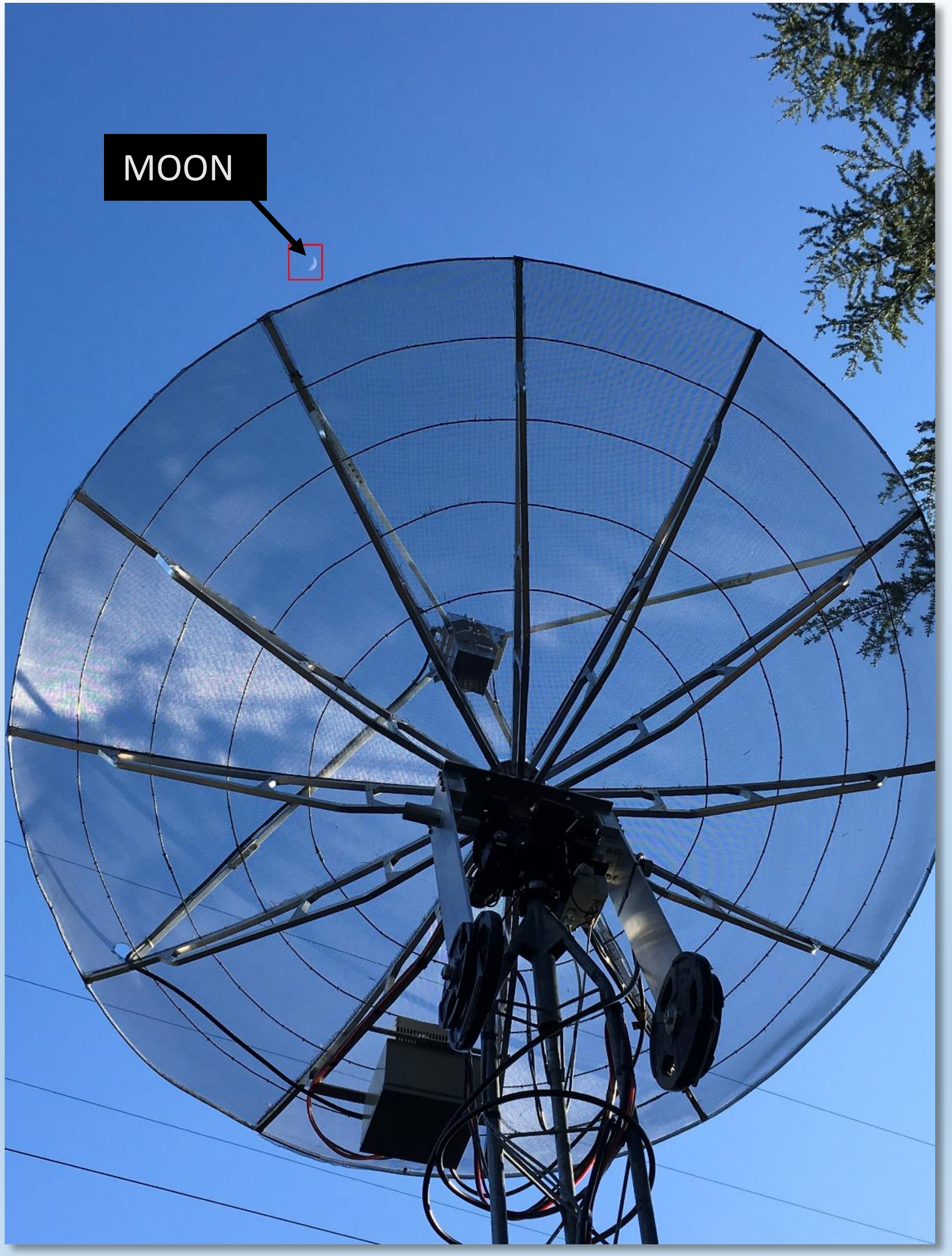
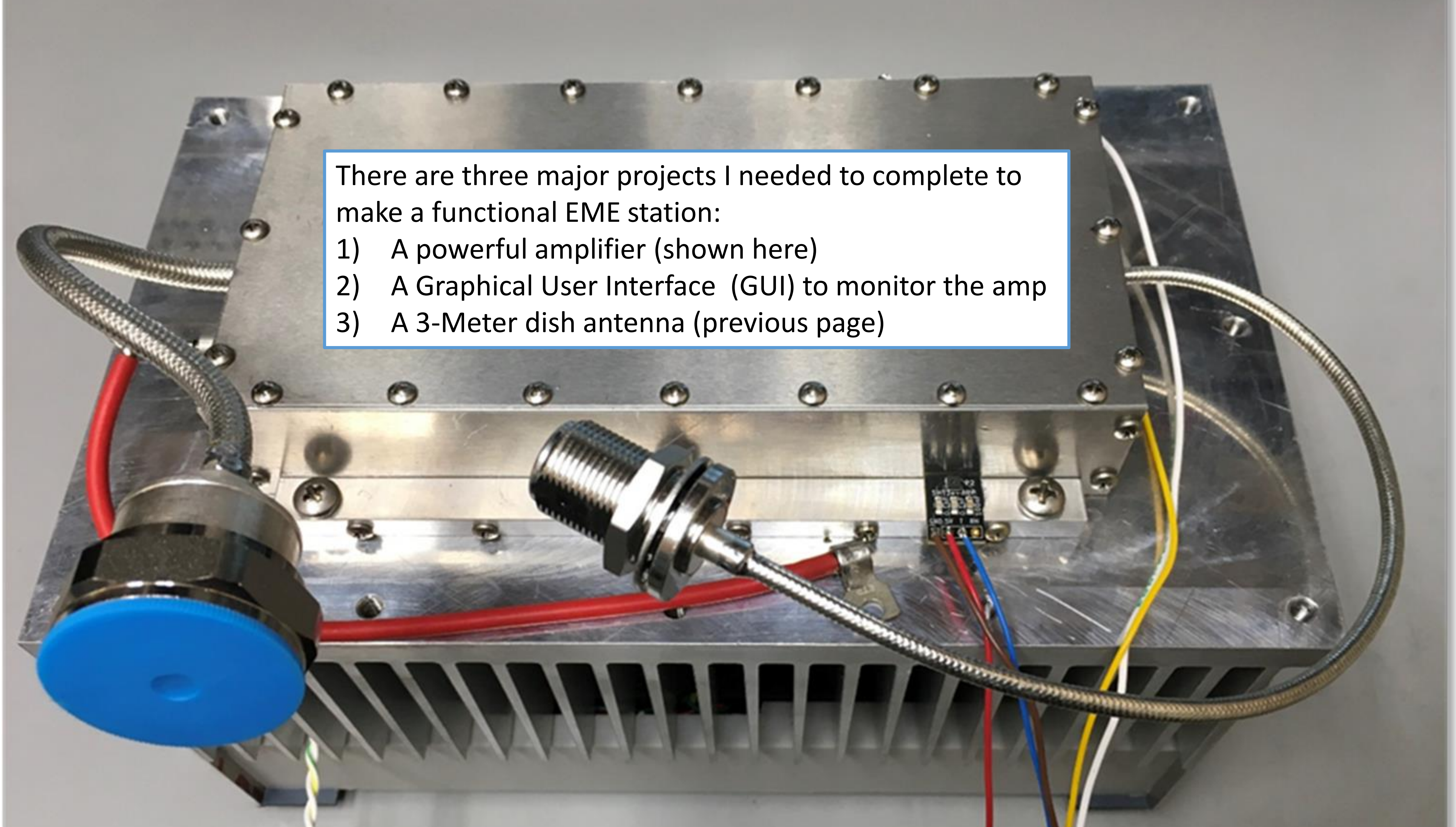


WA6HTP 23cm EME

Eight months ago I decided to communicate with other Amateur Radio operators by bouncing my signals off the Moon. They call this means of communication EME (Earth-Moon-Earth.)

As I'm writing this, the Moon is only two hundred and thirty thousand miles from Earth (I'm pointing to it in the picture.) At the speed of light my signals will take approximately 2.7 seconds to make the round trip. How hard could this possibly be?

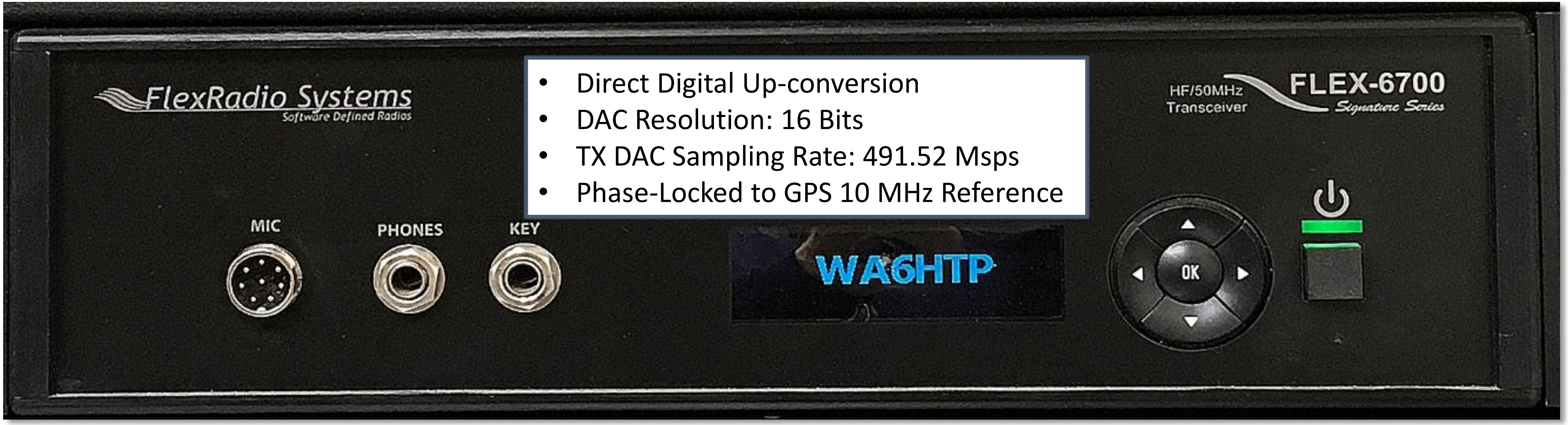


There are three major projects I needed to complete to make a functional EME station:

1) A powerful amplifier (shown here)
2) A Graphical User Interface (GUI) to monitor the amp
3) A 3-Meter dish antenna (previous page)

SSPA EXCITATION

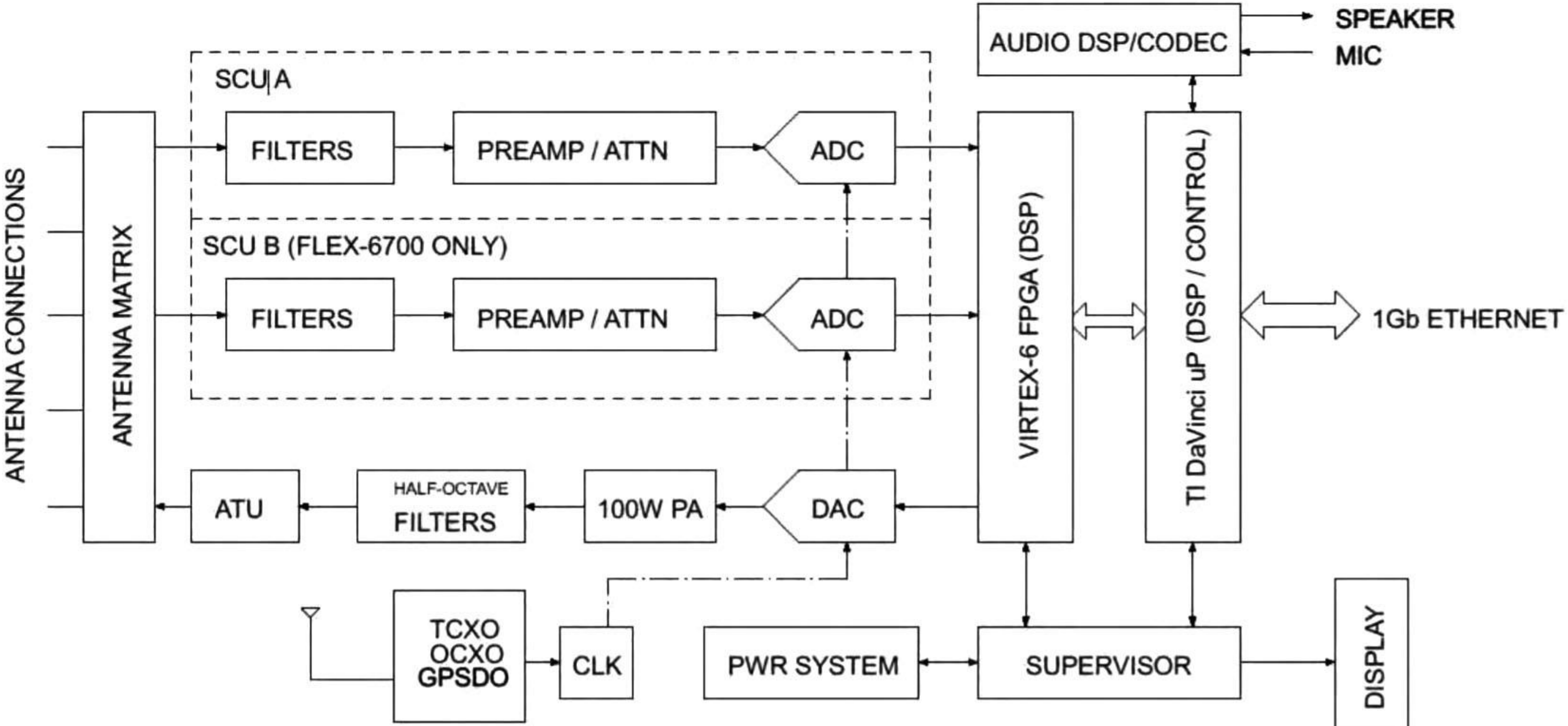
This next slide shows the equipment I am using to generate and receive signals on the 23 cm band (1296 MHz) My challenge was to build an amplifier to increase the strength of that signal enough to be able to bounce it off the moon and detect the echo. I need a LOT of POWER!!



- Direct Digital Up-conversion
- DAC Resolution: 16 Bits
- TX DAC Sampling Rate: 491.52 Msps
- Phase-Locked to GPS 10 MHz Reference

- Phase-Locked to 10 MHz Reference
- Max Output Power: 18W

Flex-6700 DSP Transceiver Block Diagram

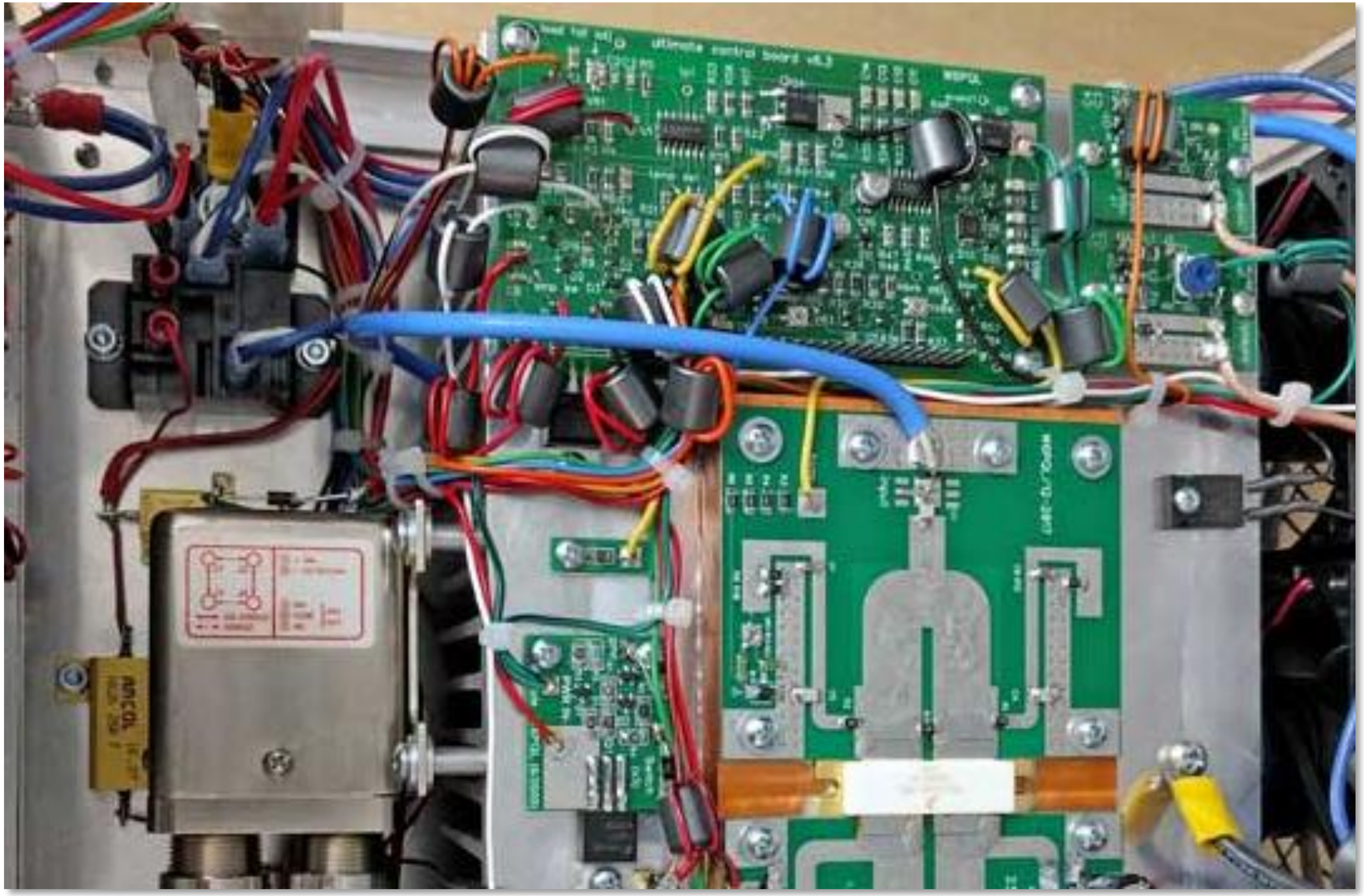


23cm, 600-Watt SSPA

SSPA stands for “Solid State Power Amplifier”. I’ll be using some building blocks that are manufactured by a local Ham, W6PQL. Although I used his LDMOS amplifier module and controller, there was a lot that I had to deal with myself…

The SSPA uses this single solid state device called an LDMOS. In the past it would have required a big vacuum tube.

W6PQL SSPA Components



LDMOS AMP

- Amp
- Heat Spreader
- ***HEAT SINK***

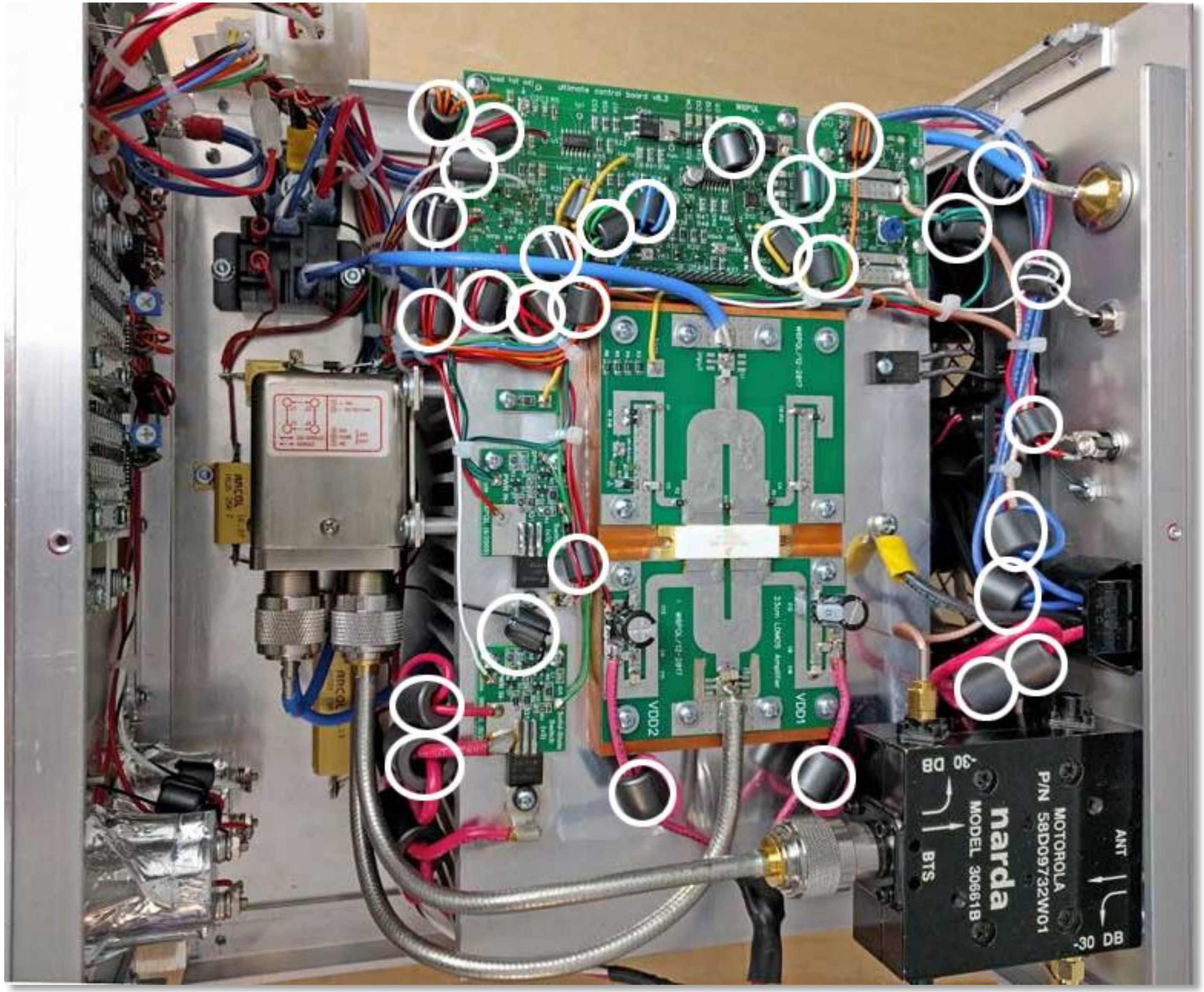
CONTROLLER

- Bias
- 12 VDC
- Fan Control
- High VSWR Shut Down
- Sequencing

FET SWITCHES

- DC Power to LDMOS Amp
- LNA Relay

EMI (Electromagnetic Interference)



Although I was extremely happy with W6PQL's LDMOS amplifier subassembly and his Controller, I wanted to take a different approach to construction.

The amplifier creates an intense electromagnetic field and that field can cause problems for sensitive circuitry. He used many toroids to try to reduce EMI.

EMI

There are four areas that must be considered when dealing with EMI. I list them on the nect slide. The two most common approaches in use are Shielding to deal with radiation, and filtering to deal with conducted EMI propagating through signal and power wiring.

Electromagnetic Interference (EMI)

RADIATED EMISSION

- Radiated emission is the electromagnetic energy propagated through space. The noise is subsequently transferred to susceptible equipment.

CONDUCTED EMISSION

- Conducted emissions are internal electromagnetic emissions propagated along a power or signal conductor, creating noise. The noise is subsequently transferred to susceptible equipment.

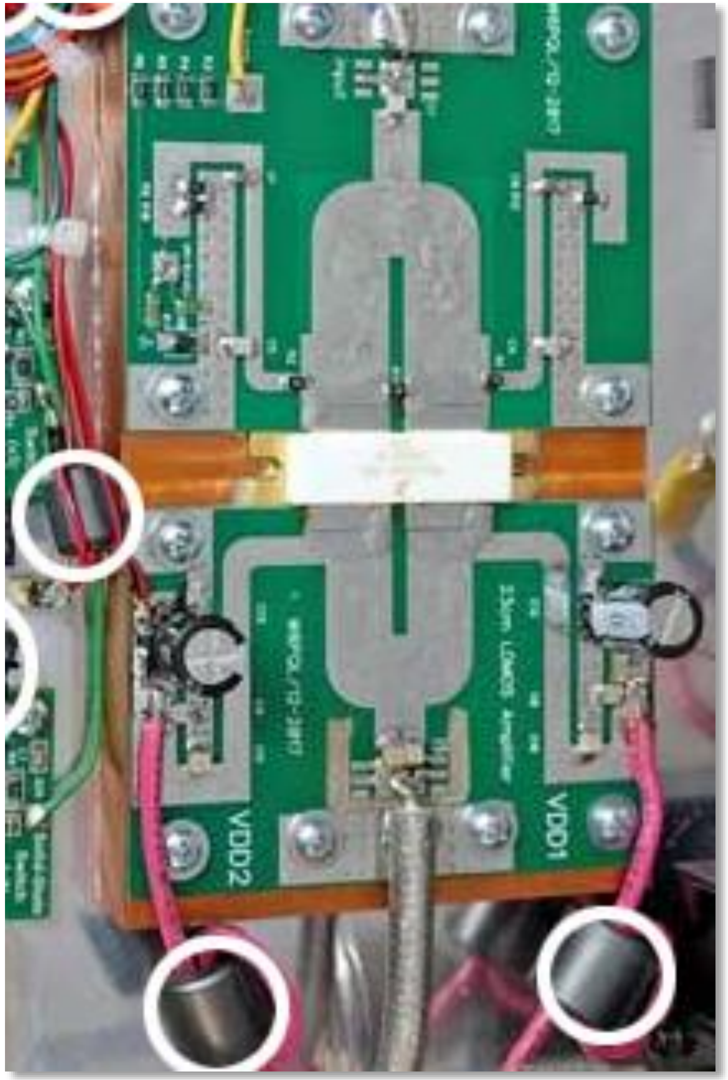
RADIATED SUSCEPTIBILITY

- A device's ability to operate in the presence of an external interference signal propagated via free space.

CONDUCTED SUSCEPTIBILITY

- A device's ability to operate in the presence of an external interference signal propagated via a conductor.

W6PQL EMI Mitigation Using Toroids



CONDUCTED EMISSIONS

- 2 Chokes on VDD
- 1 Choke on Bias

RADIATED EMISSIONS

- *Lid Lined with RF Absorbent Material*

Energy radiating from this amplifier board can couple back into these lines on the other side of the chokes!

Conducted Emissions

LC (Pi) EMI Filter

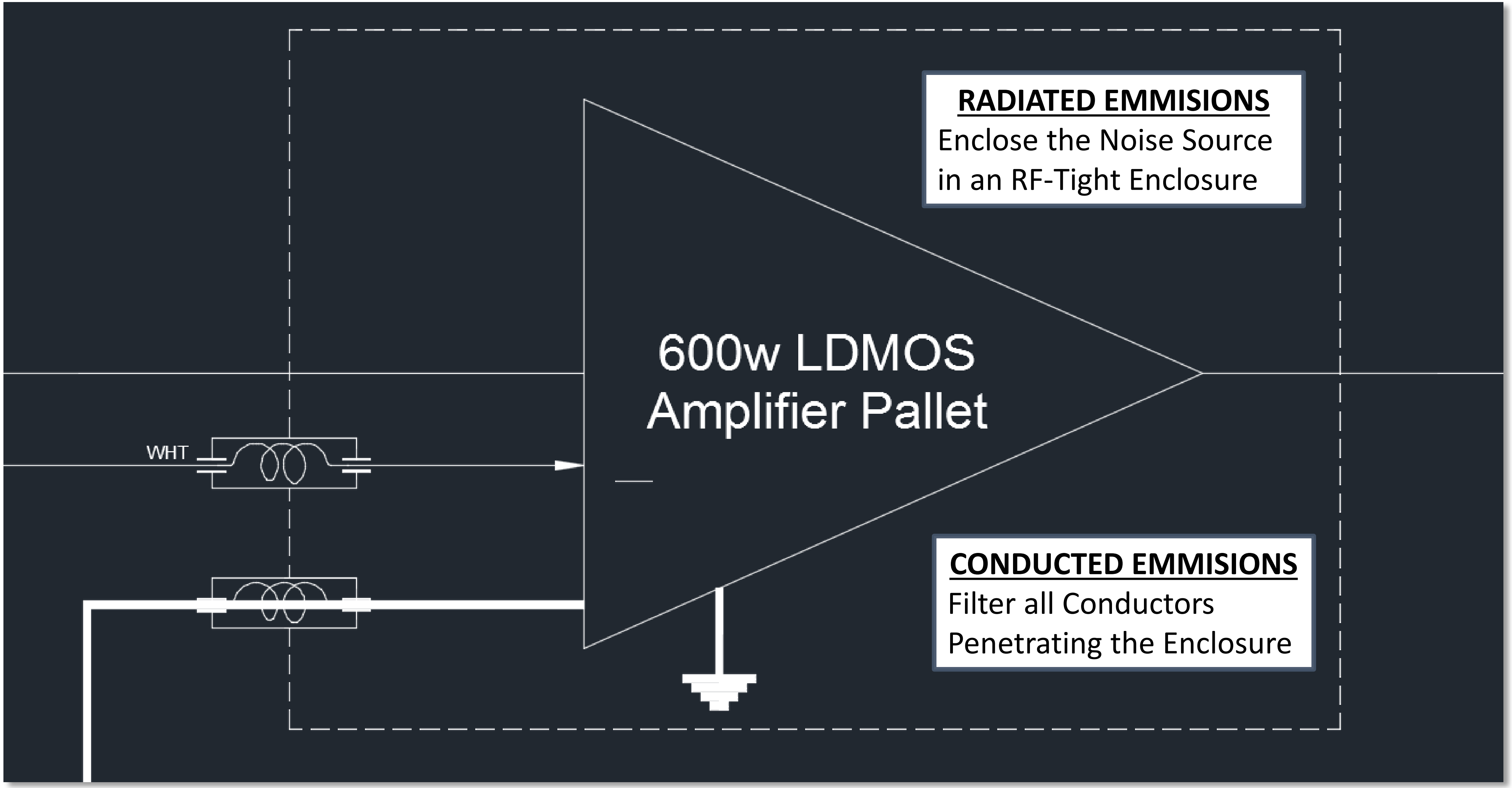
3rd Order Low Pass

This is a common type of EMI filter that can allow a signal or power wire to pass through a shielded enclosure. Drill a hole, screw it in, and solder the wires to each end!

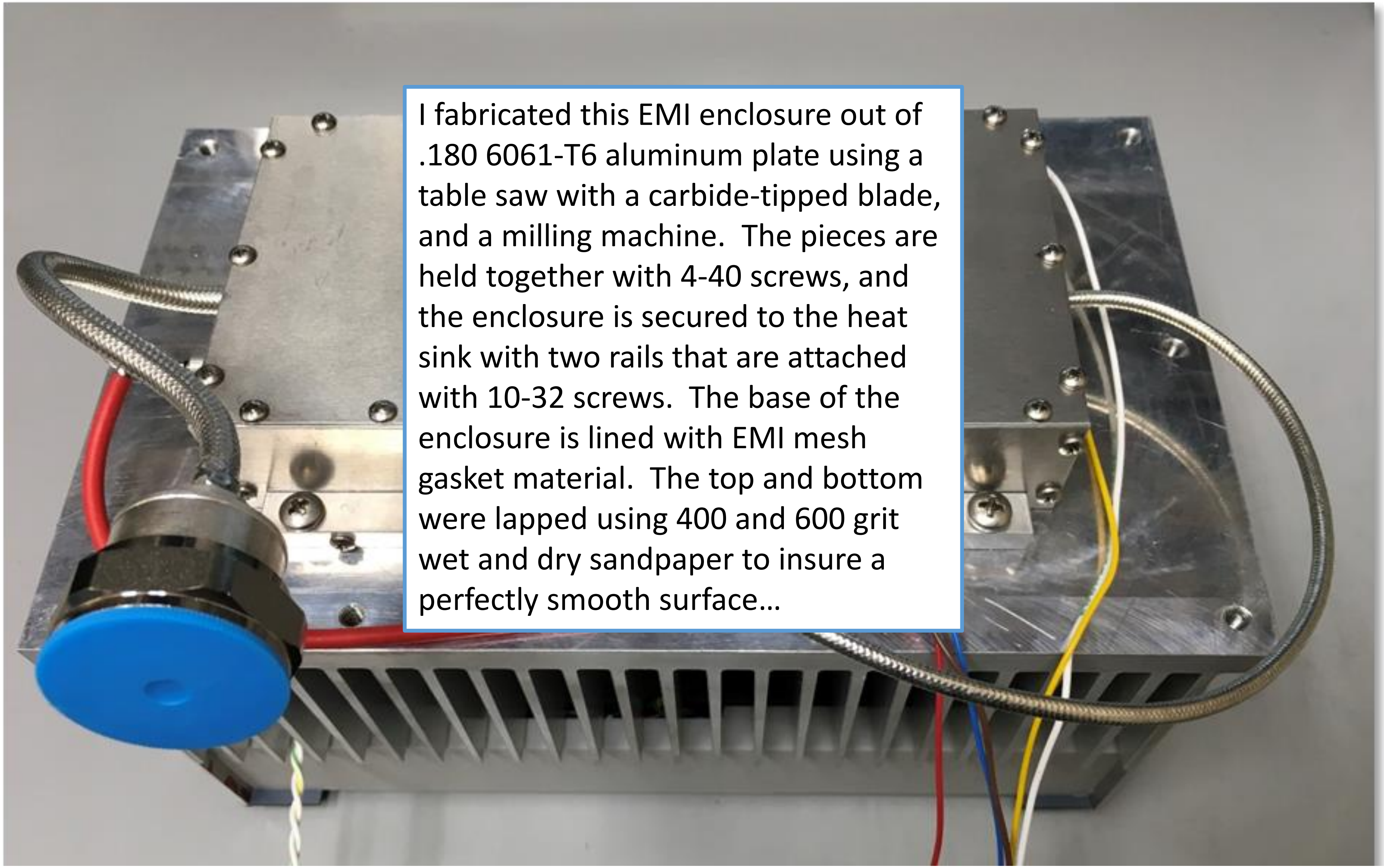
70 dB of attenuation at 1 GHz!

5500	350	100	10 A	I.R. MIN. @ 100 (VDC.)	DWV	20	65	70	70
	85°C	125 °C				10 MHz	100 MHz	1 GHz	10 GHz
MIN. CAP. (pF)	WORKING VOLTAGE (WVdc)		CURRENT IDC	10 G Ω	700 vdc	MINIMUM NO LOAD INSERTION LOSS (dB) AT 25°C PER MIL-STD -220			

EMI Suppression – Shielding and Filtering

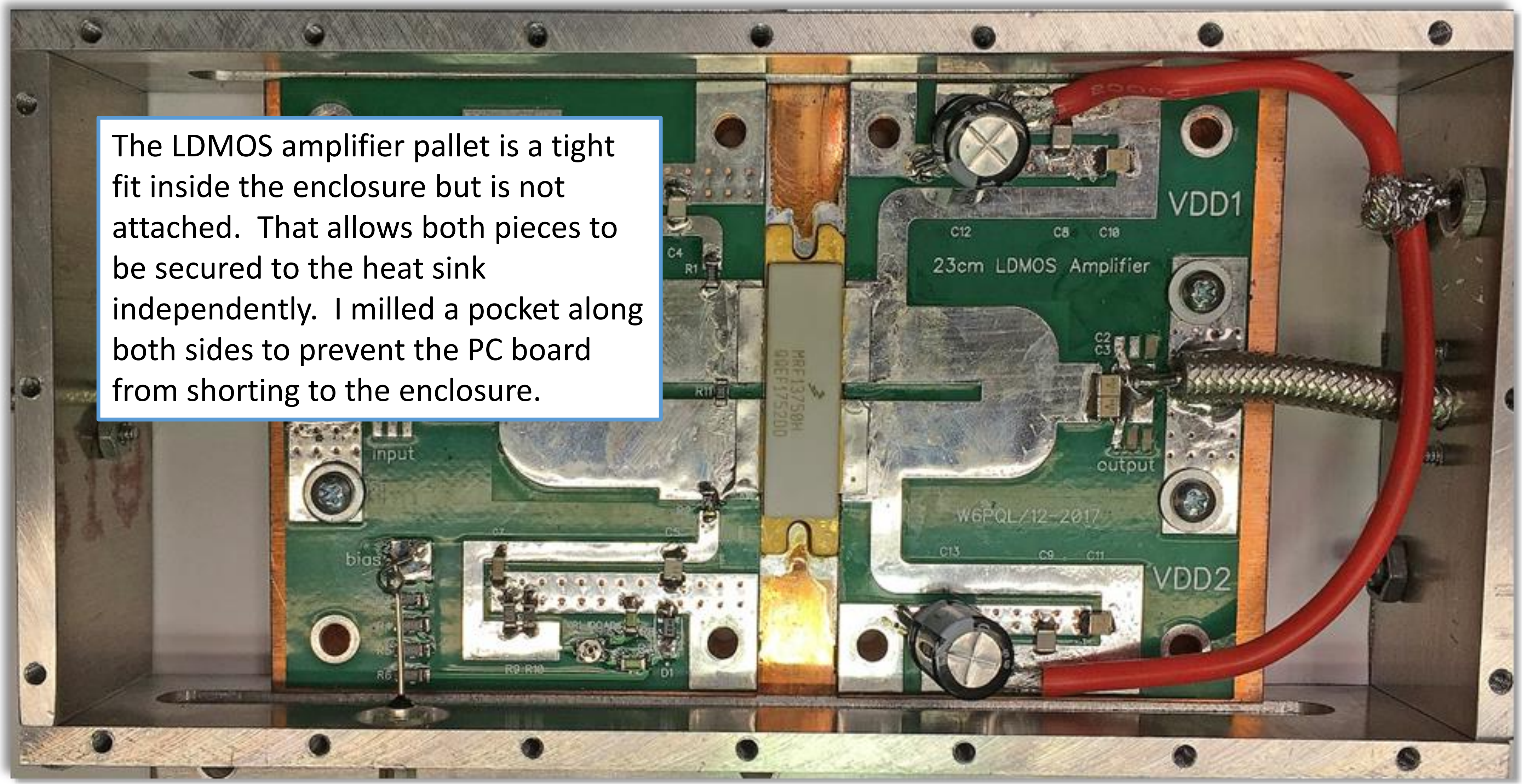


EMI Enclosure



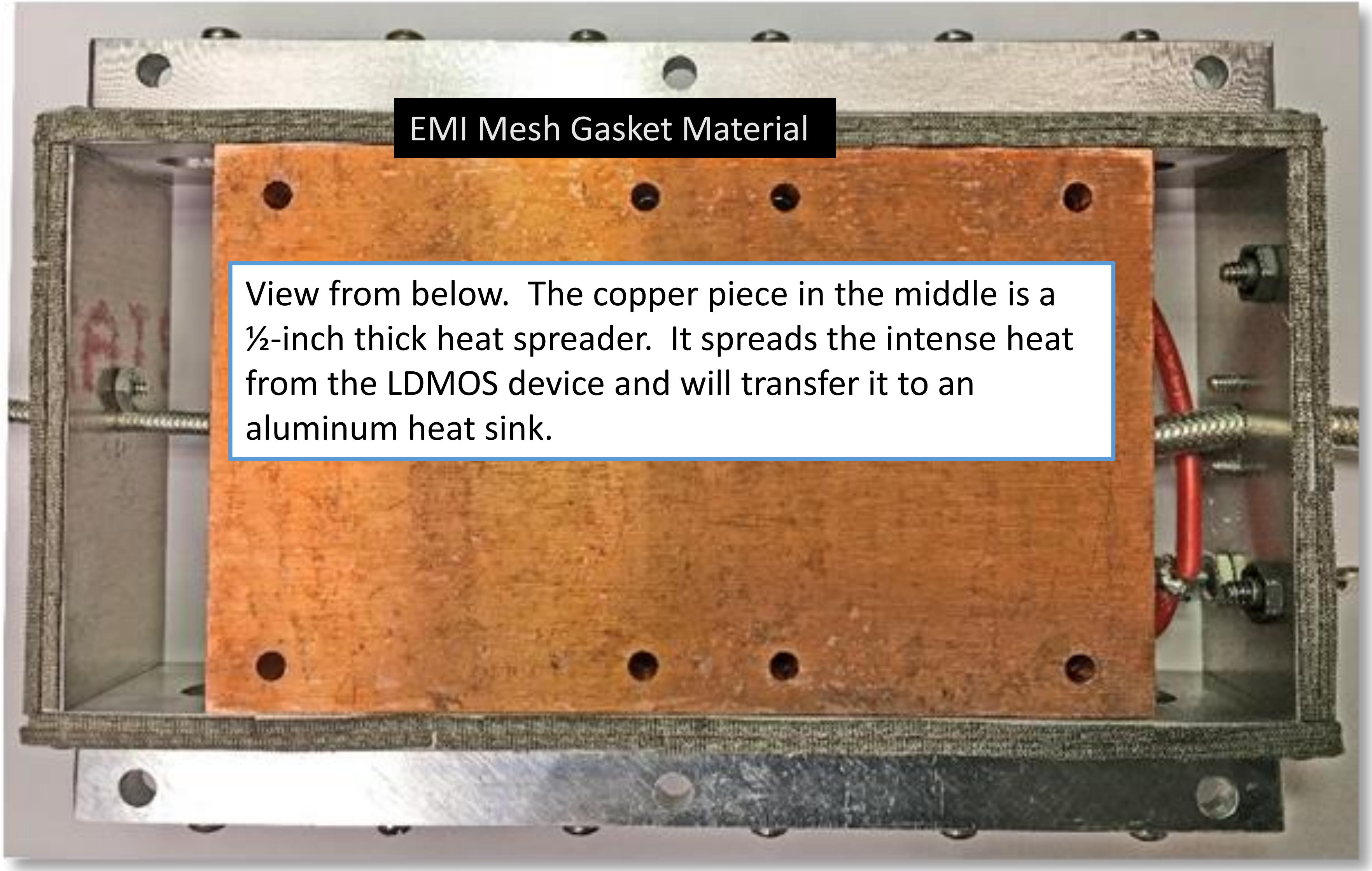
I fabricated this EMI enclosure out of .180 6061-T6 aluminum plate using a table saw with a carbide-tipped blade, and a milling machine. The pieces are held together with 4-40 screws, and the enclosure is secured to the heat sink with two rails that are attached with 10-32 screws. The base of the enclosure is lined with EMI mesh gasket material. The top and bottom were lapped using 400 and 600 grit wet and dry sandpaper to insure a perfectly smooth surface…

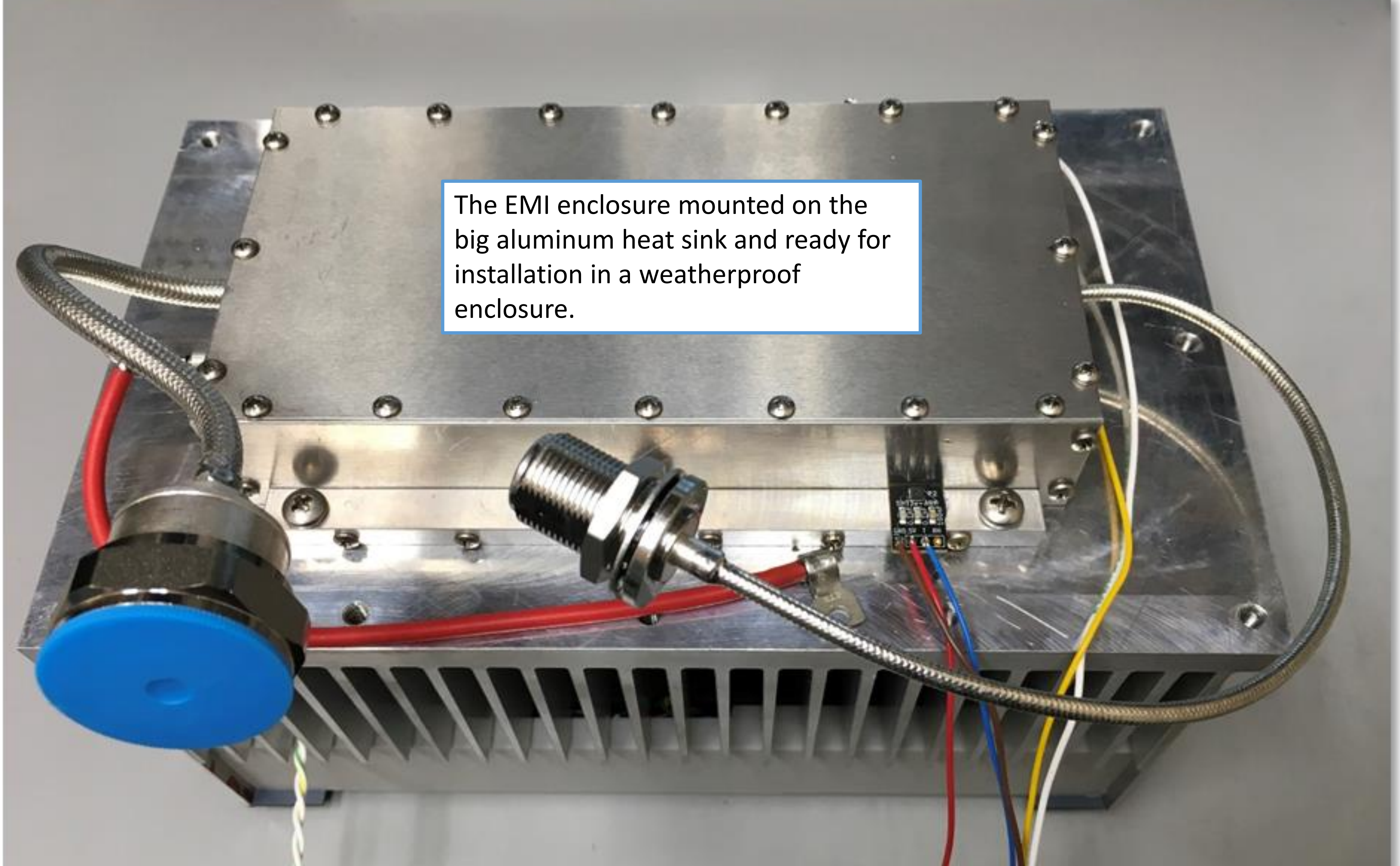
LDMOS Amplifier with EMI Enclosure



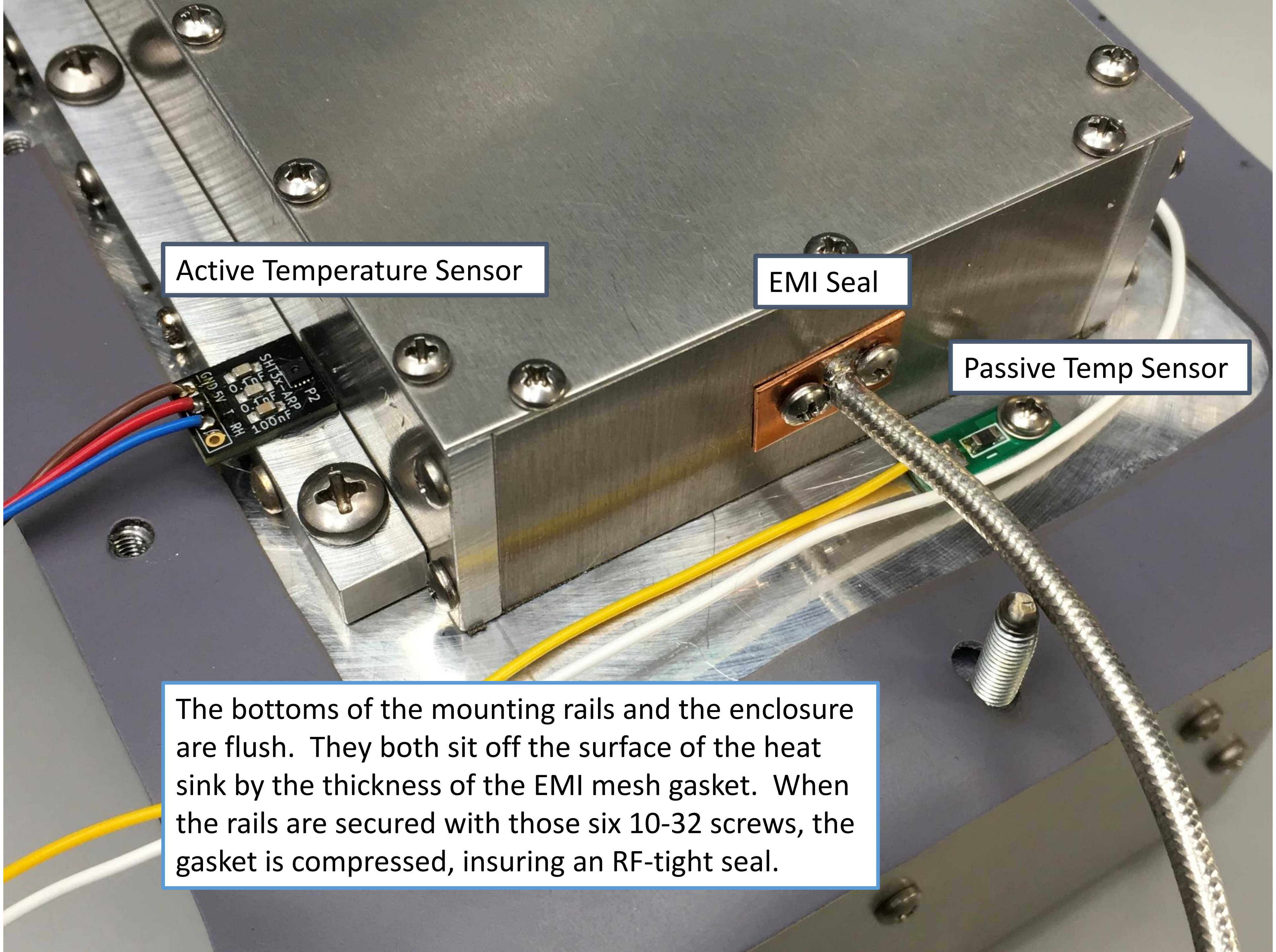
The LDMOS amplifier pallet is a tight fit inside the enclosure but is not attached. That allows both pieces to be secured to the heat sink independently. I milled a pocket along both sides to prevent the PC board from shorting to the enclosure.

Bottom View of EMI Enclosure



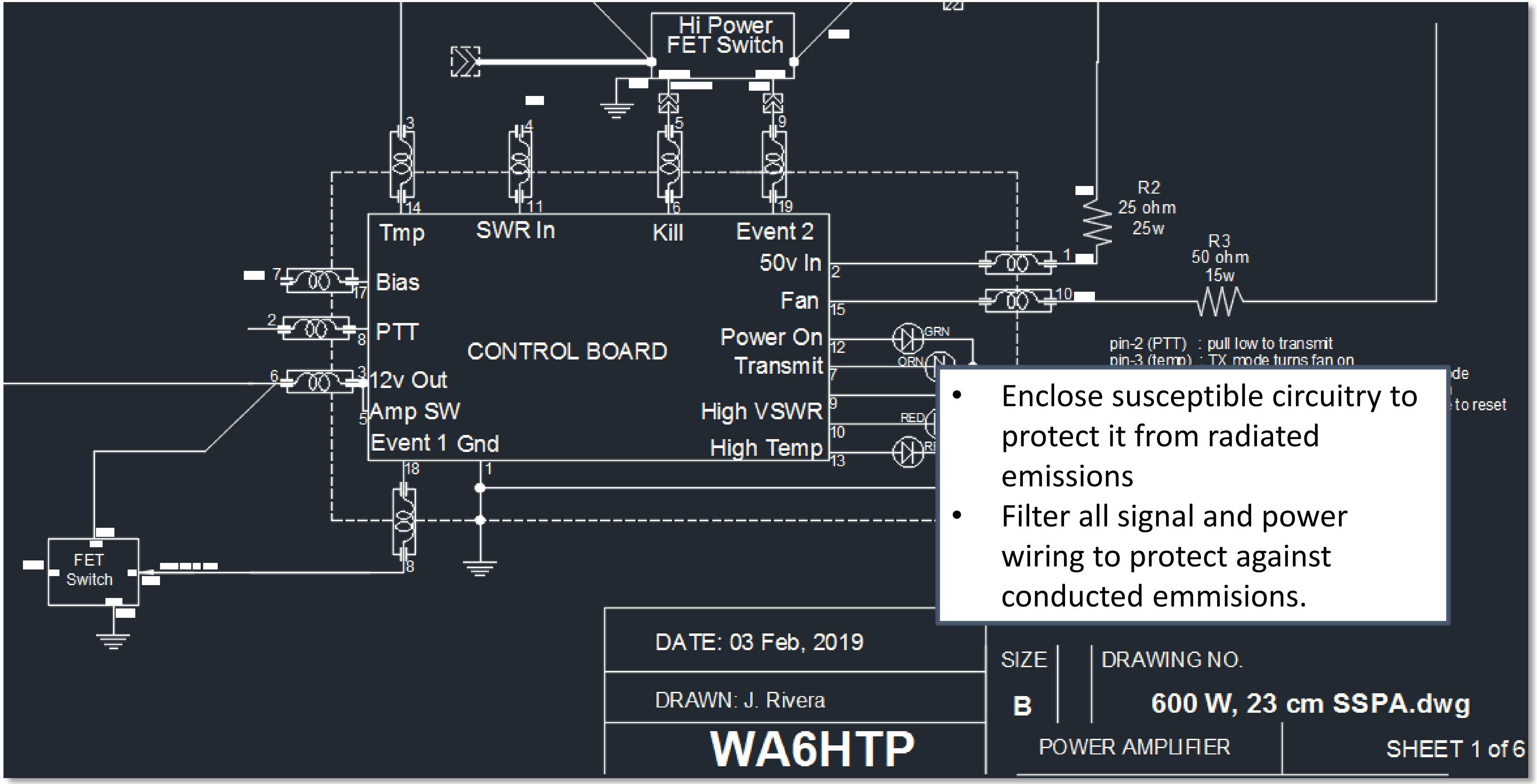


The EMI enclosure mounted on the big aluminum heat sink and ready for installation in a weatherproof enclosure.



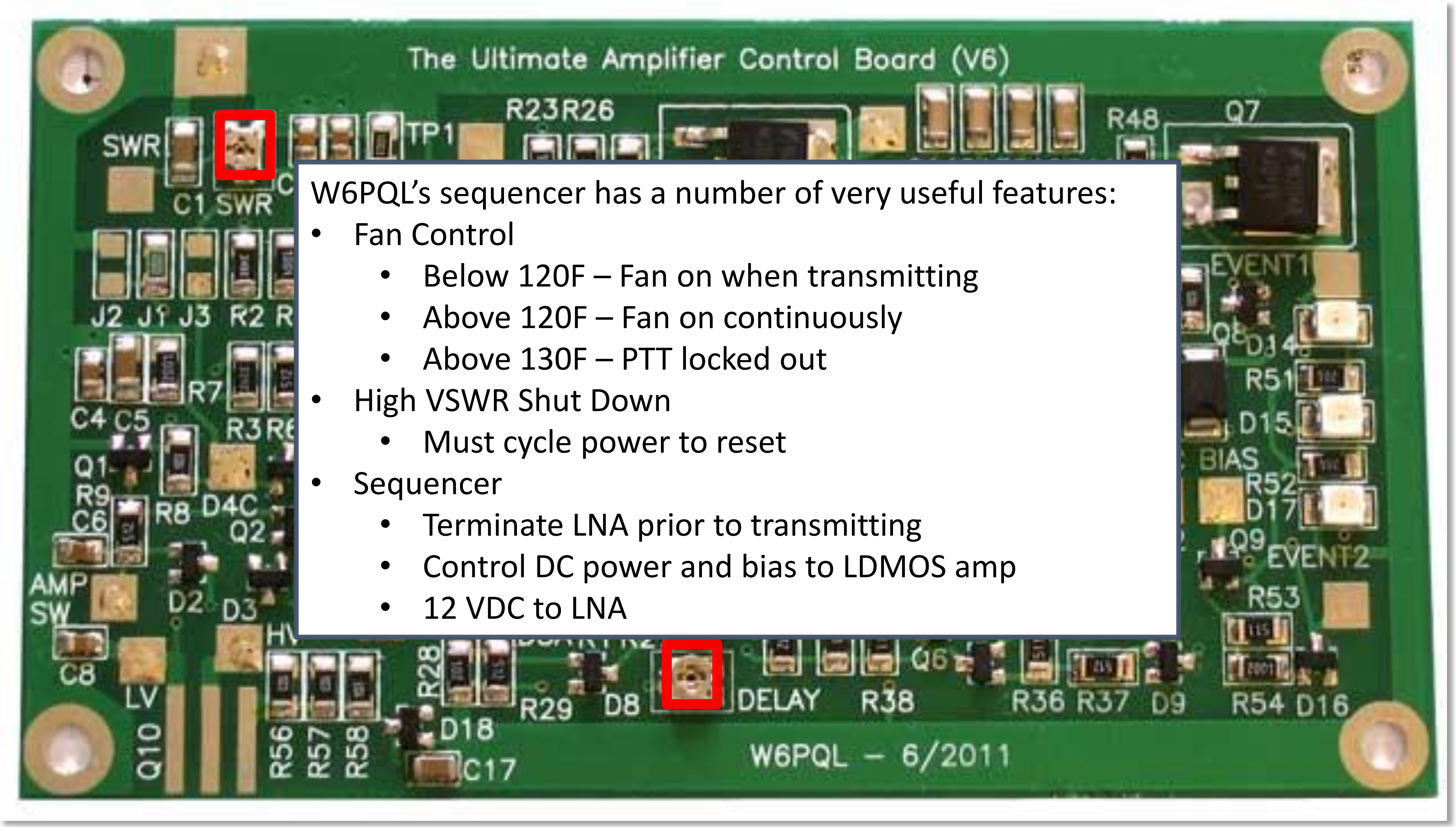
The bottoms of the mounting rails and the enclosure are flush. They both sit off the surface of the heat sink by the thickness of the EMI mesh gasket. When the rails are secured with those six 10-32 screws, the gasket is compressed, insuring an RF-tight seal.

EMI Susceptibility (Analog Control Board)



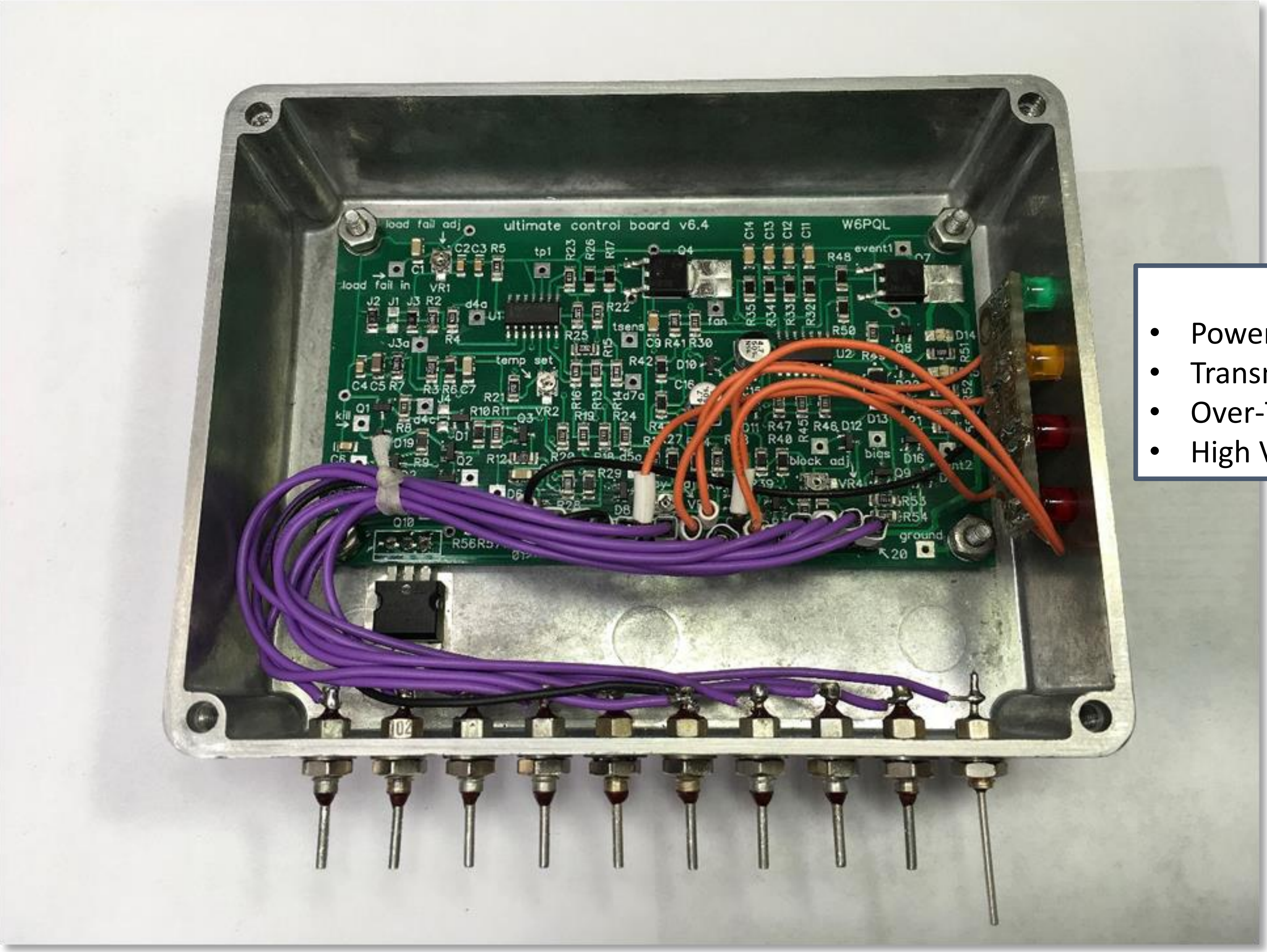
- Enclose susceptible circuitry to protect it from radiated emissions
- Filter all signal and power wiring to protect against conducted emmisions.

W6PQL Analog Control / Sequencer Board



W6PQL's sequencer has a number of very useful features:

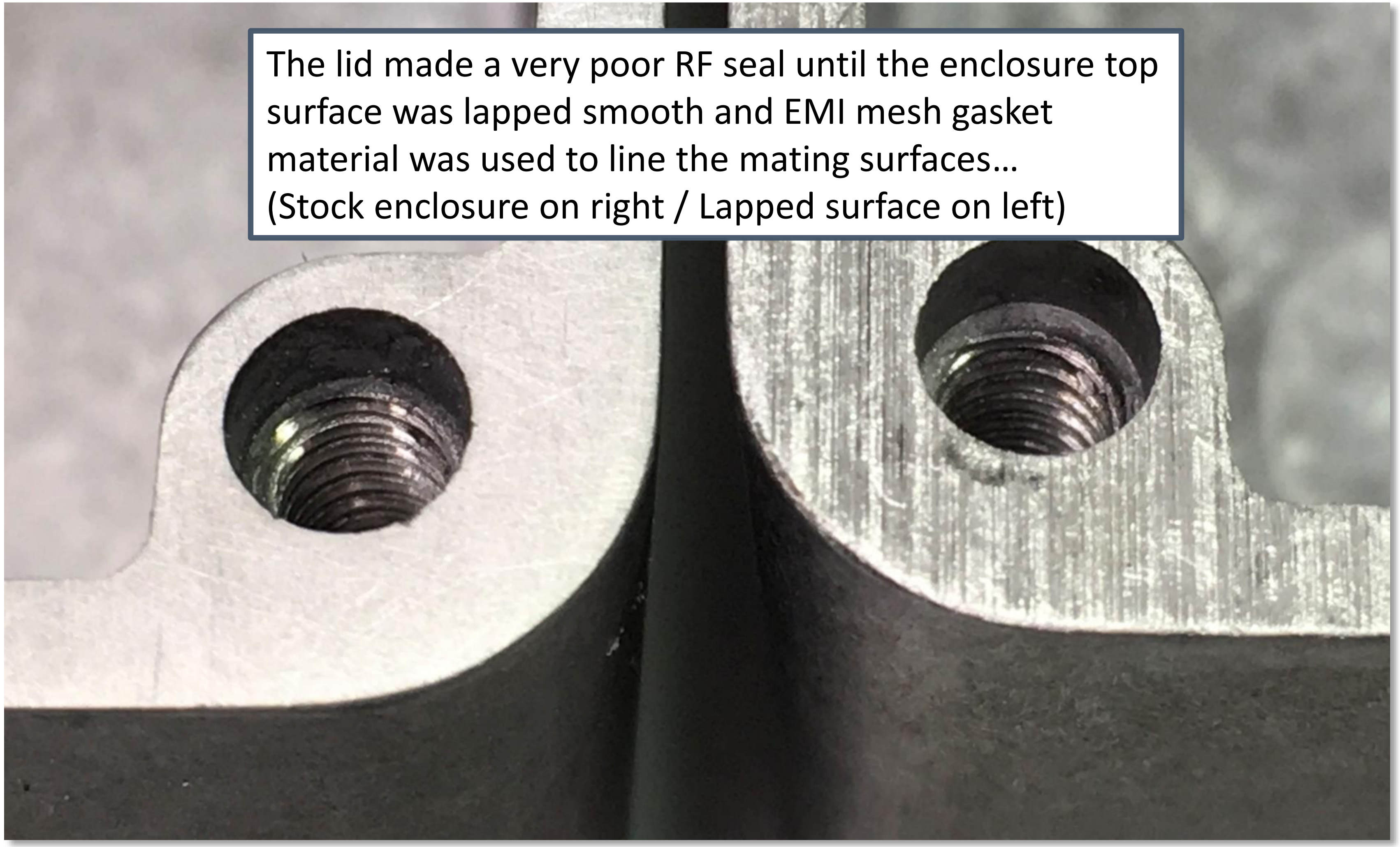
- Fan Control
  - Below 120F – Fan on when transmitting
  - Above 120F – Fan on continuously
  - Above 130F – PTT locked out
- High VSWR Shut Down
  - Must cycle power to reset
- Sequencer
  - Terminate LNA prior to transmitting
  - Control DC power and bias to LDMOS amp
  - 12 VDC to LNA



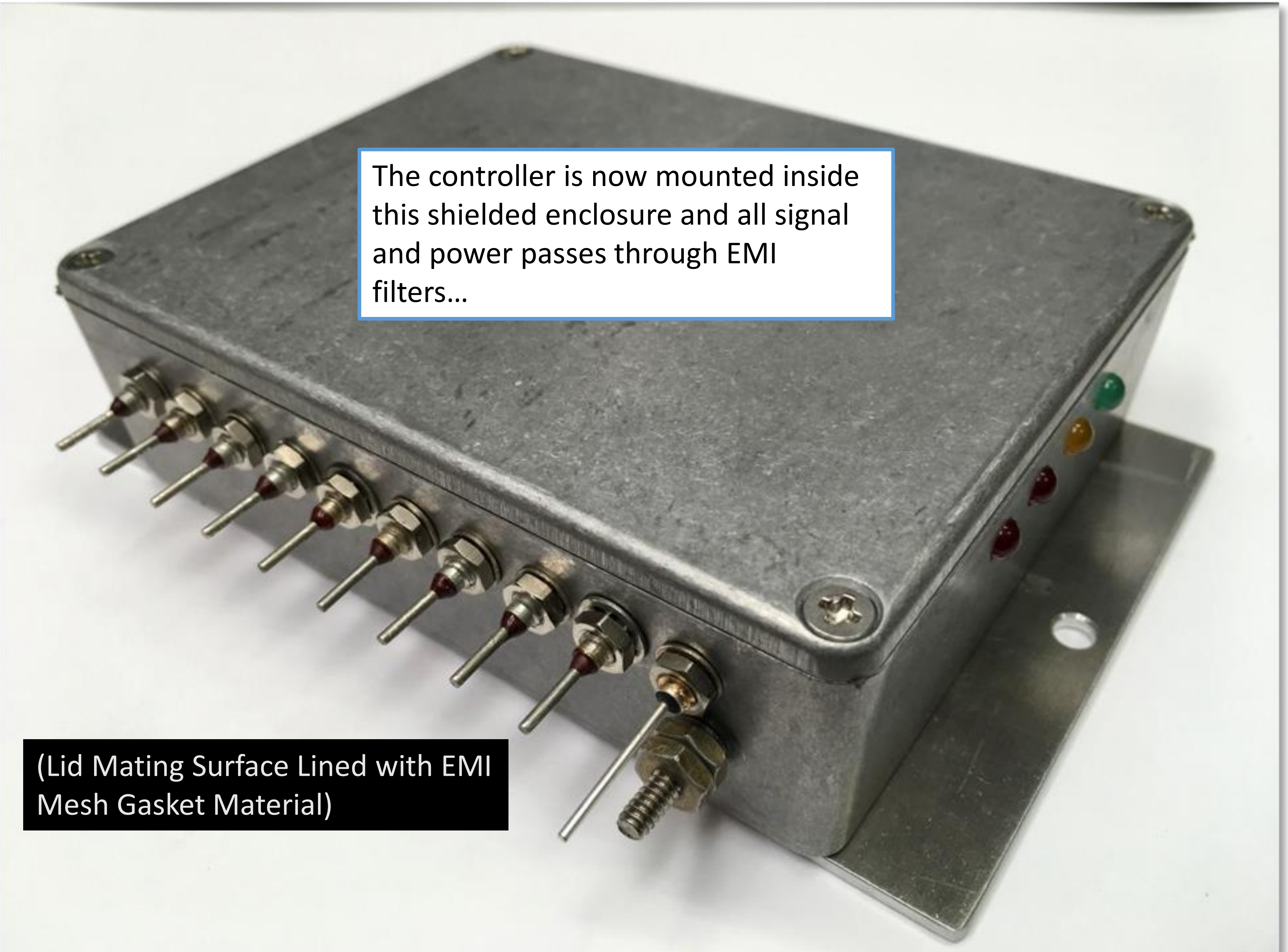
4 LED’s:

- Power
- Transmit
- Over-Temperature
- High VSWR Shutdown

Lapped Enclosure Surface

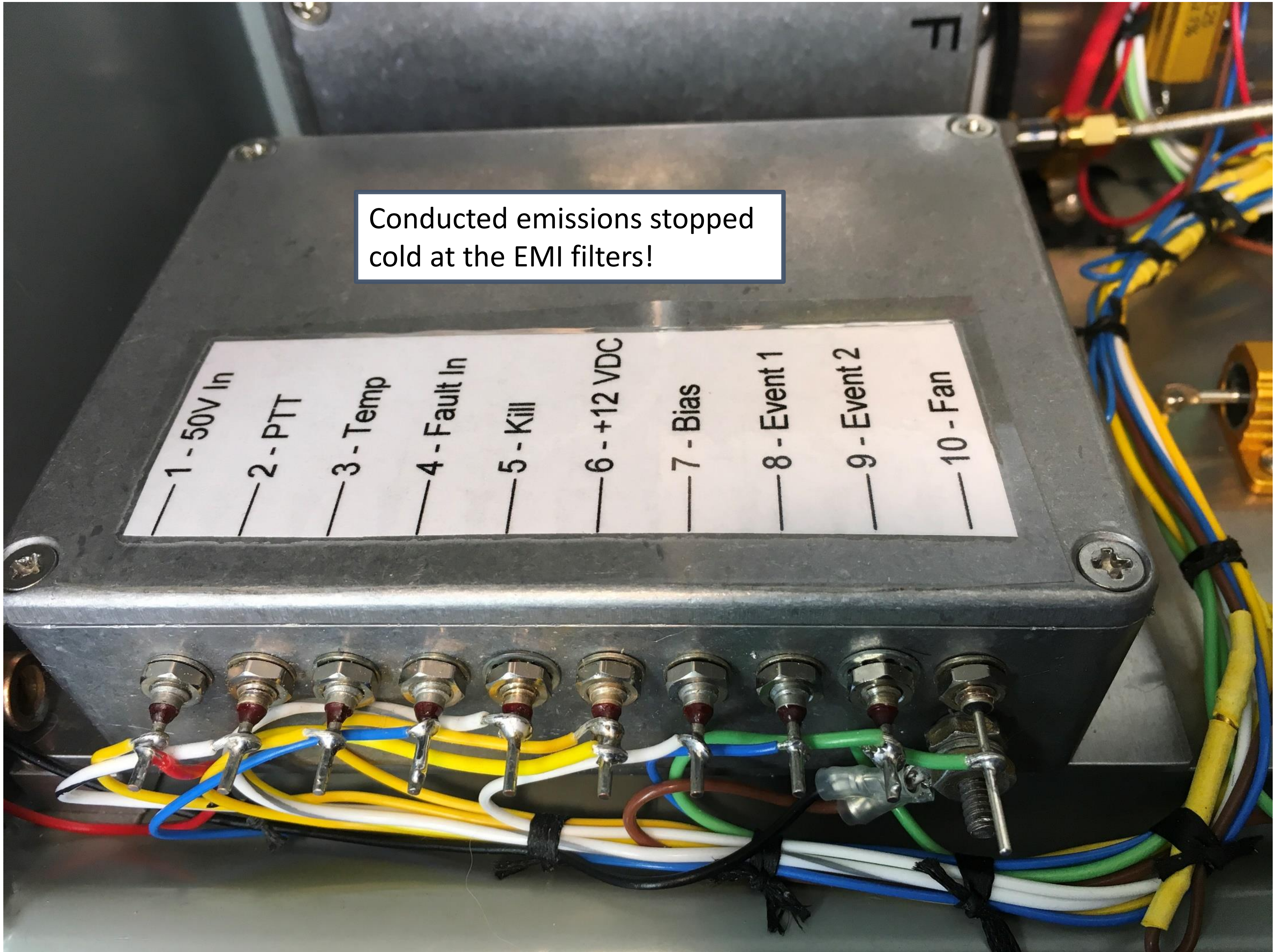


The lid made a very poor RF seal until the enclosure top surface was lapped smooth and EMI mesh gasket material was used to line the mating surfaces…
(Stock enclosure on right / Lapped surface on left)



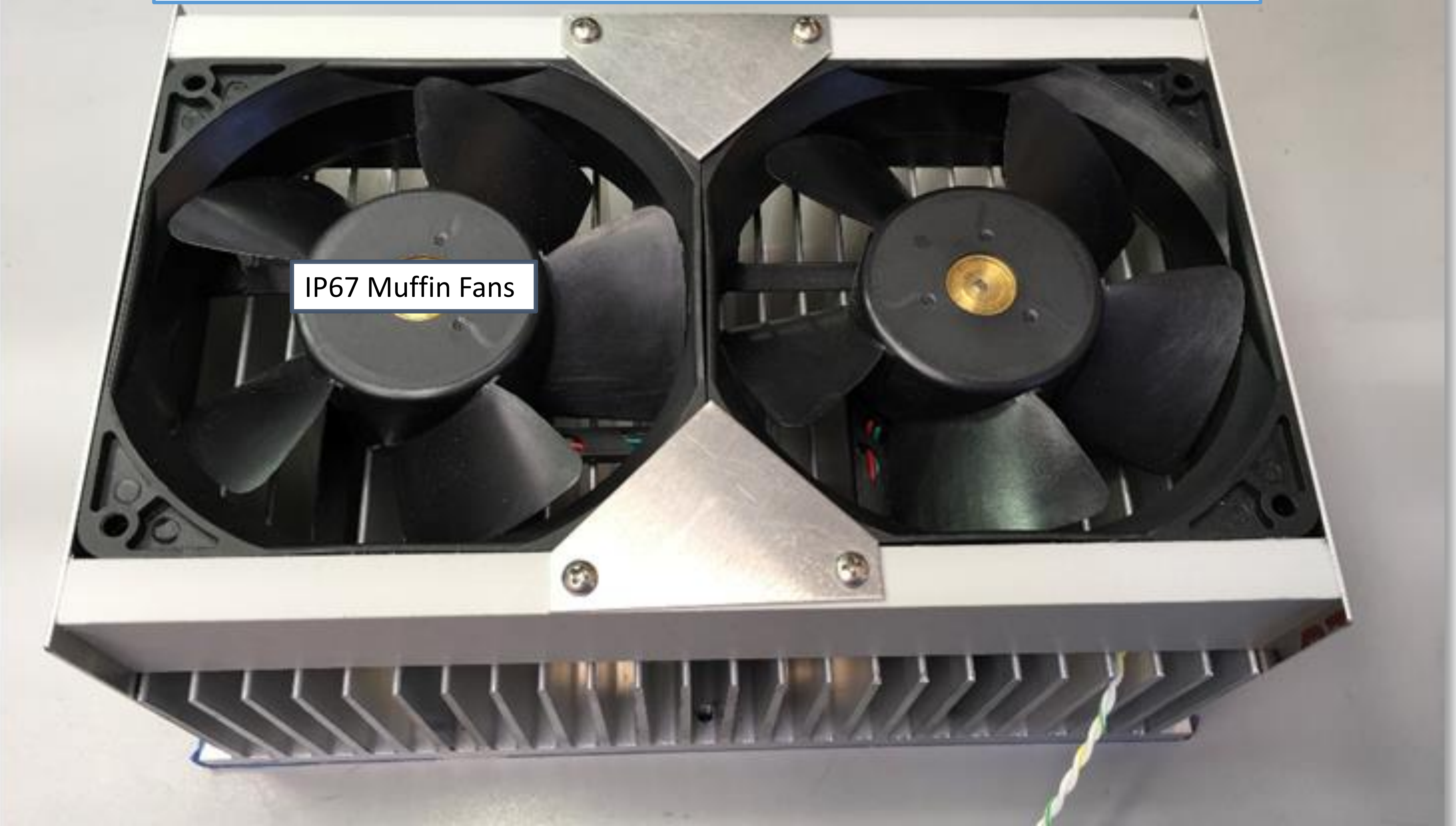
The controller is now mounted inside this shielded enclosure and all signal and power passes through EMI filters…

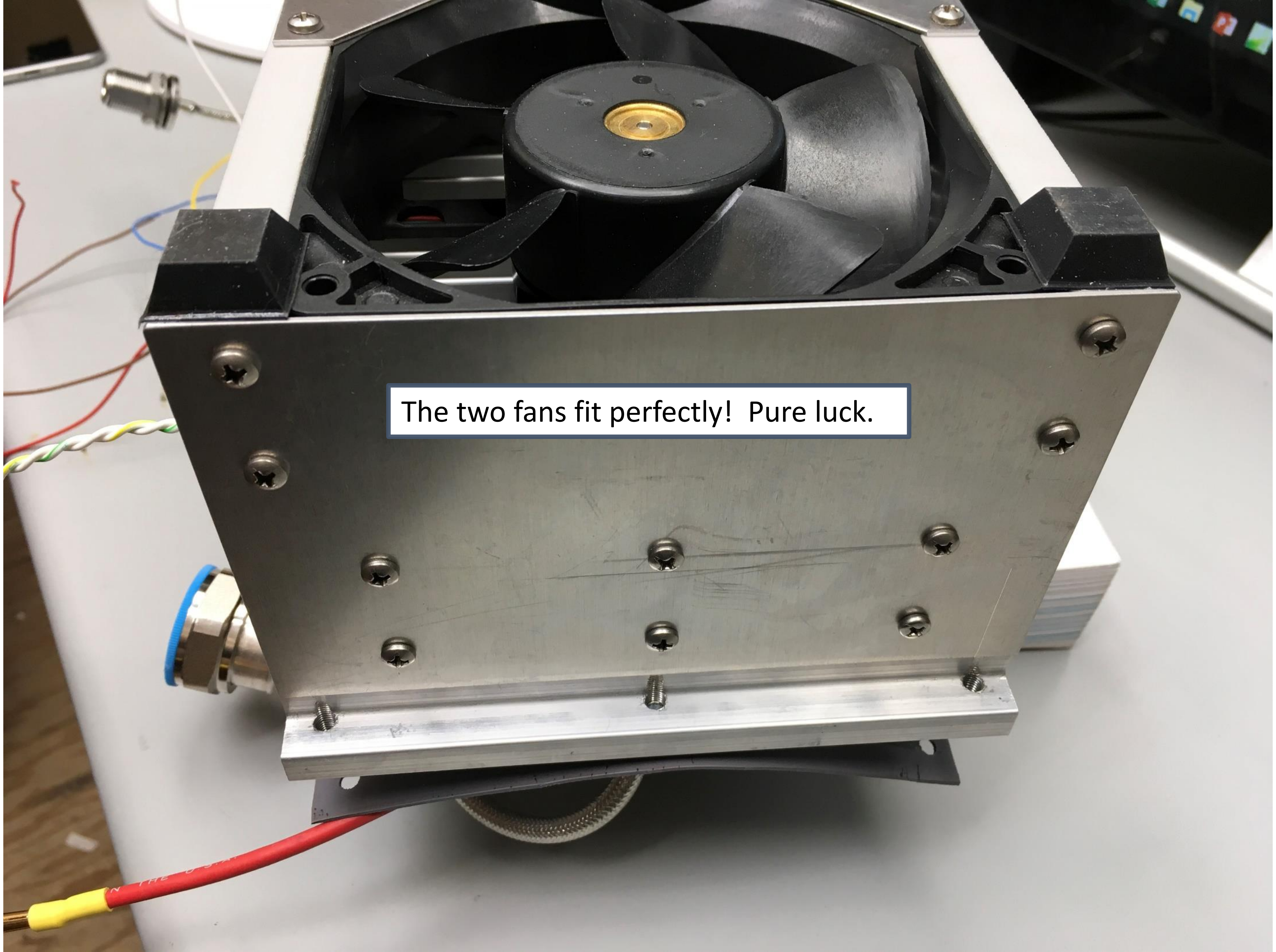
(Lid Mating Surface Lined with EMI Mesh Gasket Material)

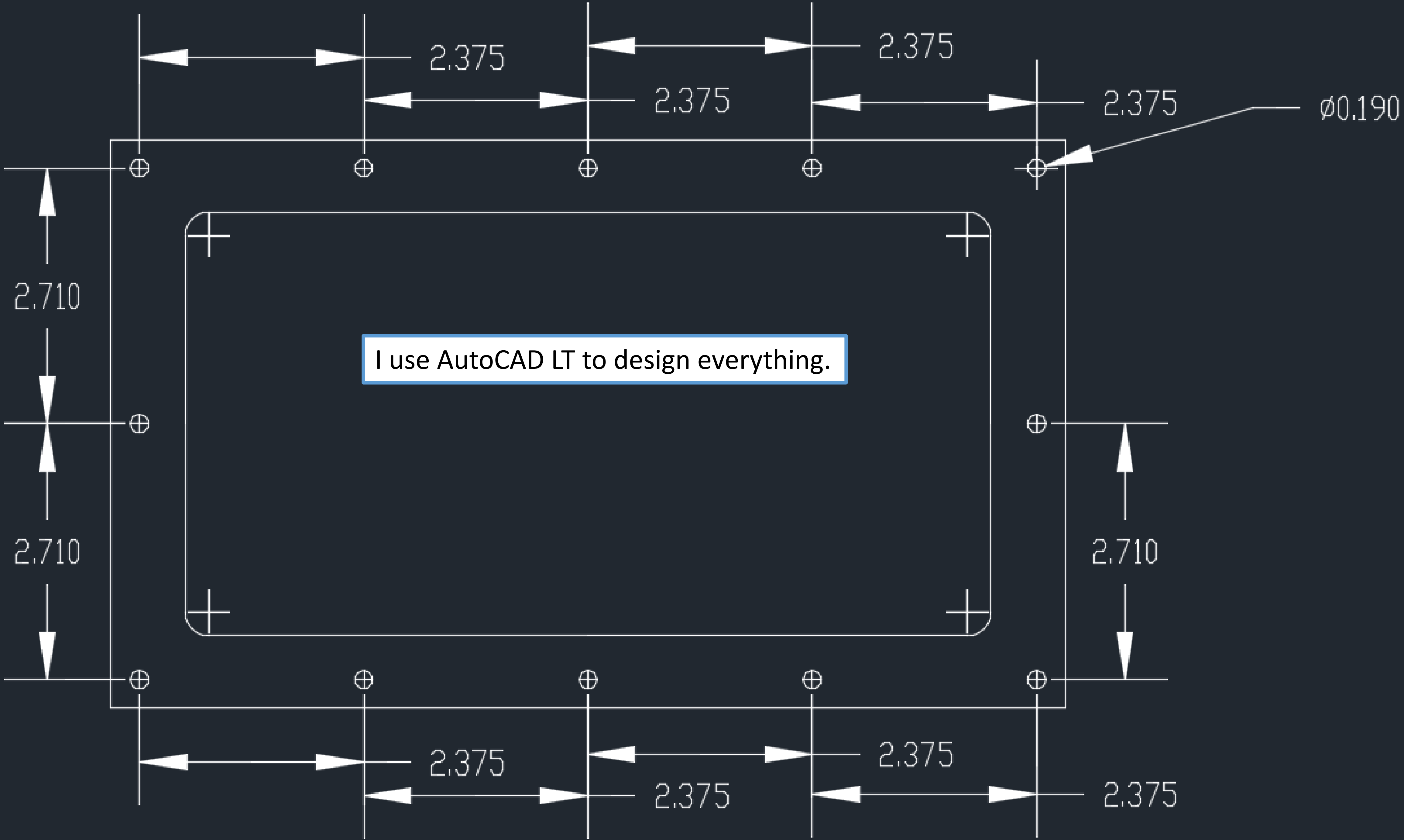


Conducted emissions stopped cold at the EMI filters!

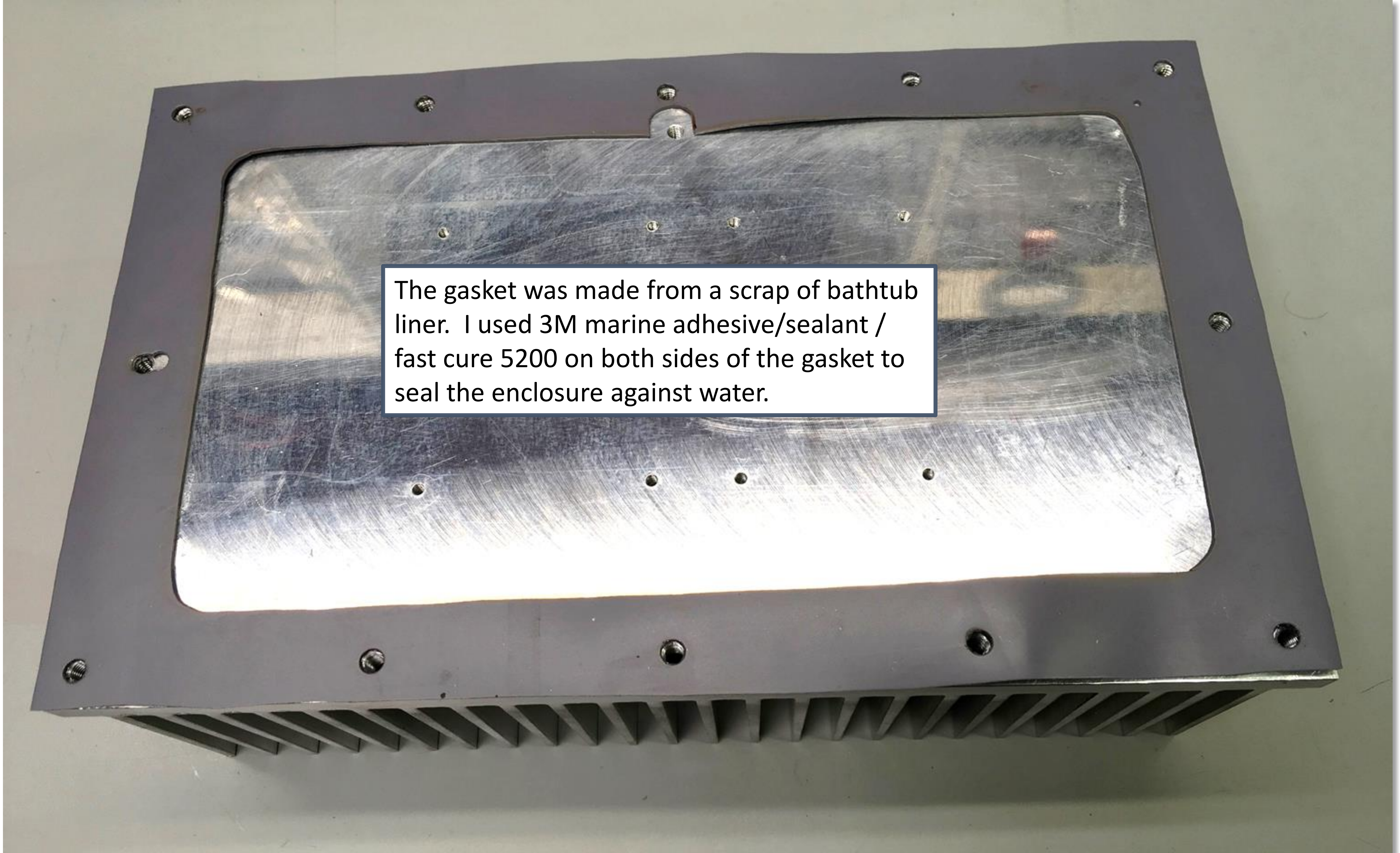
The heat sink is on the outside of the enclosure and exposed to the elements. These fans are rated to take a hose-directed stream of water without a problem.




The two fans fit perfectly! Pure luck.

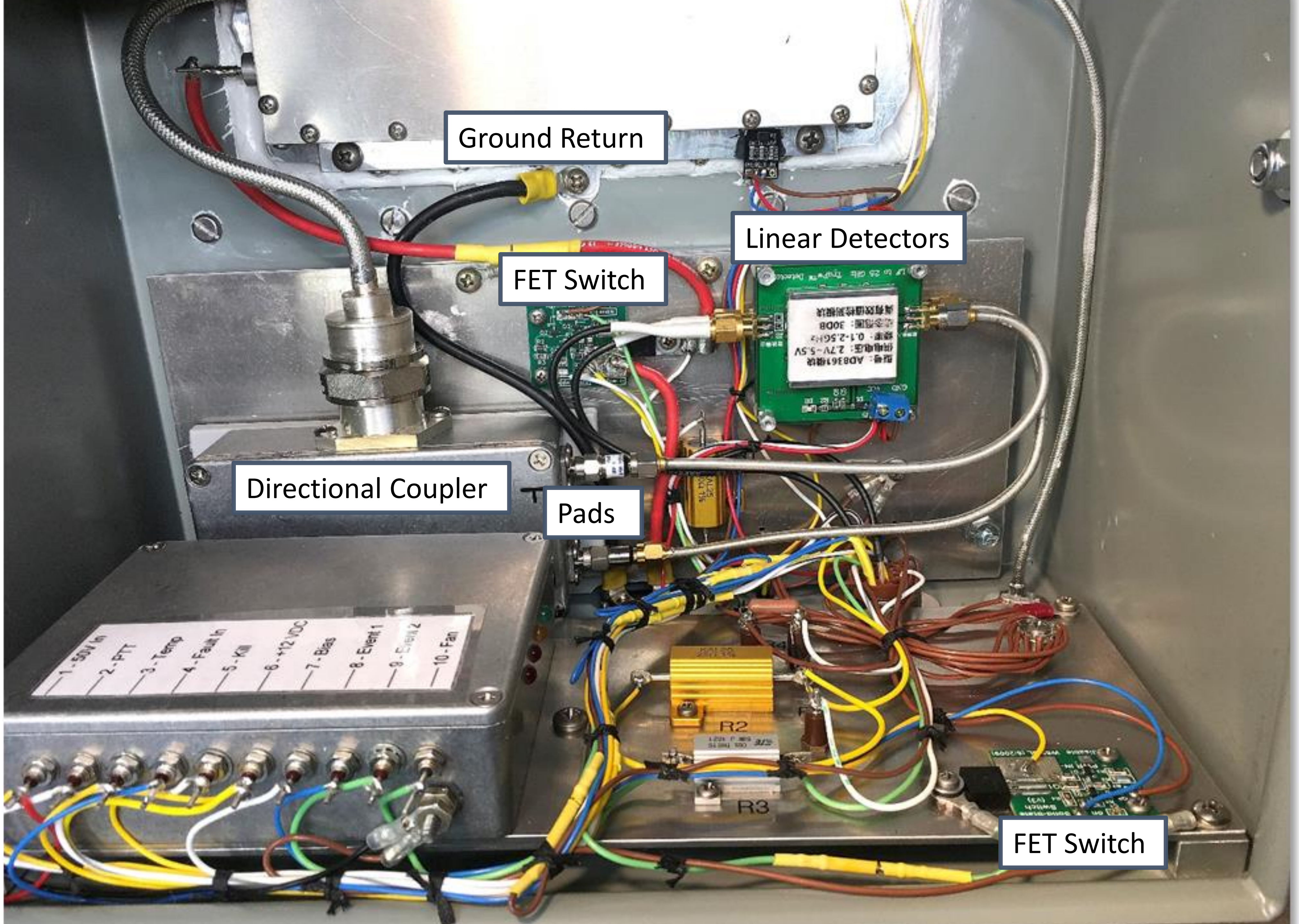


I use AutoCAD LT to design everything.



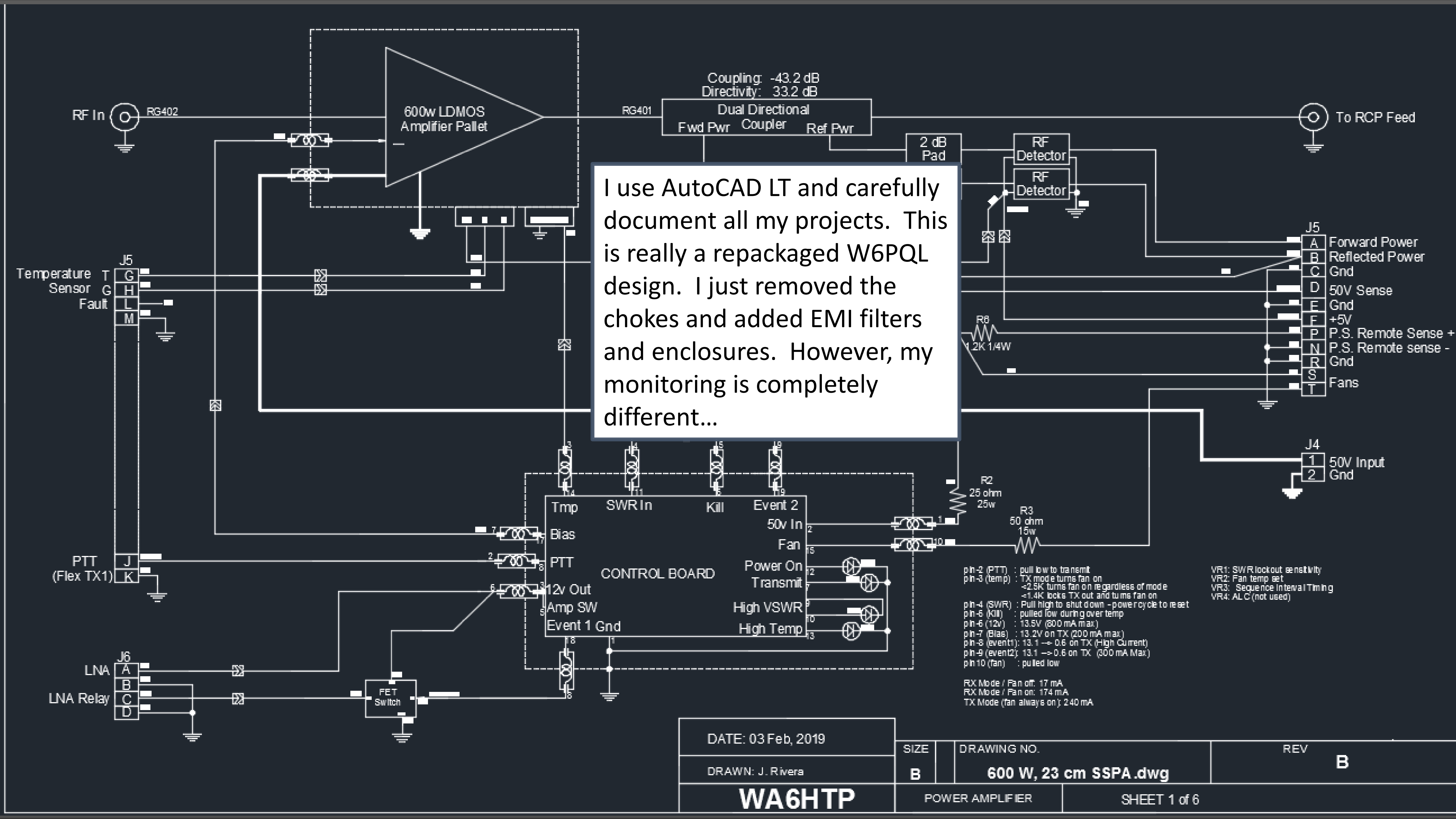
The gasket was made from a scrap of bathtub liner. I used 3M marine adhesive/sealant / fast cure 5200 on both sides of the gasket to seal the enclosure against water.


This is the inside of the weatherproof enclosure that will house the SSPA. It will be mounted on my tower.
DC Return
O-Ring Sealing Screws

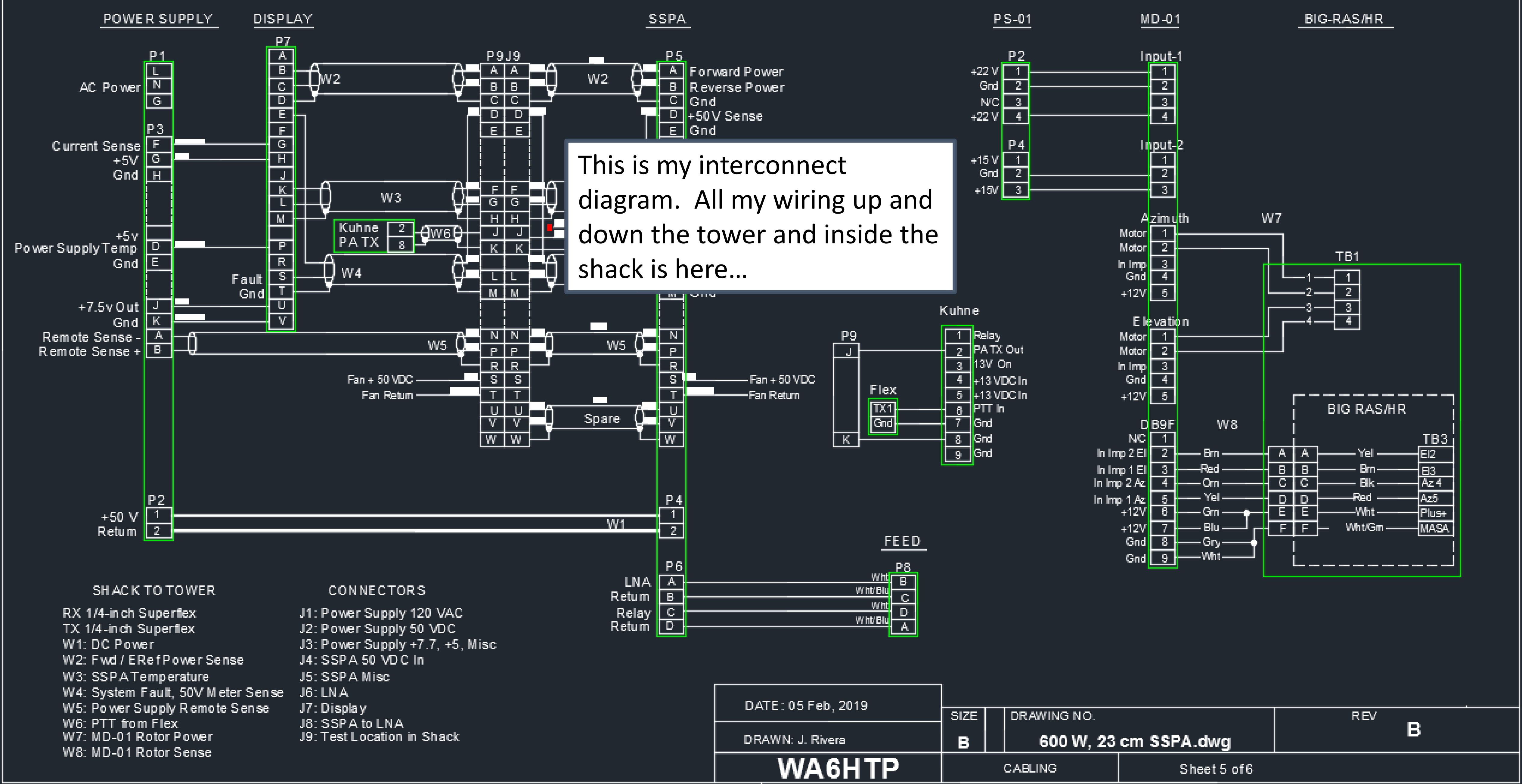

Ground Return
Linear Detectors
FET Switch
Directional Coupler
Pads
FET Switch
1 - 50V In
2 - PTT
3 - Temp
4 - Fault In
5 - Kill
6 - +12 VDC
7 - Bias
8 - Event 1
9 - Event 2
10 - Fan
R2
R3


Muffin Fan

I use AutoCAD LT and carefully document all my projects. This is really a repackaged W6PQL design. I just removed the chokes and added EMI filters and enclosures. However, my monitoring is completely different…



This is my interconnect diagram. All my wiring up and down the tower and inside the shack is here…



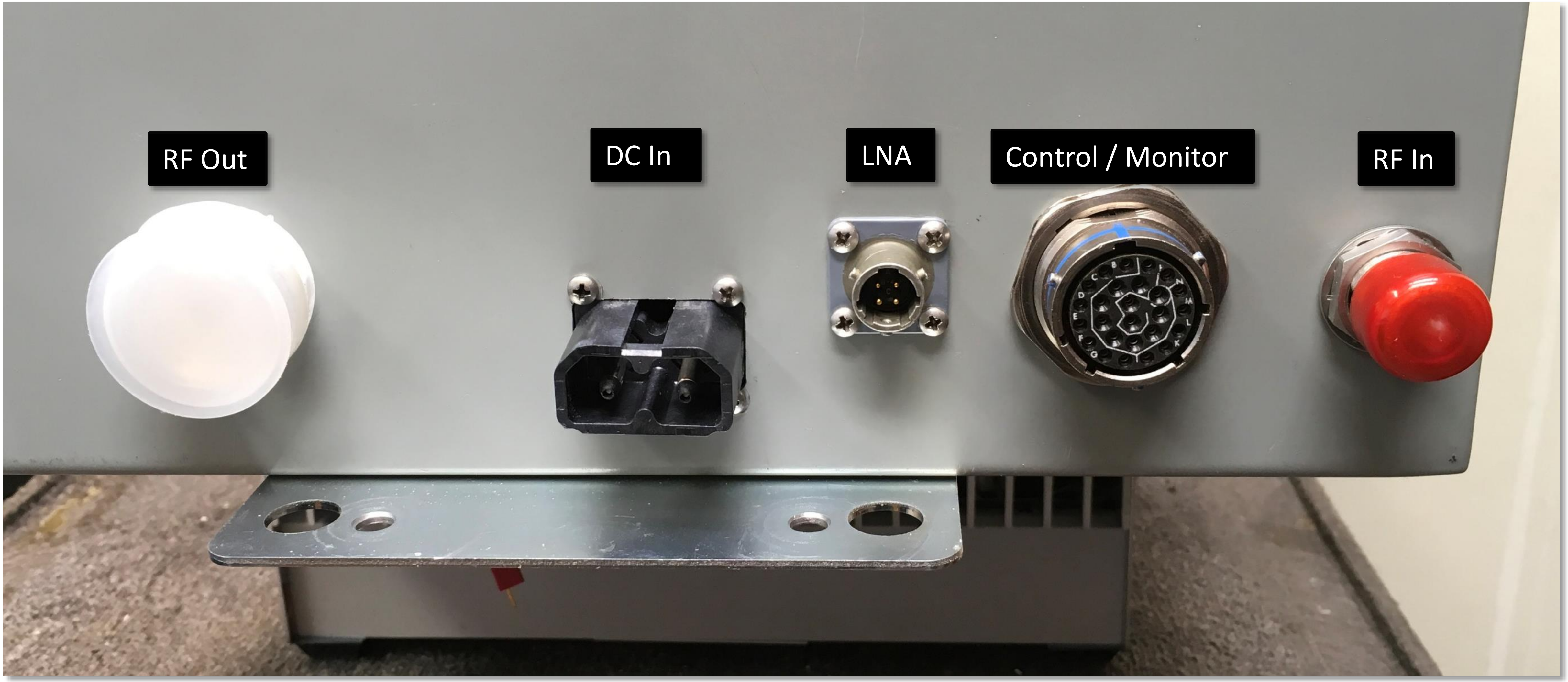
Completed SSPA Exterior

The SSPA is ready to mount on the back of my dish (to keep the losses low between the SSPA and the dish feed.

NEMA 3R Rated Enclosure

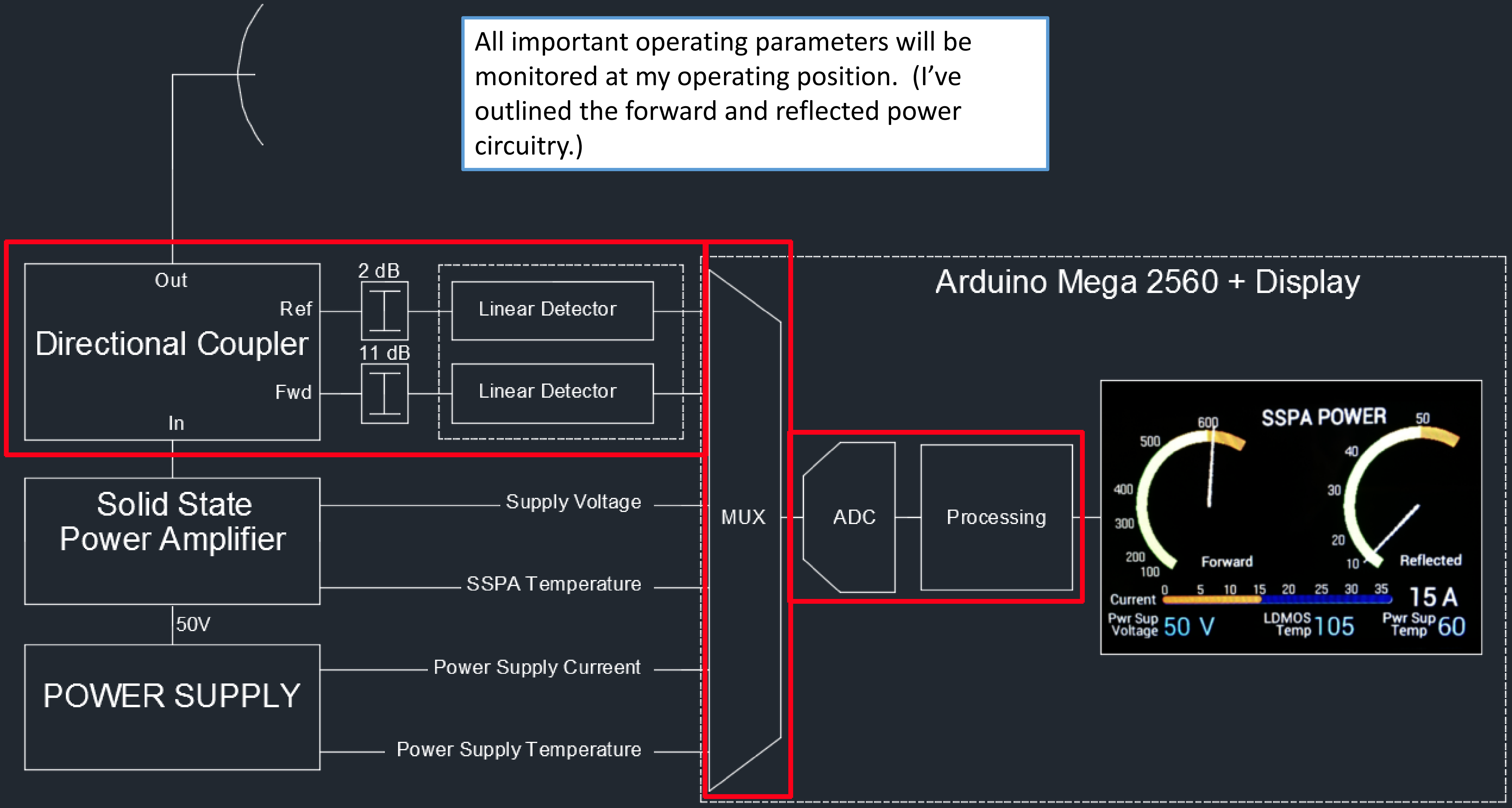
- *“NEMA 3R enclosures are intended for outdoor use primarily to provide a degree of protection against rain, sleet, and damage from external ice formation…”*

Completed SSPA Exterior (Bottom)



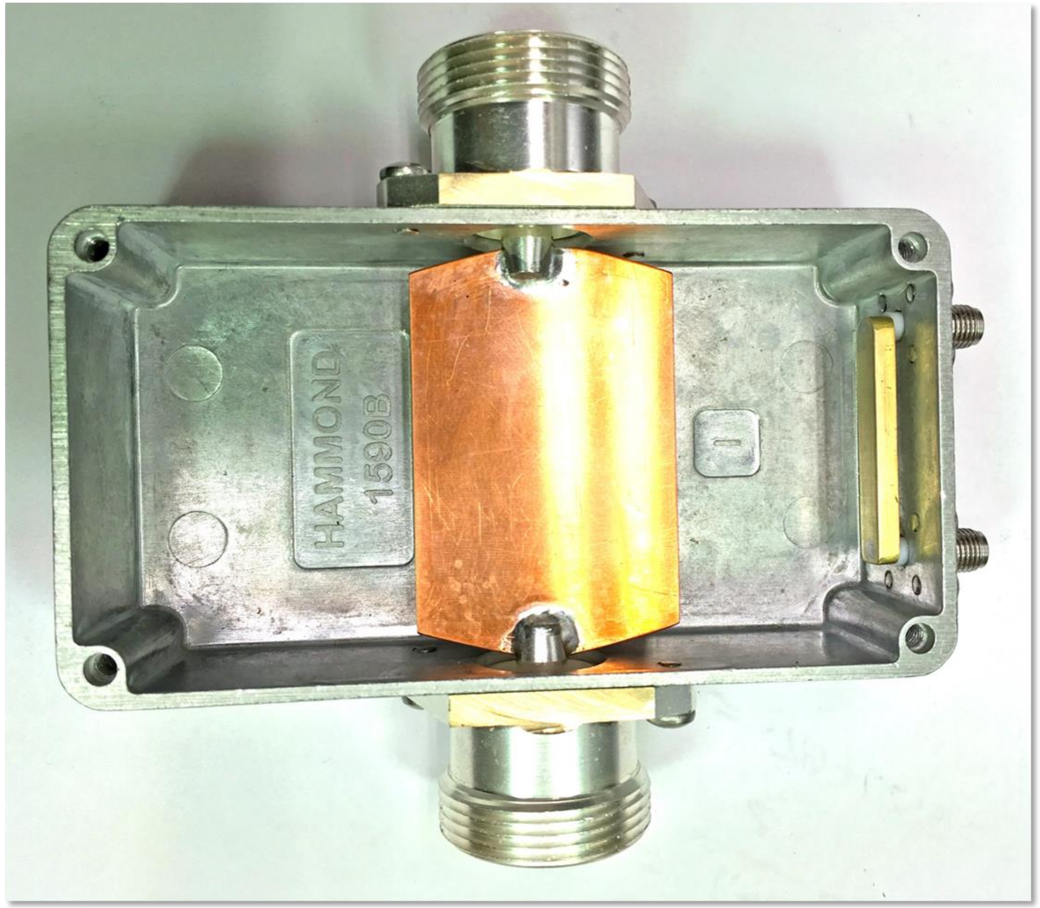
INSTRUMENTATION

All important operating parameters will be monitored at my operating position. (I've outlined the forward and reflected power circuitry.)



W1GHZ High-Power Directional Coupler

This was an extremely interesting project that I cover in more detail in another write-up. Thanks to Paul Wade, W1GHZ, for the design!



ATTENTION TO DETAIL

- Precision is critically important.

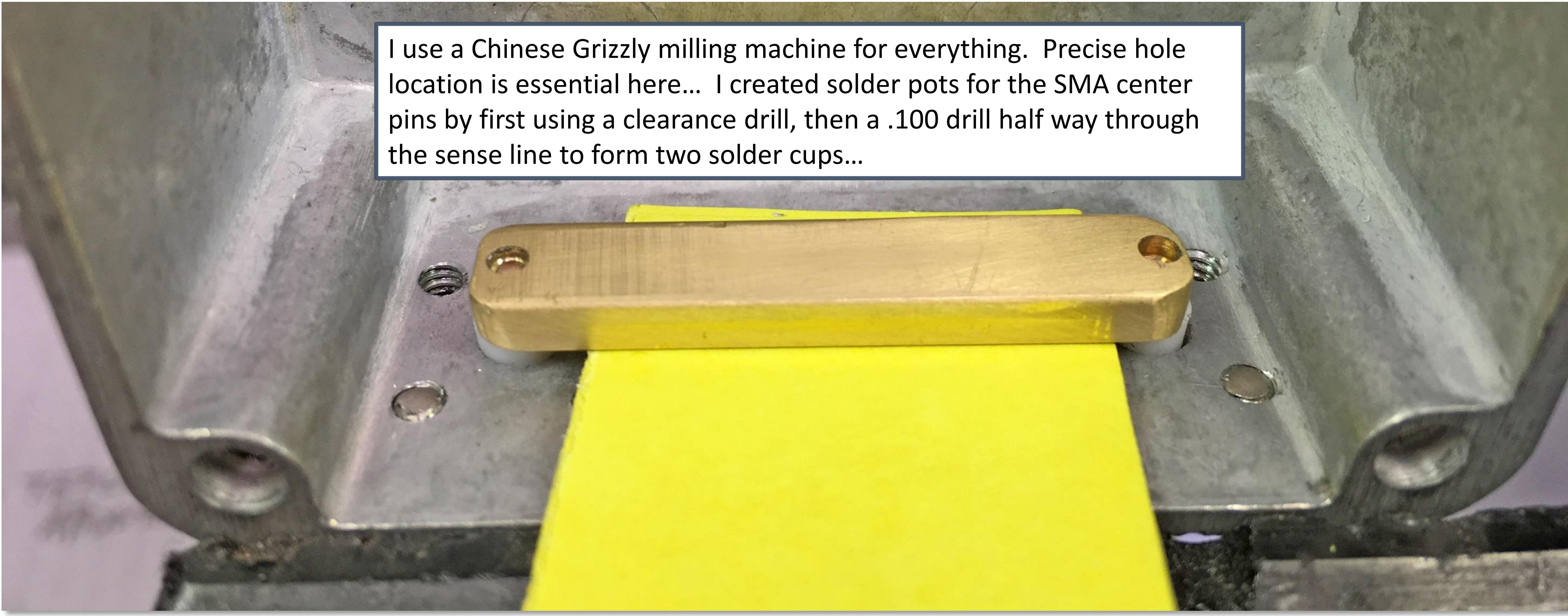
SYMETRY

- Every discontinuity, lump, bump, or protruding screw can have an impact on performance.

THE LID

- A perfect RF-tight lid is absolutely essential.

Sense Line Ready to Solder



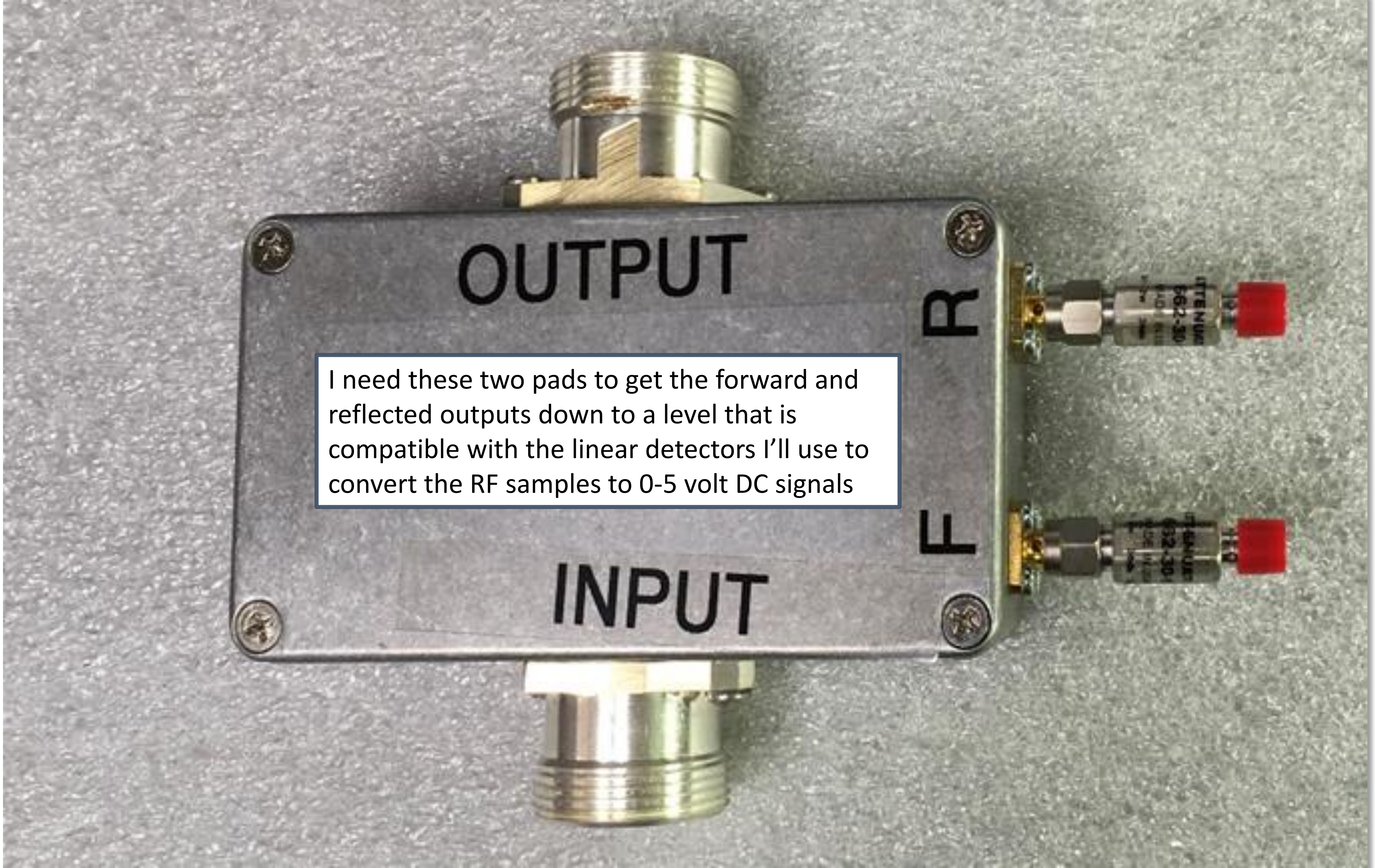
I use a Chinese Grizzly milling machine for everything. Precise hole location is essential here… I created solder pots for the SMA center pins by first using a clearance drill, then a .100 drill half way through the sense line to form two solder cups…


I flowed solder into the solder cups and then sanded the surface smooth with 400 and 600 grit wet and dry sandpaper…

Modified 7/16 DIN Connector

I opted for 6/17 DIN connectors, but they are bigger than the enclosure, so I milled off the two opposite corners…


J2
T
G
G
H
ault
L
M
J
Temp
Sense
Bias
1 uh
PTT



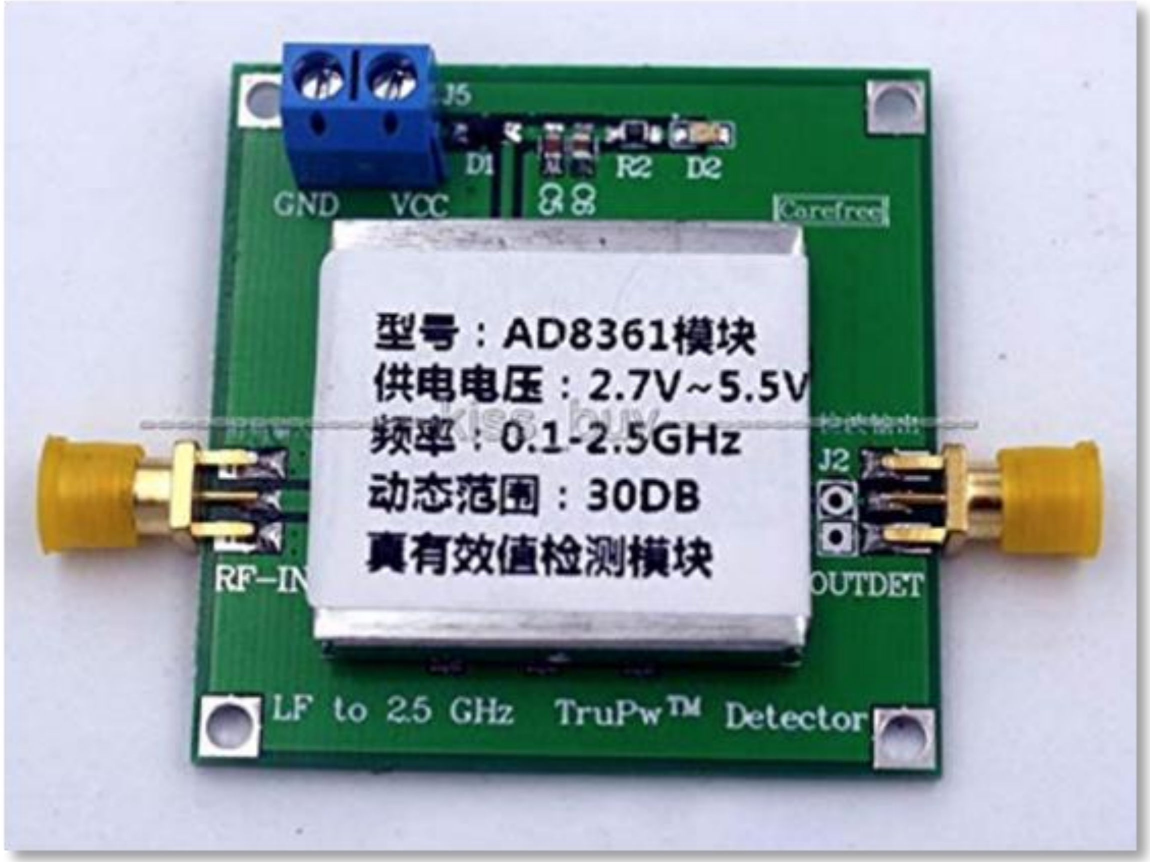
I need these two pads to get the forward and reflected outputs down to a level that is compatible with the linear detectors I'll use to convert the RF samples to 0-5 volt DC signals

High-Power Directional Coupler Test Results

	Paul Wade's	My 1st Attempt	My 2nd Attempt	Copper Foil Added to Lid	Copper Foil Replaced with EMI Gasket
COUPLING	-43.8 dB	-47.0 dB	-42.8 dB	-42.8 dB	-43.2 dB
DIRECTIVITY	32.1 dB	23.0 dB	15.0 dB	27.0 dB	33.3 dB
INSERTION LOSS	0.10 dB	0.086 dB	0.06 dB	0.06 dB	0.06 dB

My second directional coupler had amazing performance only after the lid was properly sealed. Directivity improved from 15 dB to 33.3 dB!

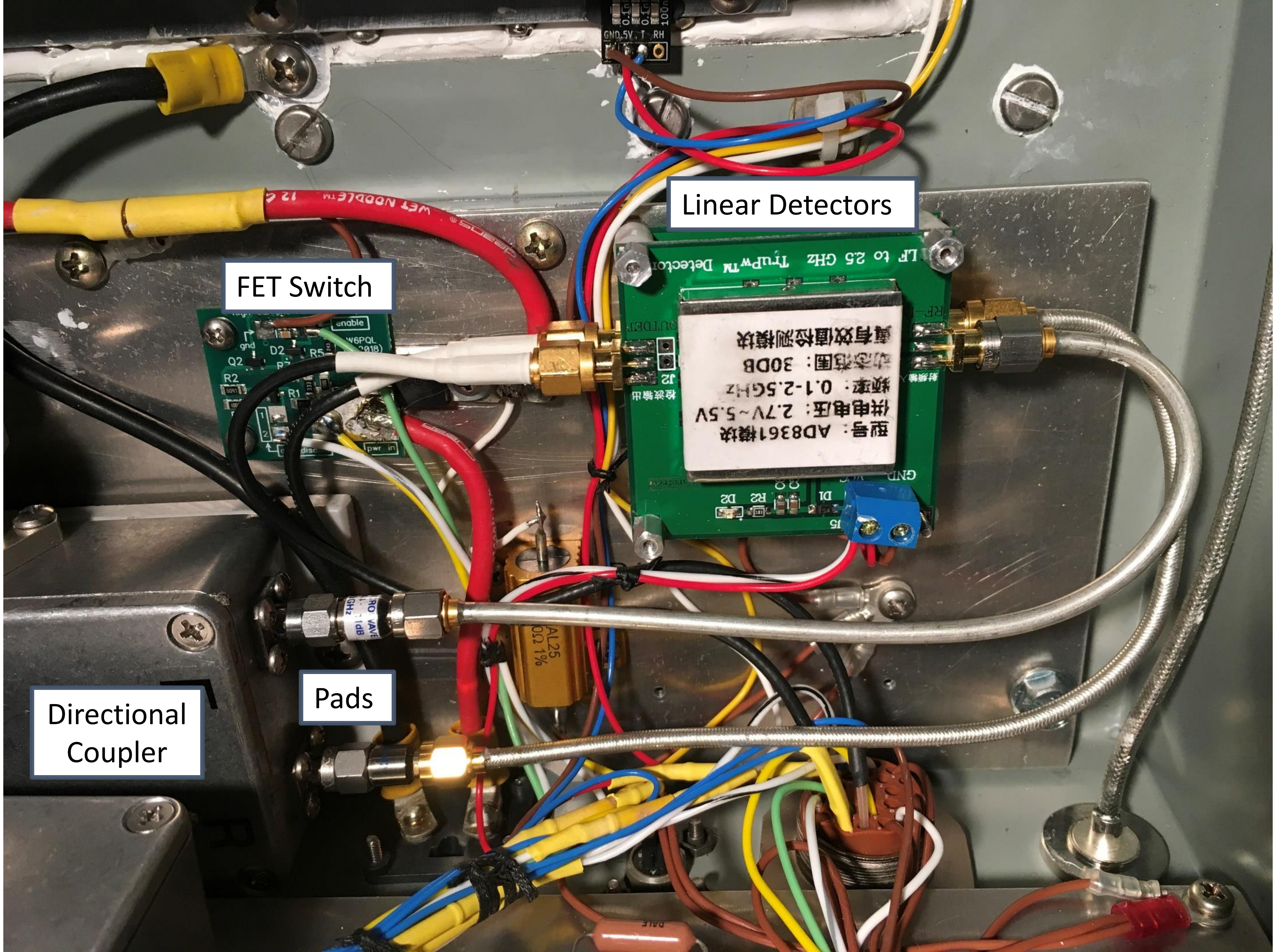
AD8361 Linear Detector



FEATURES

Calibrated rms response
Excellent temperature stability
Up to 30 dB input range at 2.5 GHz
700 mV rms, 10 dBm, re 50 Ω maximum input
±0.25 dB linear response up to 2.5 GHz
Single-supply operation: 2.7 V to 5.5 V

The RF outputs from the forward and reflected sense ports will be converted to DC voltages by two AD8361 linear detectors.

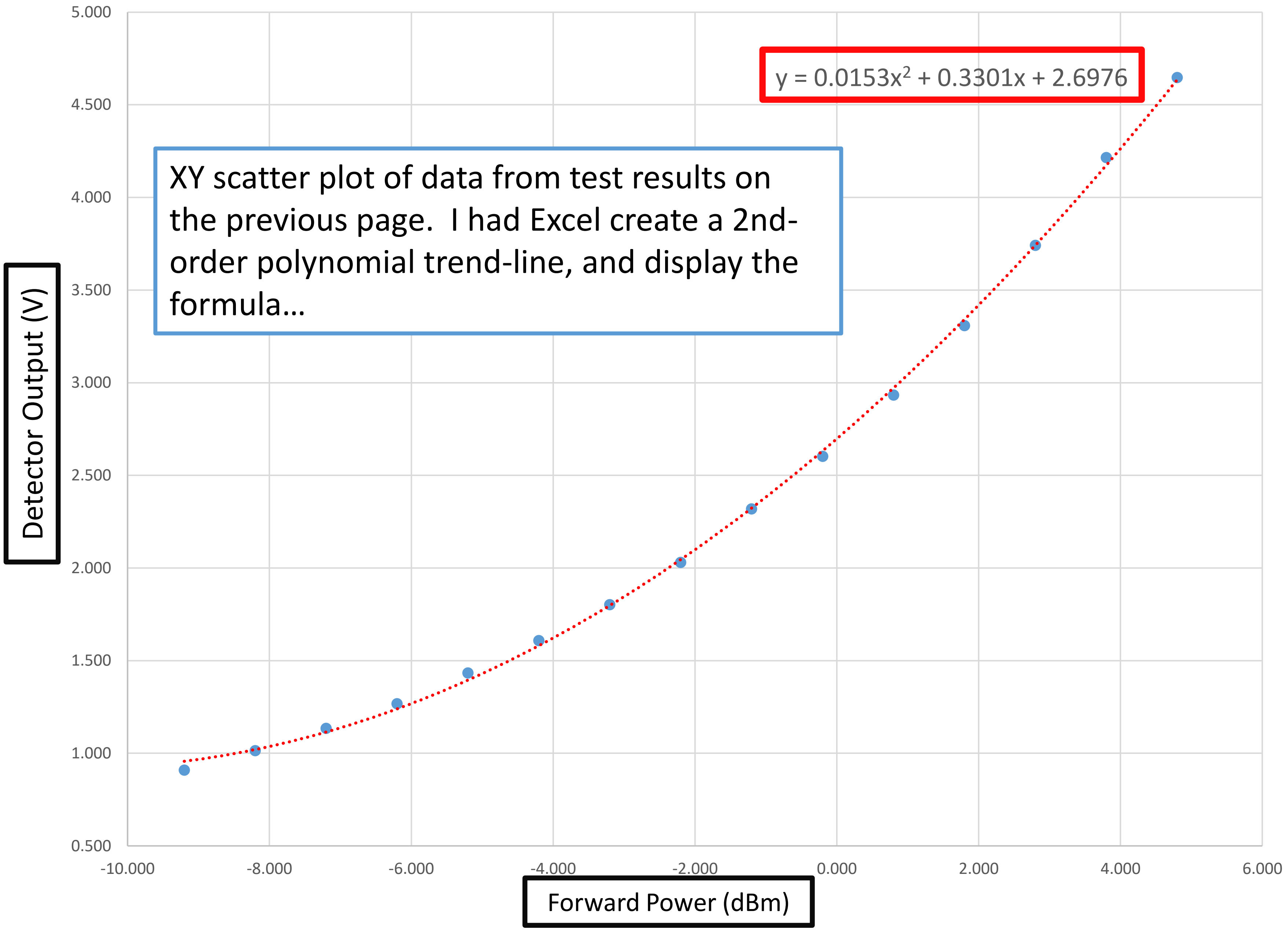


Linear Detectors
FET Switch
Pads
Directional
Coupler

Linear Detector Test results

RF Output (dBm)	RF Output (Watts)	-43.2 dB Coupling Loss	11 dB Pad Output (dBm)	Detector Output
59.0	794	15.800	4.800	4.647
58.0	631	14.800	3.800	4.216
57.0	501	13.800	2.800	3.742
56.0	398	12.800	1.800	3.308
55.0	316	11.800	0.800	2.933
54.0	251	10.800	-0.200	2.603
53.0	200	9.800	-1.200	2.319
52.0	158	8.800	-2.200	2.030
51.0	126	7.800	-3.200	1.803
50.0	100	6.800	-4.200	1.609
49.0	79	5.800	-5.200	1.434
48.0	63	4.800	-6.200	1.268
47.0	50	3.800	-7.200	1.135
46.0	40	2.800	-8.200	1.014
45.0	32	1.800	-9.200	0.910

2nd Order Polynomial Trend Line



SSPA_GUI_V1_0 | Arduino 1.0.5-r2

File Edit Sketch Tools Help

SSPA_GUI_V1_0

```
void loop() {


  /*************************************** FORWARD POWER AVERAGING *******************/
  // subtract the last reading:
    FP_t = FP_t - FP_readings[FP_readIndex];
  // read from the sensor:
  FP_readings[FP_readIndex] = analogRead(FP_Pin);
  // add the reading to the total:
  FP_t = FP_t + FP_readings[FP_readIndex];
  // advance to the next position in the array:
  FP_readIndex = FP_readIndex + 1;

  // if we're at the end of the array...
  if (FP_readIndex >= numReadings) {
    // ...wrap around to the beginning:
    FP_readIndex = 0;
  }

   // calculate the average:
  FP_a = FP_t / numReadings;

        y=0.0003*FP_a*FP_a*FP_a+0.0074*FP_a*FP_a-0.156*FP_a+4.7808; // 3rd ORDER POLYNOMIAL CORRECTION
//          Serial.print("Fwd Power:  ");
//          Serial.print (y/243); // at 631 Watts the detector output is 4.216V. 1024 bits/4.216=242.88 <<<<<<<<<
//          Serial.print("W   ");
```

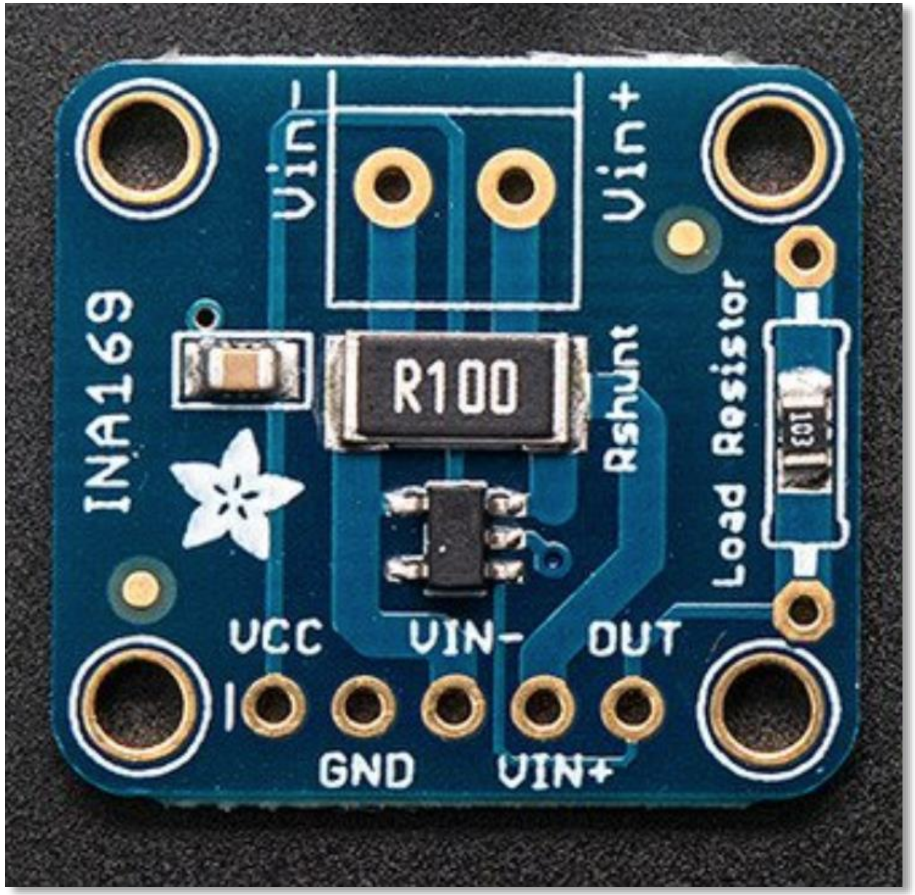
…Then I inserted the equation into the C-Code for forward power… I use a running average on all displayed values to smooth action down…

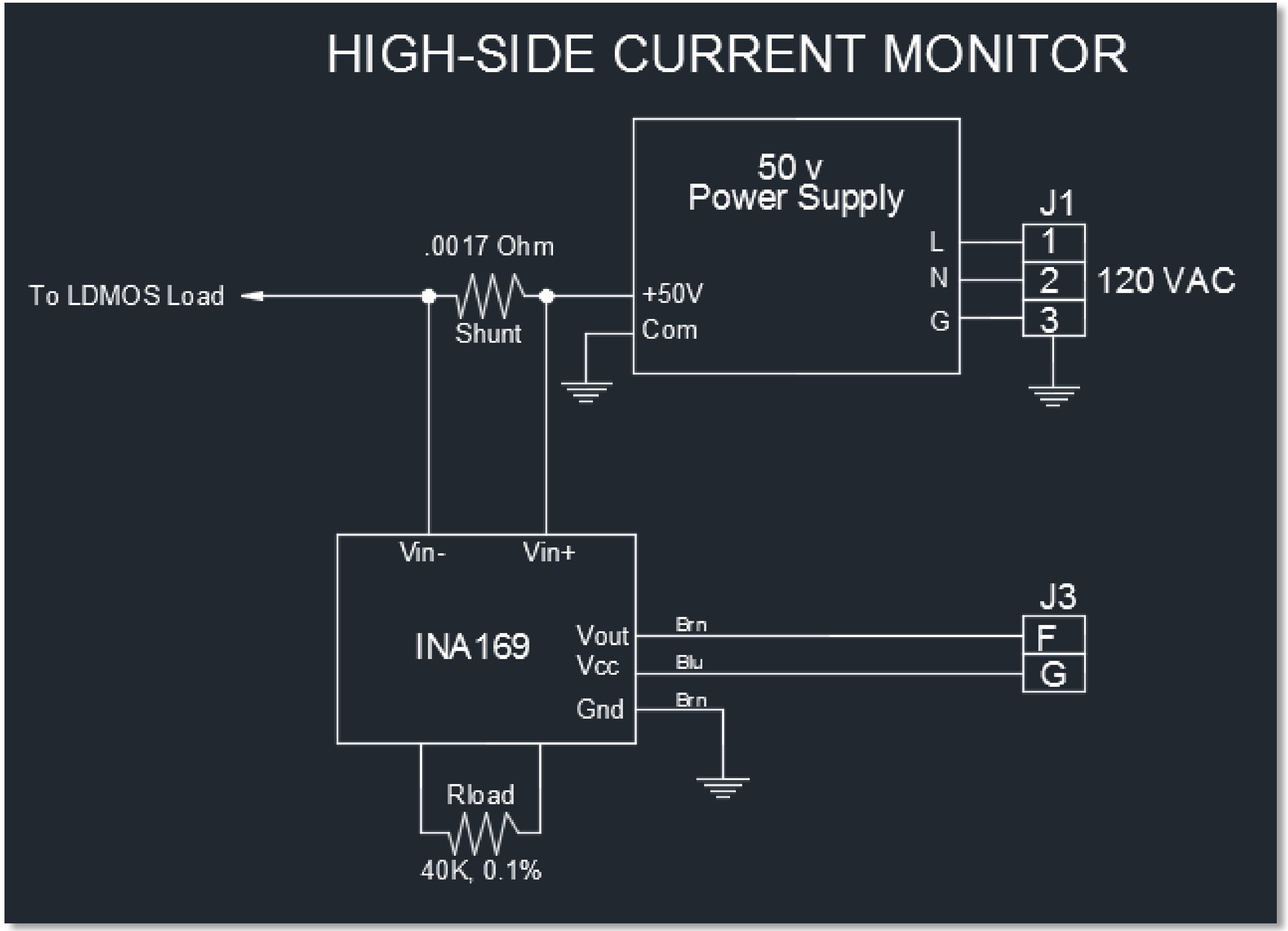
Remaining Instrumentation

- ***DC Voltage and Current***
  - 30-Amp / 50 mV Shunt
  - Texas Instruments INA169 High-Side Current Shunt Monitor

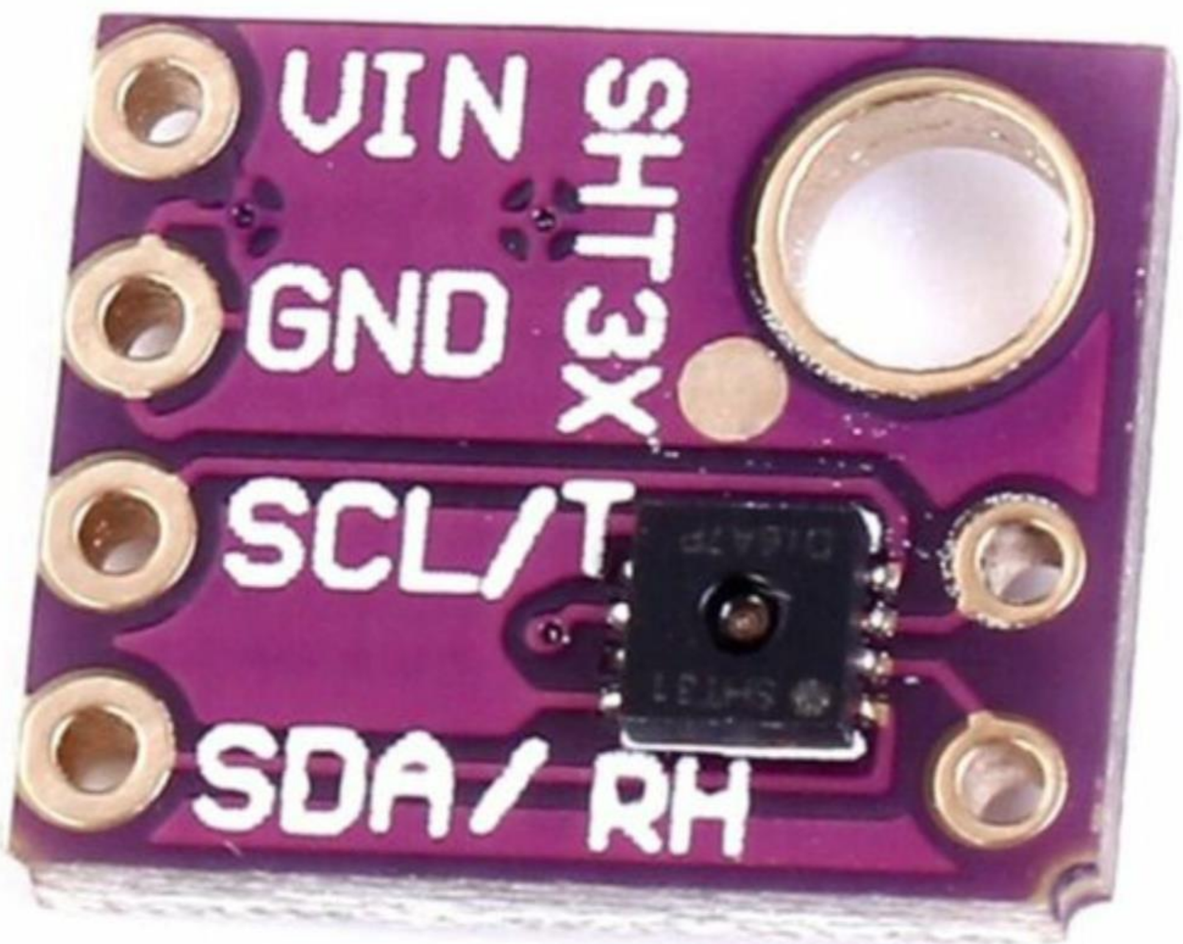
- ***LDMOS and Power Supply Temperature***
  - Sensirion SHT31-ARP Temperature / Humidity Sensors

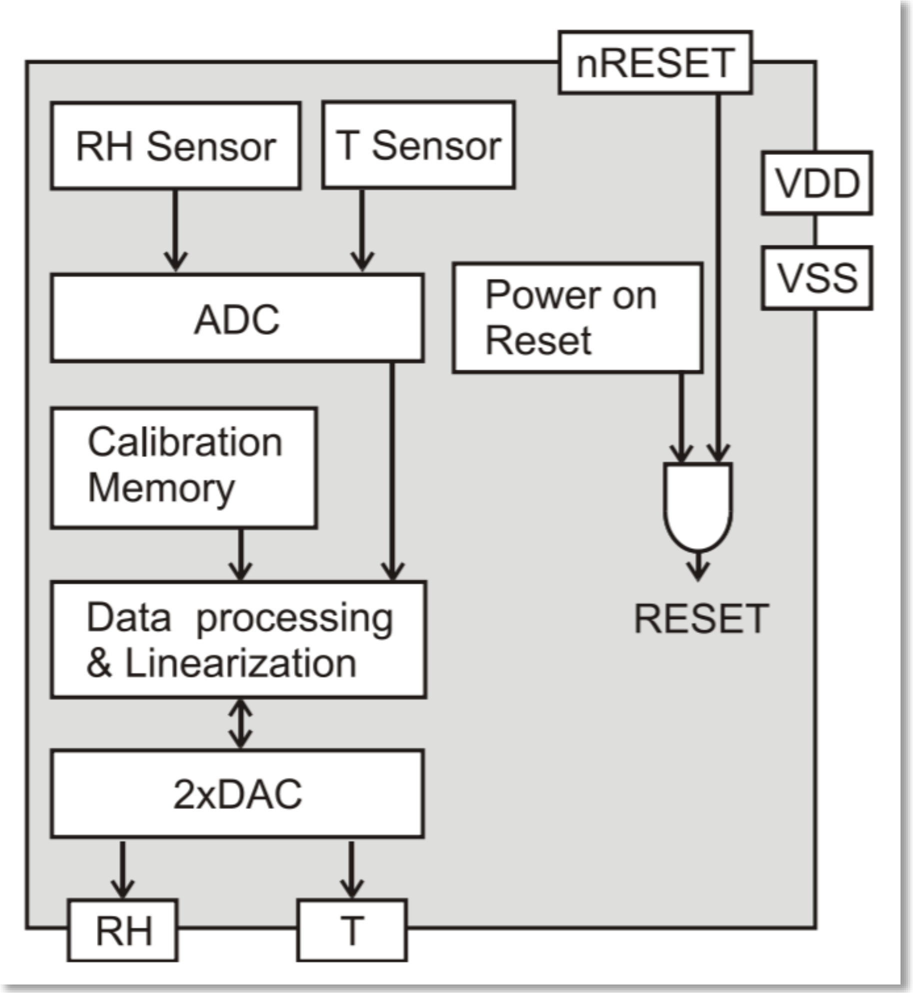
INA169 High-Side Current Monitor





Adafruit SHT31-D Temp / Humidity Sensor

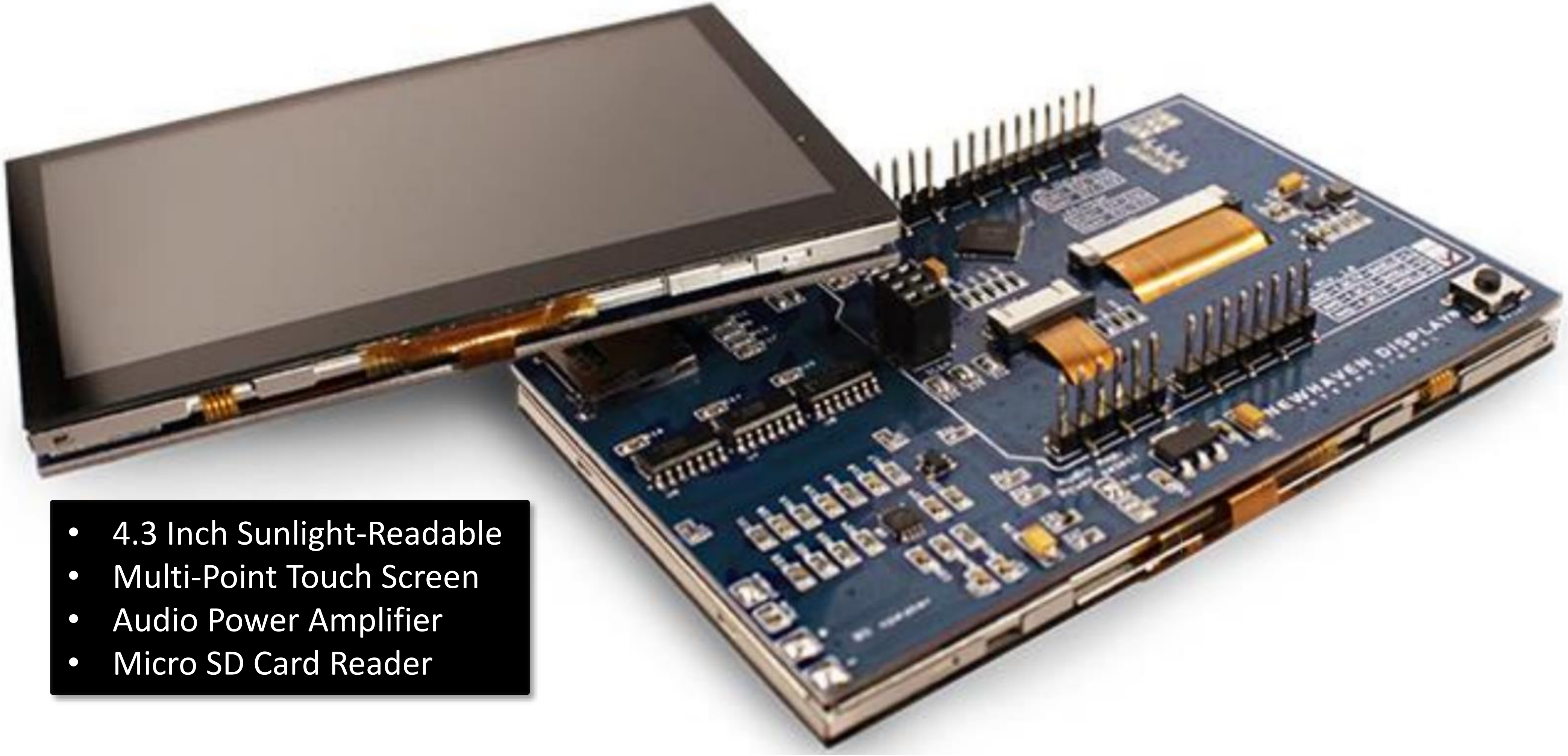




GRAPHICAL USER INTERFACE (GUI)

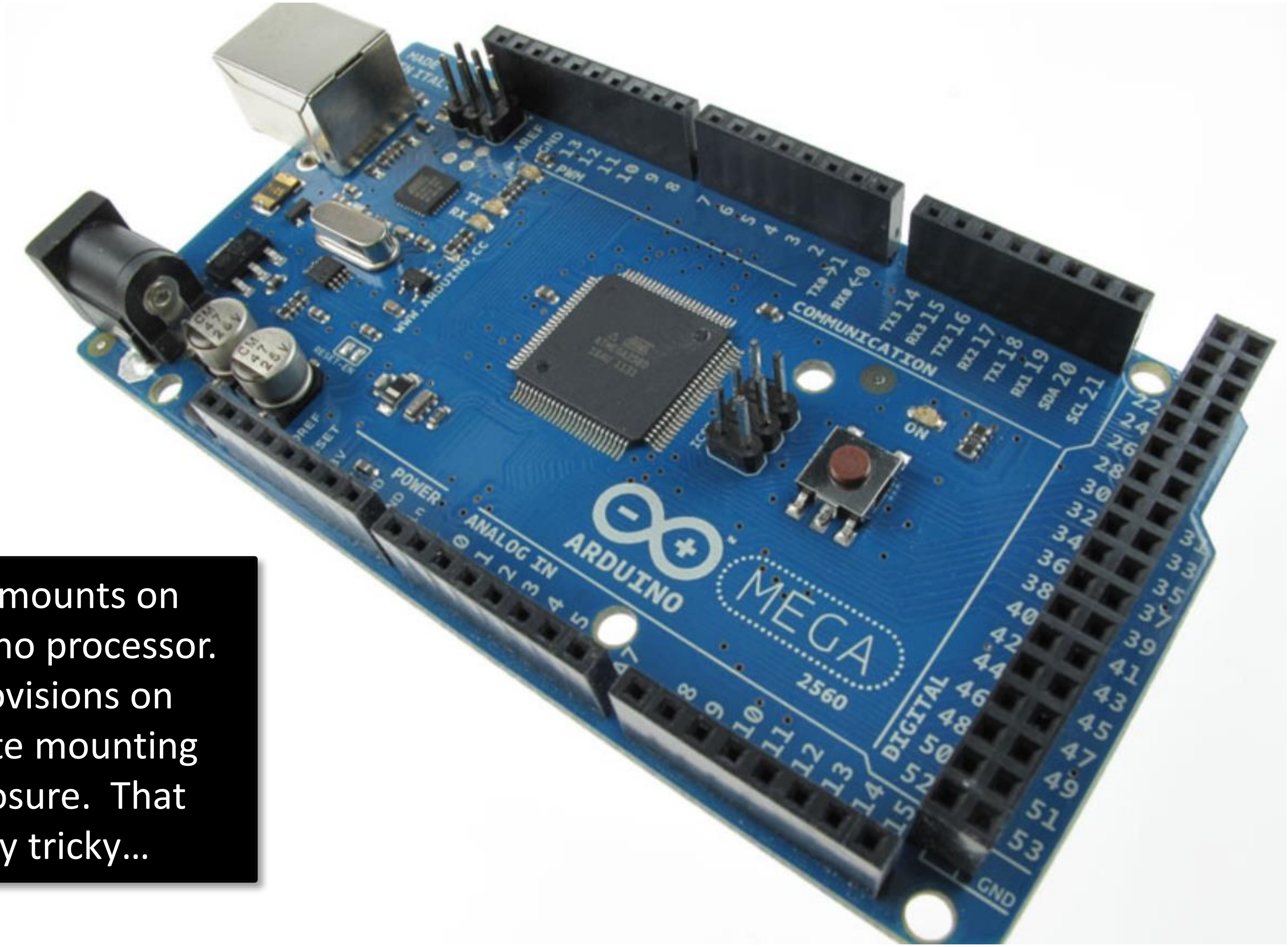
I wanted to design a graphical user interface (GUI). I have absolutely no experience in this area. What could possibly go wrong?

Newhaven Display NHD-4.3CTP-Shield-N Color LCD Display



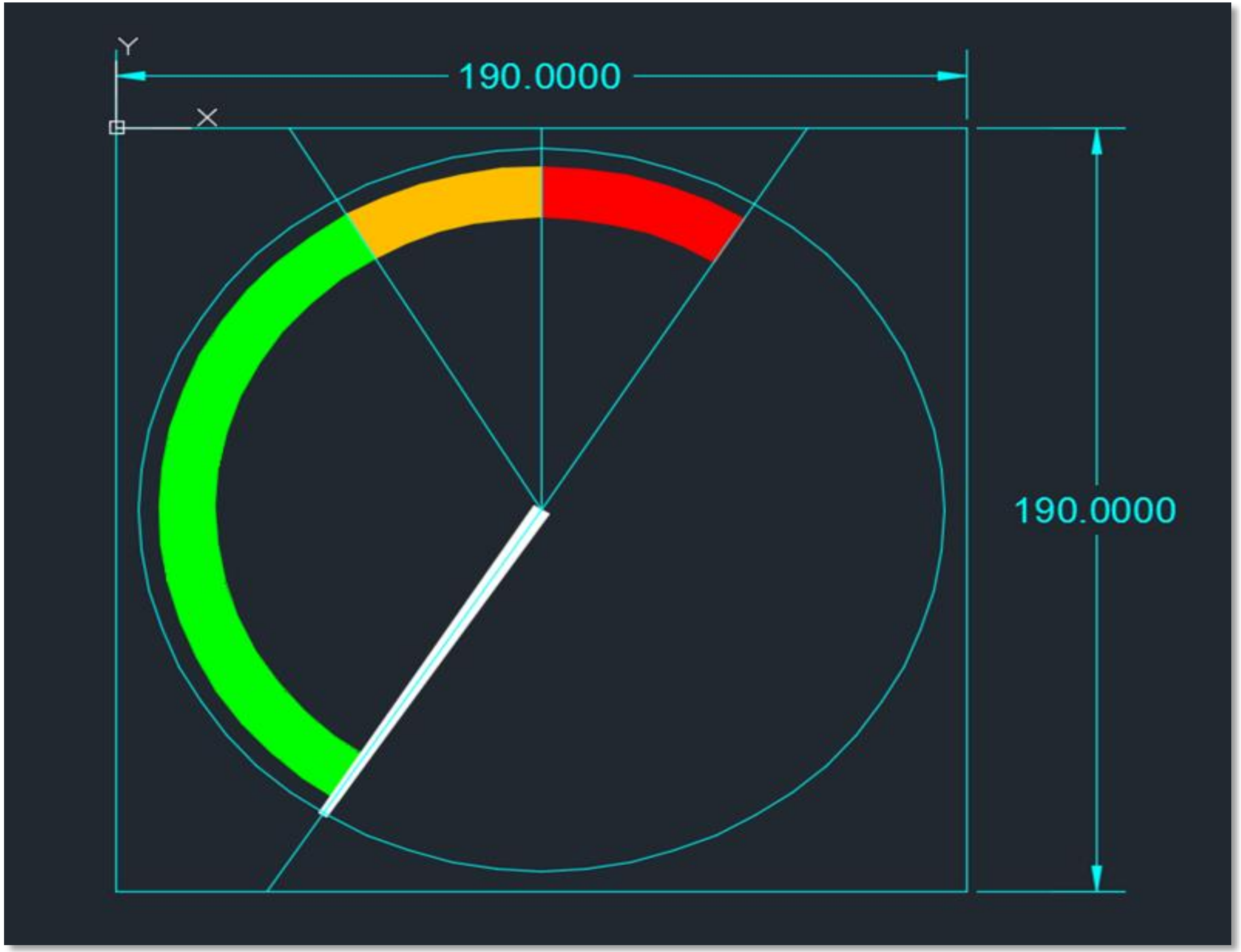
- 4.3 Inch Sunlight-Readable
- Multi-Point Touch Screen
- Audio Power Amplifier
- Micro SD Card Reader

Arduino Mega 2560 Processor



The LCD display mounts on top of the Arduino processor. There are no provisions on either to facilitate mounting them in an envlosure. That was mechanically tricky…

Graphic Primitives

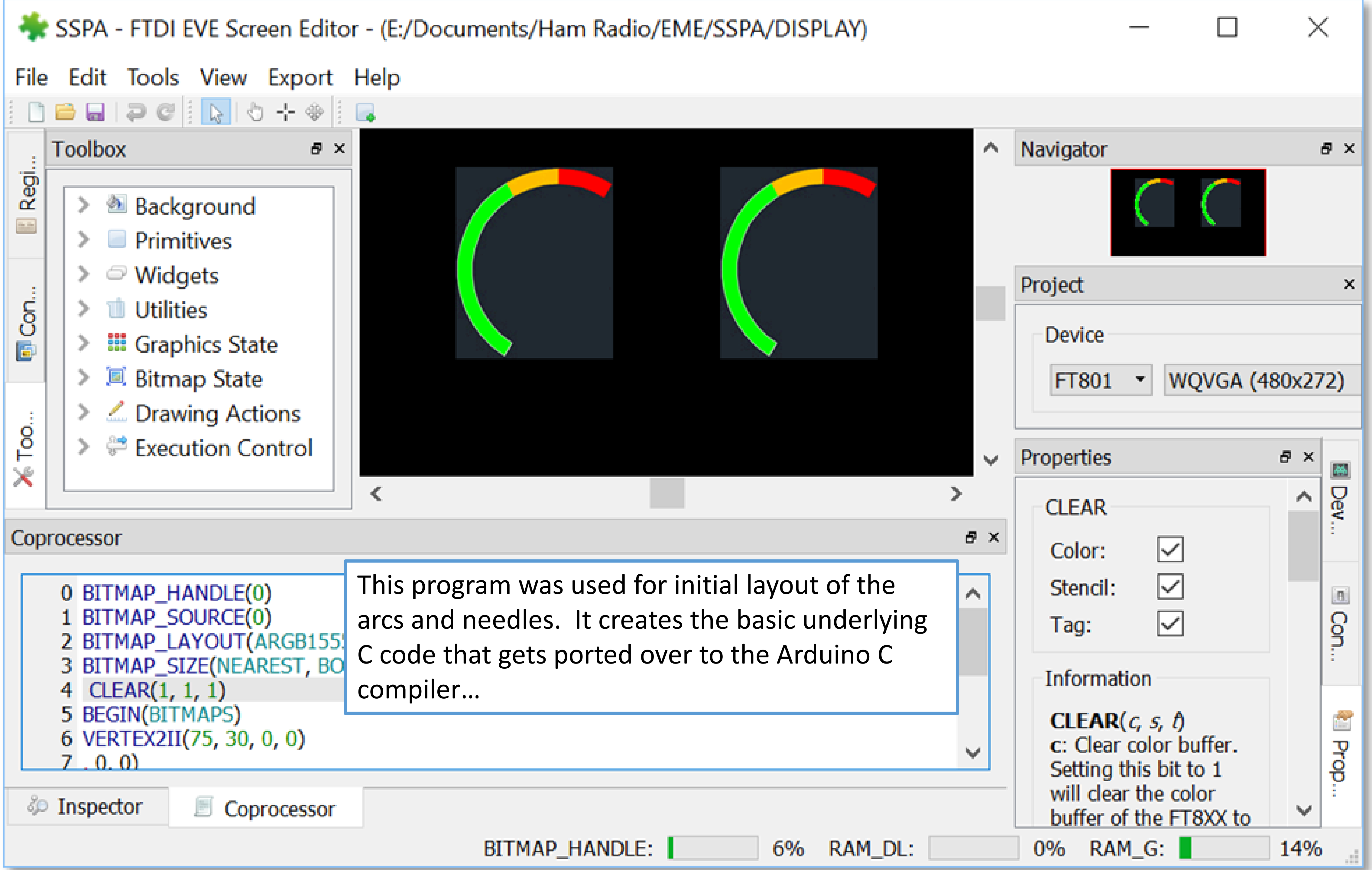


I called on my experience in aviation to model my meters after modern aircraft glass cockpit displays. I used AutoCAD for this first step. Each power meter will be 190 x 190 pixels in size.

One of the more challenging aspects of this project is that the graphic command to rotate an object (the needles), wants to use the upper left corner as the rotation axis. I had to offset the Y-axis -95 pixels, and the X-axis +95 pixels. That only took me a week to figure out…

Transparent .PNG File

- Ported from AutoCAD to Adobe Photoshop
- Scaled to 190x190 pixels
- Outer blue border removed
- Converted to a transparent .PGN file
- Completed file ready for graphics manipulation



This program was used for initial layout of the arcs and needles. It creates the basic underlying C code that gets ported over to the Arduino C compiler…

SSPA_GUI_V1_0 | Arduino 1.0.5-r2

File Edit Sketch Tools Help

SSPA_GUI_V1_0

```
void loop() {


  /*************************************** FORWARD POWER AVERAGING *******************/
  // subtract the last reading:
    FP_t = FP_t - FP_readings[FP_readIndex];
  // read from the sensor:
  FP_readings[FP_readIndex] = analogRead(FP_Pin);
  // add the reading to the total:
  FP_t = FP_t + FP_readings[FP_readIndex];
  // advance to the next position in the array:
  FP_readIndex = FP_readIndex + 1;

  // if we're at the end of the array...
  if (FP_readIndex >= numReadings) {
    // ...wrap around to the beginning:
    FP_readIndex = 0;
  }

   // calculate the average:
  FP_a = FP_t / numReadings;

        y=0.0003*FP_a*FP_a*FP_a+0.0074*FP_a*FP_a-0.156*FP_a+4.7808; // 3rd ORDER POLYNOMIAL CORRECTION
//          Serial.print("Fwd Power: ");
//          Serial.print (y/243); // at 631 Watts the detector output is 4.216V. 1024 bits/4.216=242.88 <<<<<<<<<
//          Serial.print("W   ");
```

Quite soon I was forced to program in C. I have no experience here either. As I said, what could possibly go wrong?

Here's that 2nd-order polynomial equation from Excel…

Final GUI Design

In the next slide you'll see the final design in operation. Everything I want to know about the performance of the SSPA is right in front of my eyes. The Kuhne transverter shows my drive level.

The SSPA is producing 600 Watts out, and only 4 or 5 Watts of reflected power. The Septum feed was tuned prior to installation on the dish, but I had about 22 Watts of reflected power once it was installed. Using my GUI reflected power meter I was able to retune the feed and lower the reflected power substantially.

The temperature sensors are highly accurate and, unlike the other parameters, the exact conversion formula was published by the manufacturer, so no calibration was required.

Of all of the parameters, I have the most trouble calibrating the DC input current. I have a 1000 Amp clamp-on current probe, but that is a very poor choice. My only other method is to measure the voltage across the 50 mV shunt with my multimeter and do the math. I think I'm reading high at the moment. I need a more accurate calibration method…

Because the directivity is so good on my directional coupler, I can trust that low reflected power reading!

GUI CALLIBRATION

All of those parameters need to be calibrated, starting with RF power…

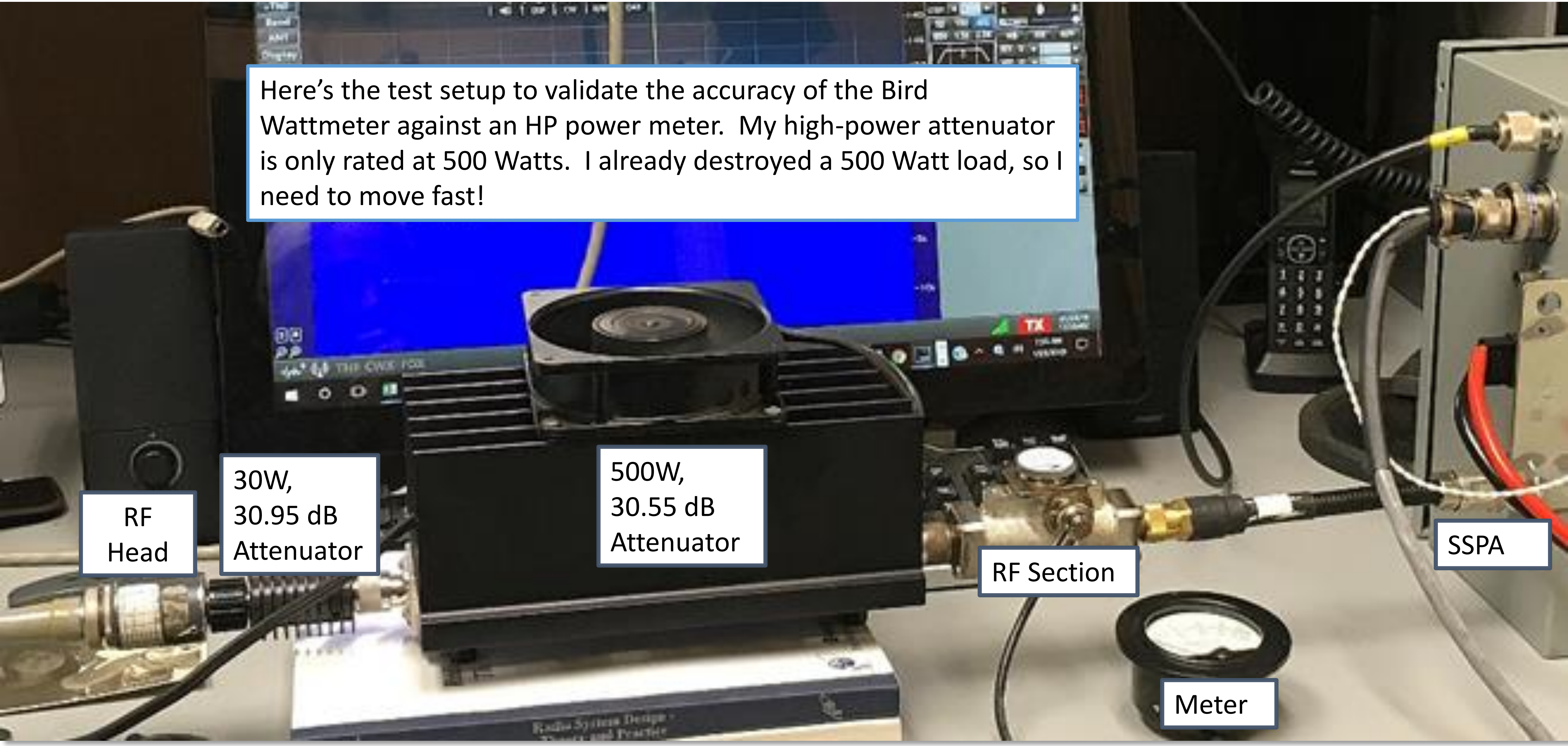
The software is reprogrammed via a USB cable. The process is to make a change to a calibration constant in the C code, recompile, upload the new code, and check the results. Everything is done using the free Arduino compiler.

Connector Center Pin Limits Max Power

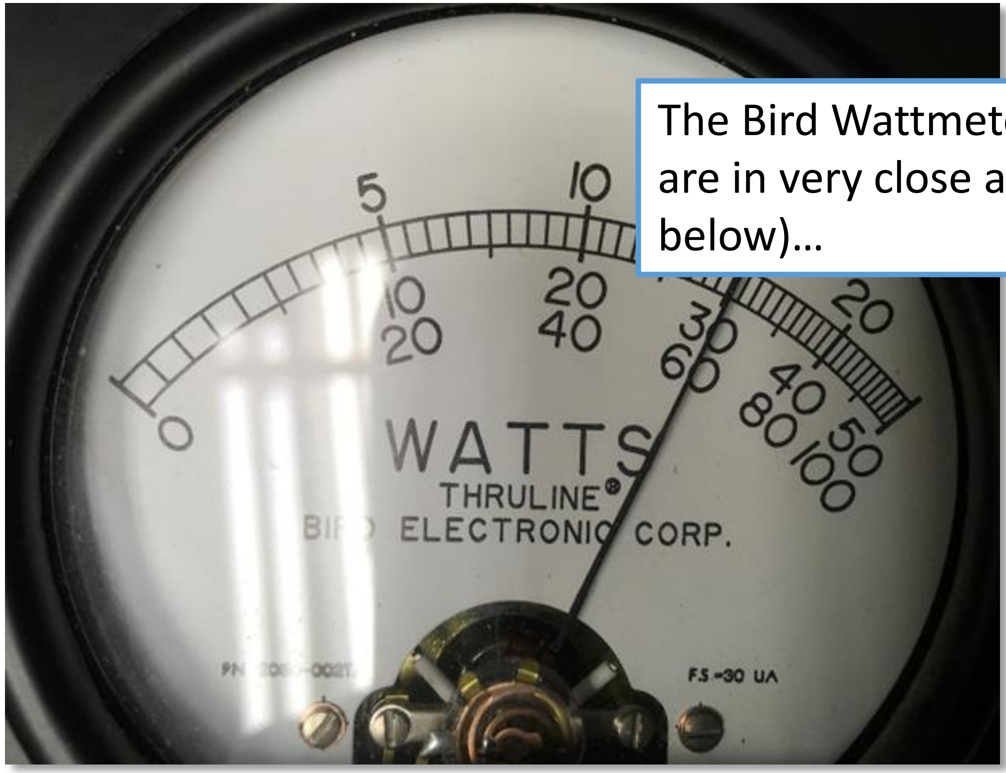
I'll use my trusty Bird Model 43 Thruline Wattmeter. I purchased this element especially for this project. It's only rated at 100-Watts average power because the center contacts cannot handle the high power and frequency and they will overheat.

I also destroyed a 500-Watt load during testing, even though I had a powerful fan sitting on the heatsink. I'll have to work fast

Here’s the test setup to validate the accuracy of the Bird Wattmeter against an HP power meter. My high-power attenuator is only rated at 500 Watts. I already destroyed a 500 Watt load, so I need to move fast!



Bird 43 Wattmeter Test Results

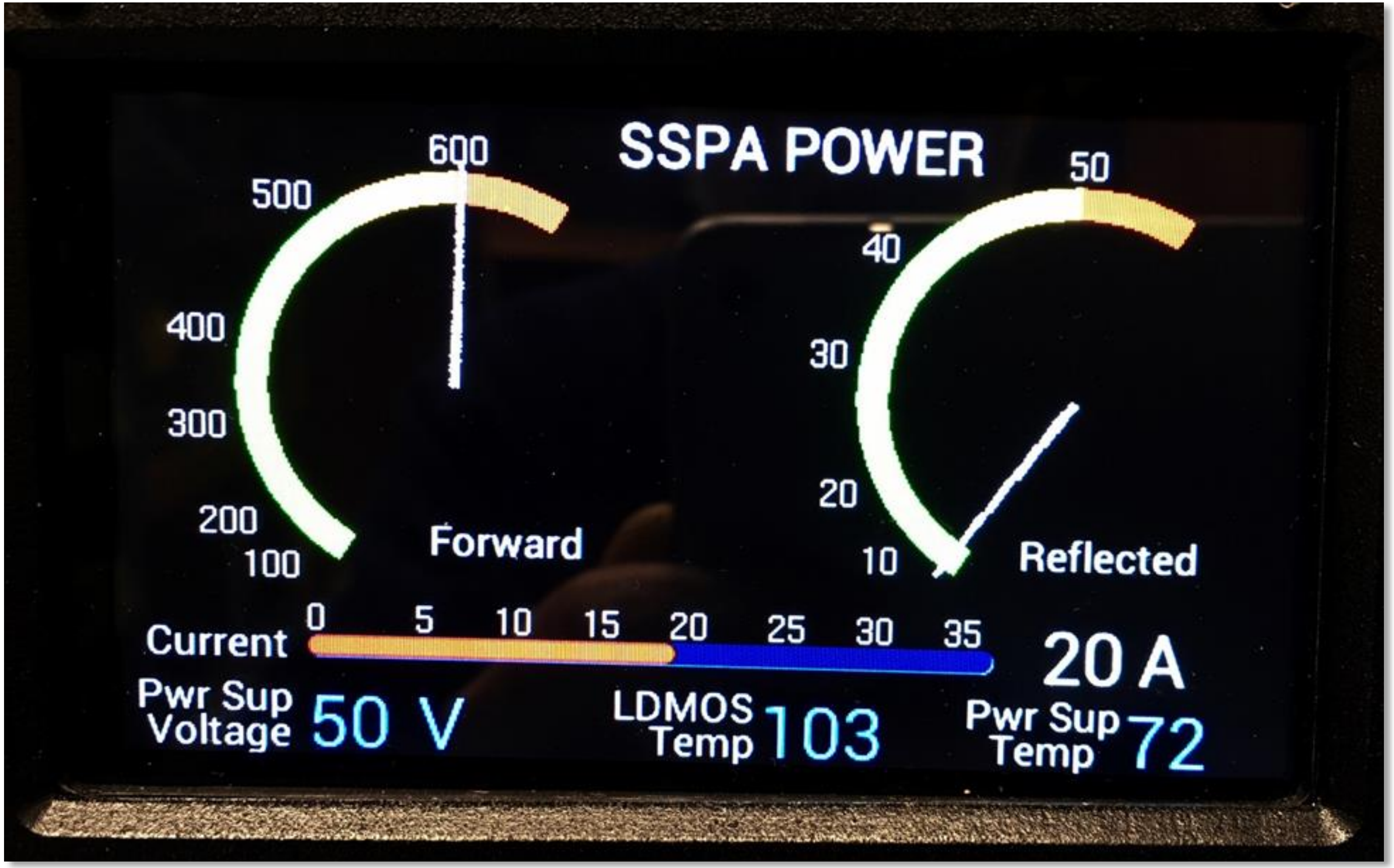


The Bird Wattmeter and the HP power meter are in very close agreement (See data below)…

- Powered for 3 days to minimize drift

FORWARD POWER (1296 MHz)						
Measured dBm	Cable Loss (dB)	Attenuator-1 (dB)	Attenuator-2 (dB)	Total Loss (dB)	Pout (dBm)	Pout (Watts)
-3.70	0.00	30.55	30.95	61.50	57.80	602.6

Power Calibration

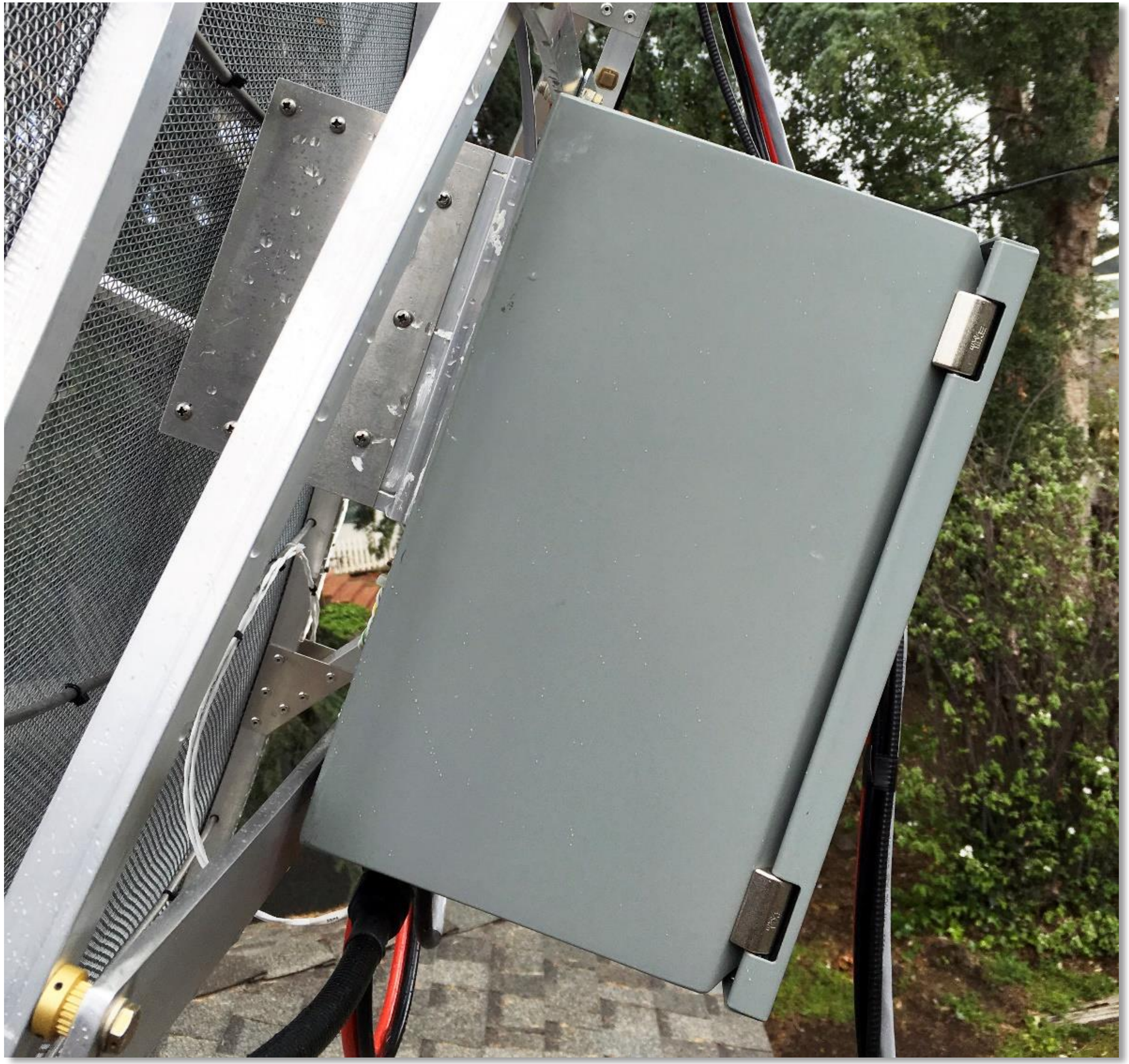


Set output power to 600 on Bird and HP meters, then adjust software scaling constand to make GUI meter read 600… I then lowered the power in 100 Watt steps and simply adjusted the X and X axis insertion points for the numbers.

3 METER DISH

My 3-meter parabolic dish was a kit from the Netherlands. Getting it mounted on my tower was a major struggle.

I managed not to rip the power line off the pole!



GOOD NEWS!!

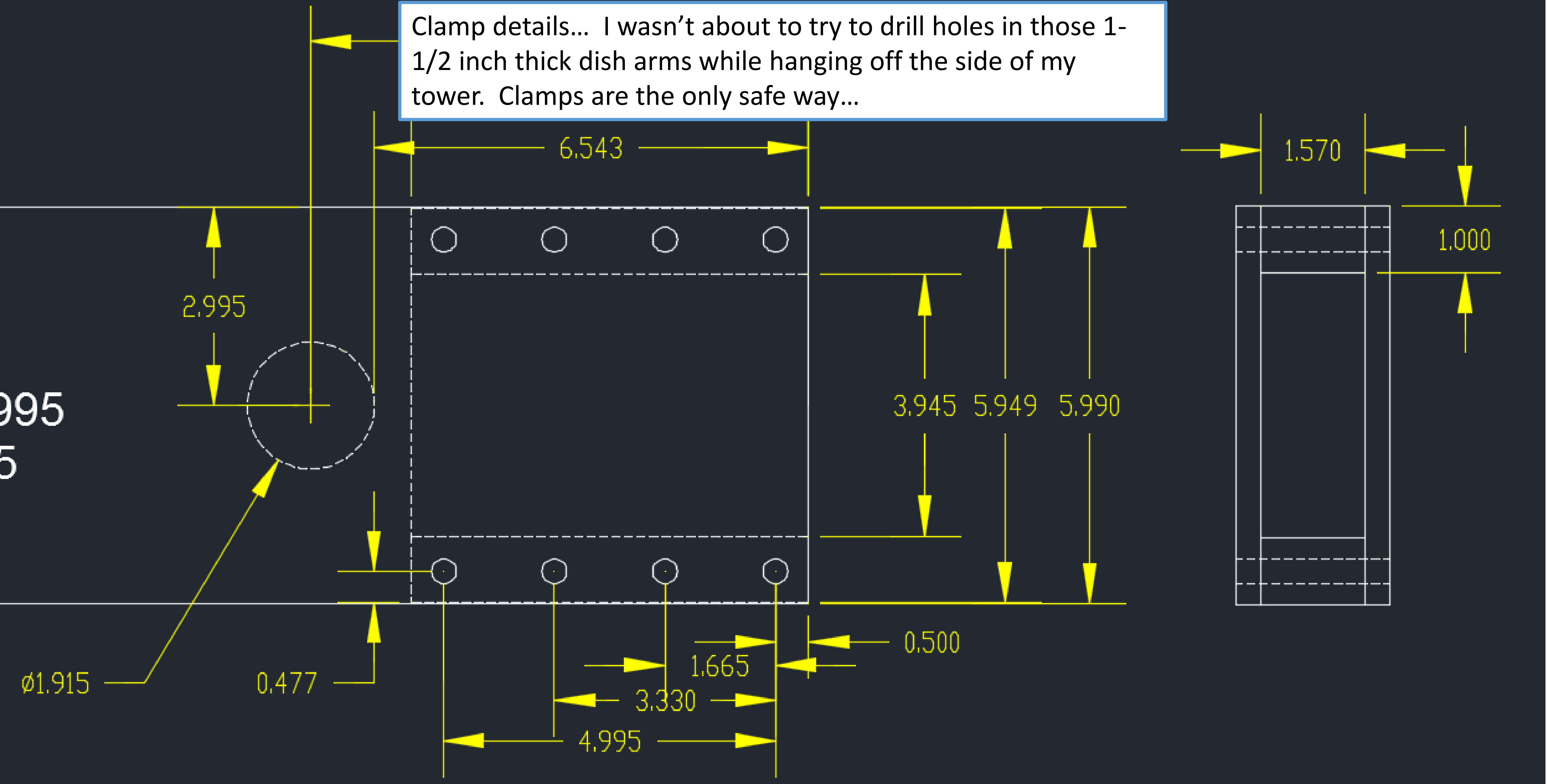
- SSPA Fit Nicely between Ribs
- Fans Protected from Flying Debris by Mesh
- Minimizes RF Output Cable Loss

BAD NEWS!!

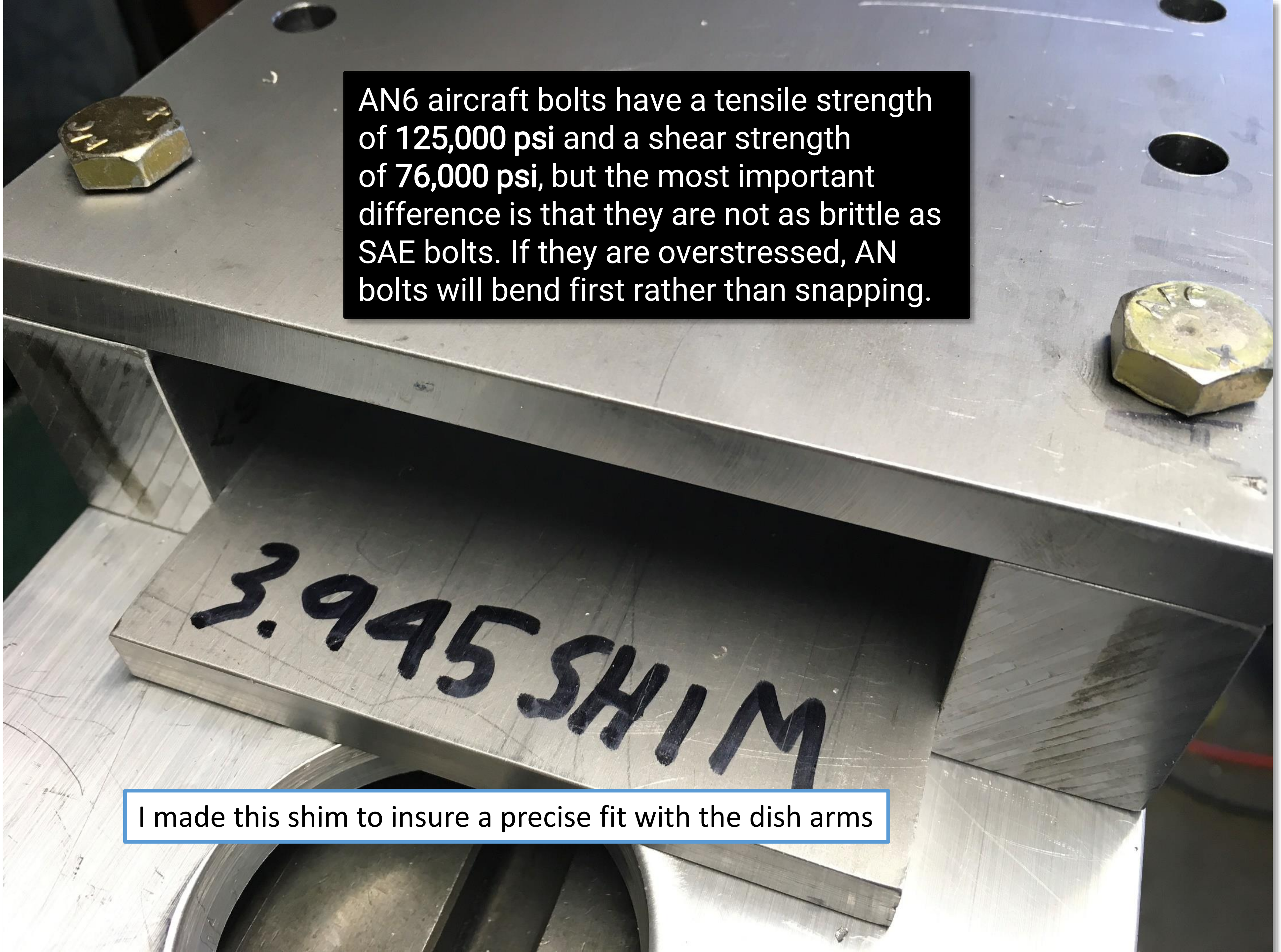
- Dish is so Unbalanced that the Rotor's Elevation Axis Ground to a Halt and Started SQUEAKING!

I need to make a counterbalance to overcome the offset weight stalling out my rotor's elevation axis. The counterbalance arms will grip these two arms. I could have simply attached the counterbalance to these arms by drilling and tapping had I known I had a problem prior to mounting the dish on my tower, but trying that while hanging off the side of the tower was too dangerous. I needed clamps once the dish was installed…

Clamp details… I wasn't about to try to drill holes in those 1-1/2 inch thick dish arms while hanging off the side of my tower. Clamps are the only safe way…

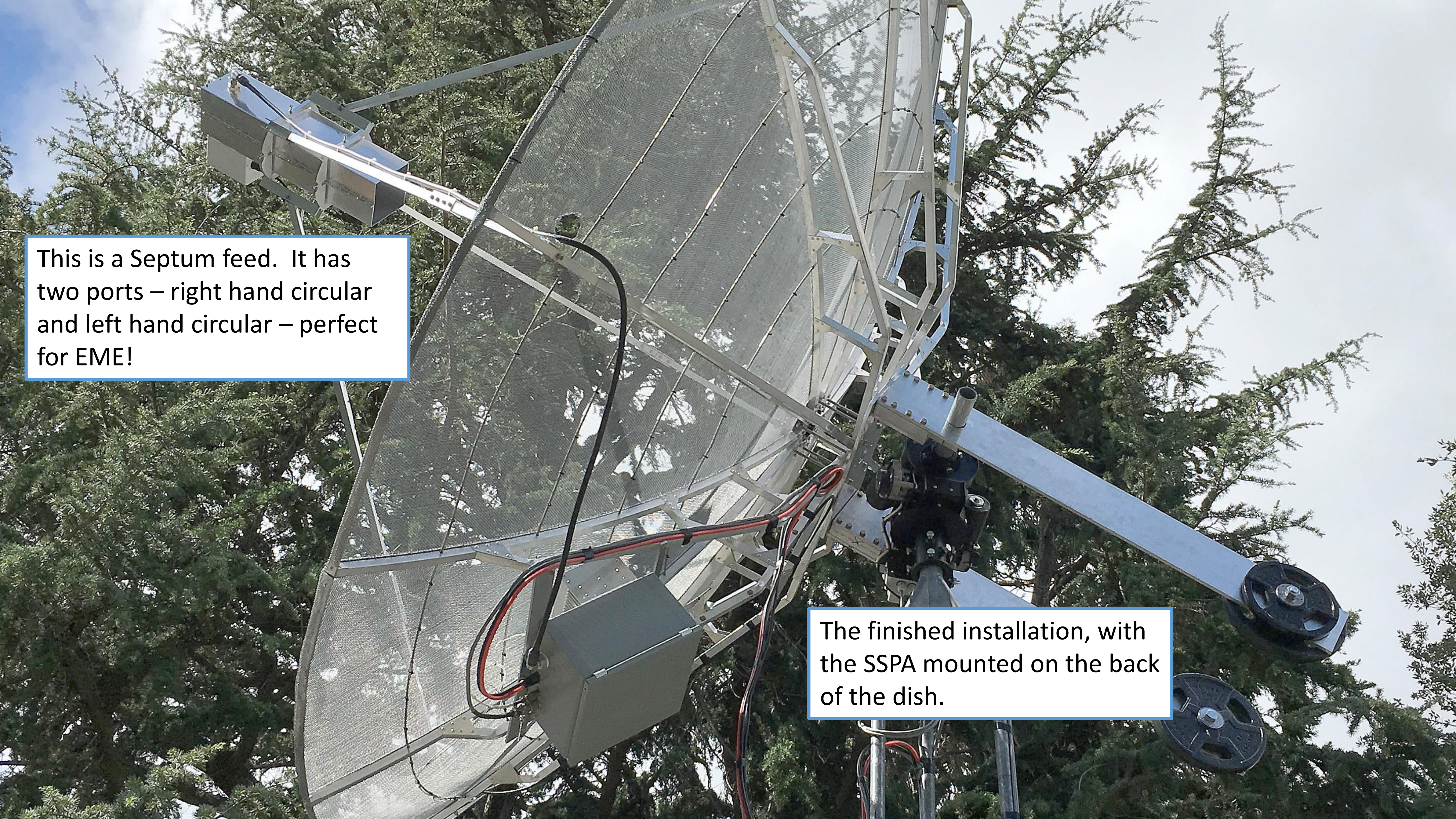


AN6 aircraft bolts have a tensile strength of **125,000 psi** and a shear strength of **76,000 psi**, but the most important difference is that they are not as brittle as SAE bolts. If they are overstressed, AN bolts will bend first rather than snapping.



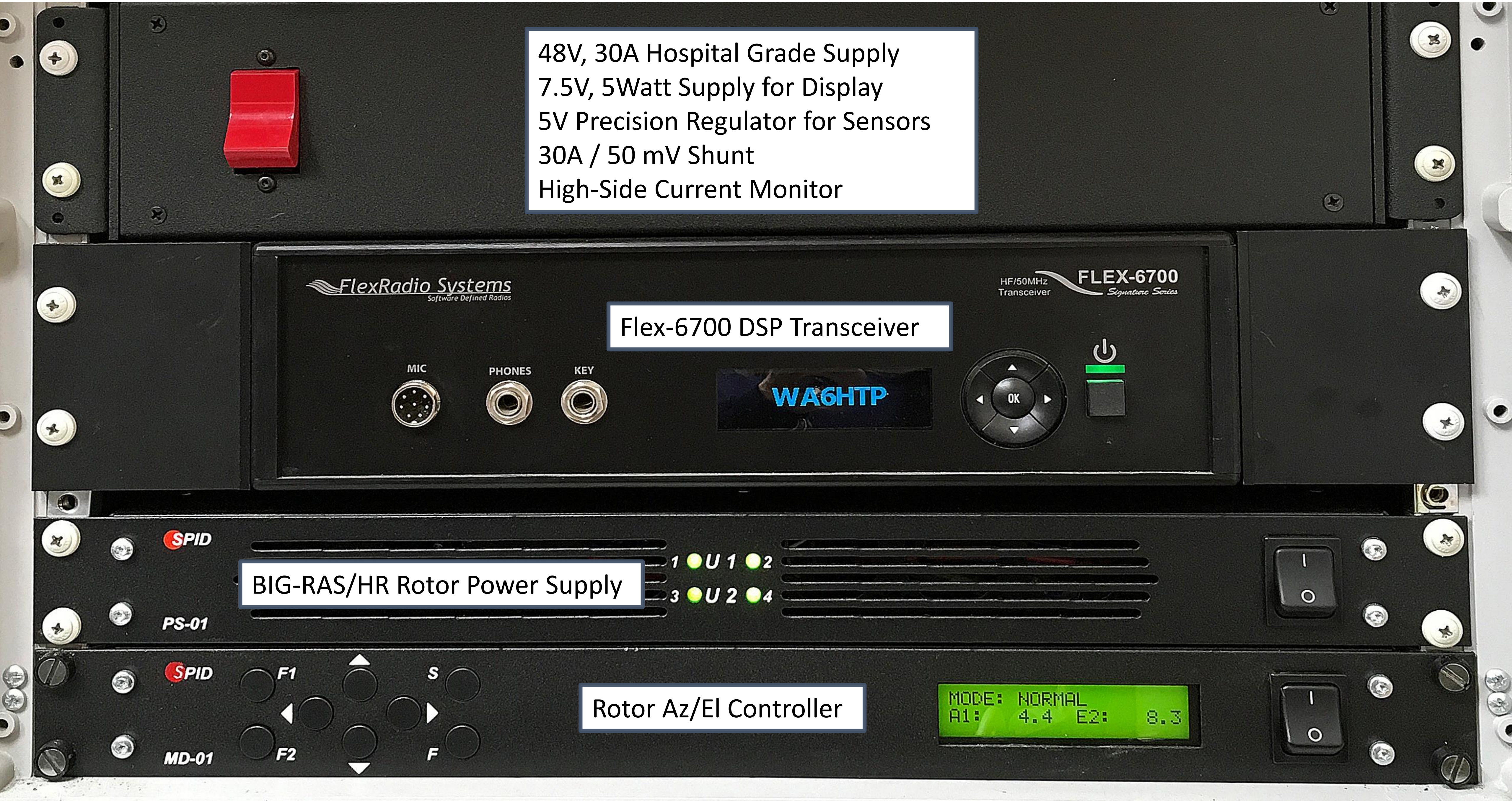
I made this shim to insure a precise fit with the dish arms

Counterbalance arms clamped tight to the dish arms and the pipe acts as a pivot point.


This is a Septum feed. It has two ports – right hand circular and left hand circular – perfect for EME!
The finished installation, with the SSPA mounted on the back of the dish.

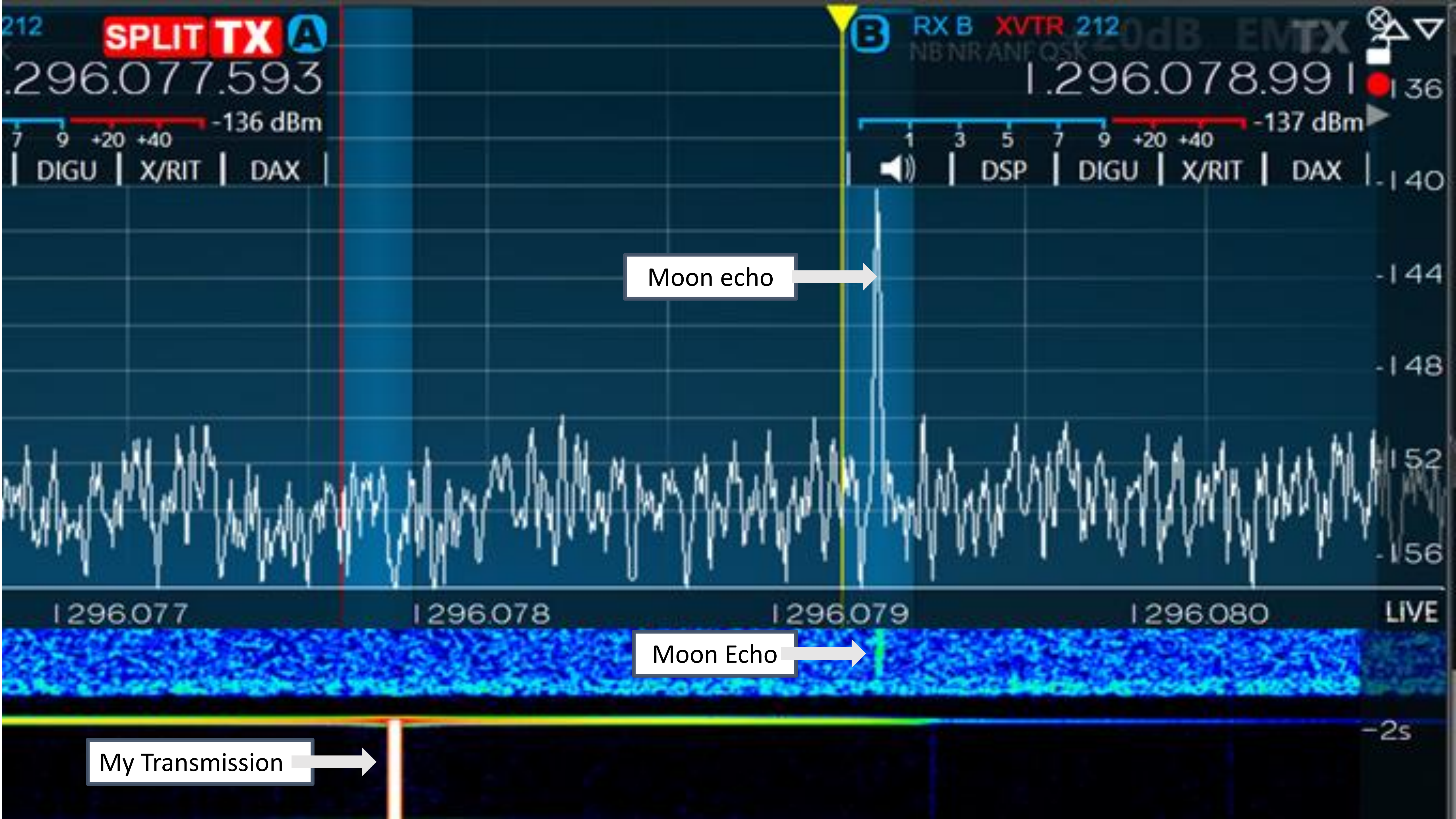

One way I can see if my tracking application is doing the job, is to track the Sun. The shadow of the feed should be directly in the middle of the dish, and the shadows of the feed supports should line up with those strips.
The square shadow (red arrow) to the left is my LNA enclosure on the side of the feed.

MY STATION


48V, 30A Hospital Grade Supply
7.5V, 5Watt Supply for Display
5V Precision Regulator for Sensors
30A / 50 mV Shunt
High-Side Current Monitor
FlexRadio Systems
Software Defined Radios
HF/50MHz Transceiver
FLEX-6700
Signature Series
Flex-6700 DSP Transceiver
MIC
PHONES
KEY
WA6HTP
OK
SPID
PS-01
BIG-RAS/HR Rotor Power Supply
1 U 1 2
3 U 2 4
SPID
MD-01
F1
F2
S
F
Rotor Az/El Controller
MODE: NORMAL
A1: 4.4 E2: 8.3

Moon Echoes!

The next slide shows my Moon echoes in the Flex-6700's waterfall (bottom) and spectrum display (top). My Moon echo is delayed by 2.7 seconds and Doppler shifted up in frequency 1,398 Hertz as the Moon approaches. My echo is 14 dB above the noise level which is very satisfying!



SPLIT TX
A
.296.077.593
-136 dBm
DIGU
X/RIT
DAX
B
RX B
XVTR
212
1.296.078.991
-137 dBm
DSP
DIGU
X/RIT
DAX
Moon echo
1296.077
1296.078
1296.079
1296.080
LIVE
Moon Echo
-2s
My Transmission

My First Contact!

After about four months of non-stop work, I finally made a contact using the Moon as a reflector. I used free software called WSJT-X. It stands for "Weak Signal Joe Taylor". Joe is an astrophysicist at Cornell University, He is also the recipient of the Nobel prize in physics and leads an all volunteer team of hams that are constantly adding features and upgrading the package.

My first EME contact using the digital mode JT65-C, was with HB9Q, Dan, in the city of Reinach in Switzerland! See the next slide…

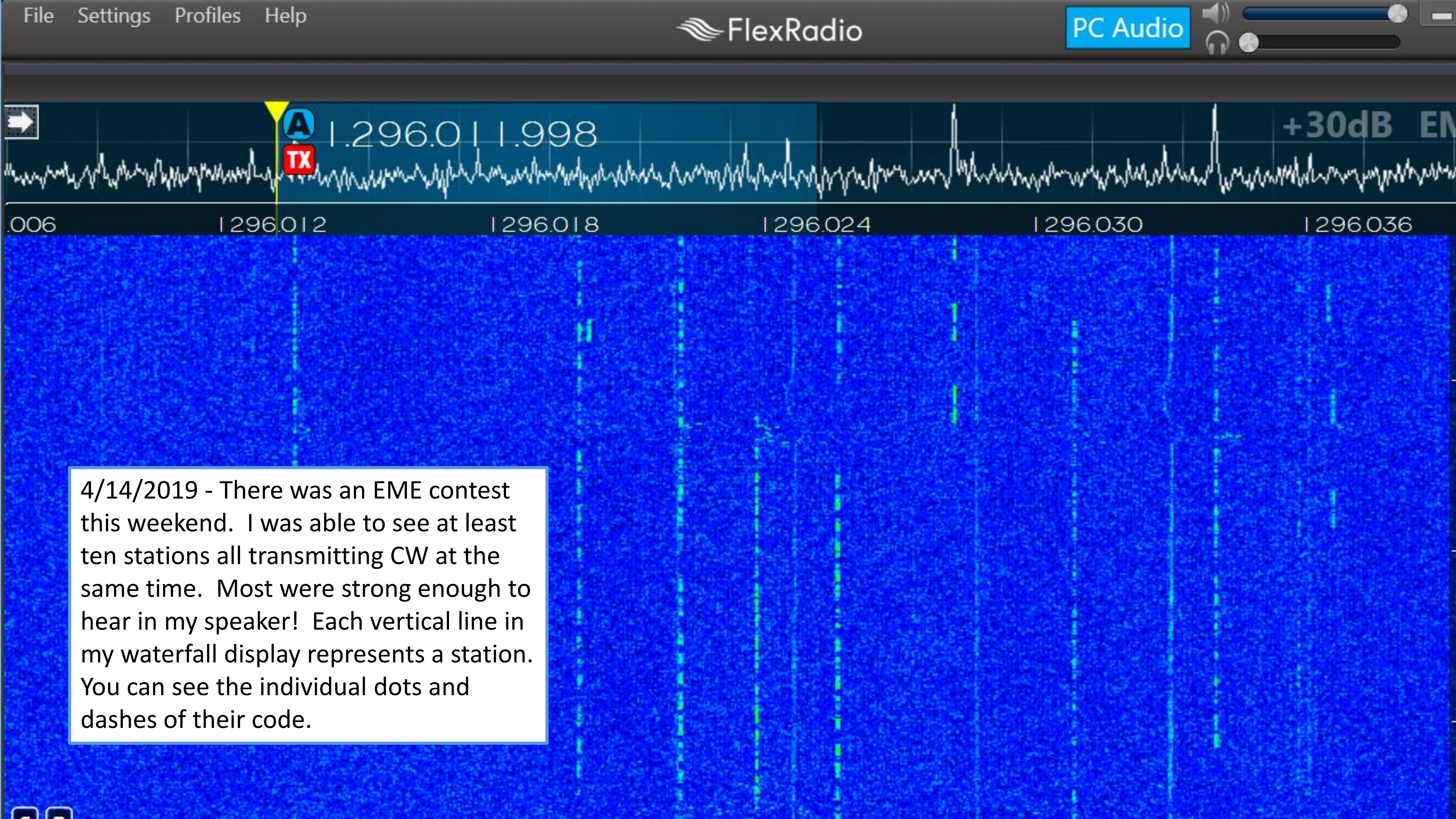
Average Decodes

UTC	dB	DT	Freq		Message	
1639	Tx		1500	#	CQ WA6HTP CM97	
1640	-1	4.8	1722	#*	WA6HTP HB9Q JN47	f
1641	Tx		1500	#	CQ WA6HTP CM97	
1641	Tx		1500	#	HB9Q WA6HTP CM97 OOO	
1642	-17	-3.1	1722	#	RO	
1643	Tx		1500	#	HB9Q WA6HTP CM97 OOO	
1644	-1	4.8	1721	#*	WA6HTP HB9Q RO	f
1645	Tx		1500	#	RO	
1646	-17	-1.9	1722	#	RRR	
1648	-1	4.7	1722	#*	TU JUAN B-6	f

JT65 contacts are kept to a bare minimum to allow extremely powerful digital processing to take place in a reasonable amount of time. A "contact" requires the exchange of call letters, location, an acknowledgement of reception, and a sign off. This process takes six minutes as the data rates are extremely slow.

My transmissions are in yellow and his are in red. In my excitement I messed up my end a bit…

Decode | Enable Tx | Halt Tx | Tune | Menus



4/14/2019 - There was an EME contest this weekend. I was able to see at least ten stations all transmitting CW at the same time. Most were strong enough to hear in my speaker! Each vertical line in my waterfall display represents a station. You can see the individual dots and dashes of their code.

As I get more experience in the festinating world of Amateur Radio EME communications I'll add to this…

APPLICATIONS I'M USING:

- Flex Radio SmartSDR
- WSJT-X, ver 2.0.1
- PstRotator

Thanks for reading. Juan(at)WA6HTP(dot)com