50MHz to 1296MHz Station Build & Lessons Learned - - Fred Caswell, K1UU, March 10/2023

STATION BUILD GOALS

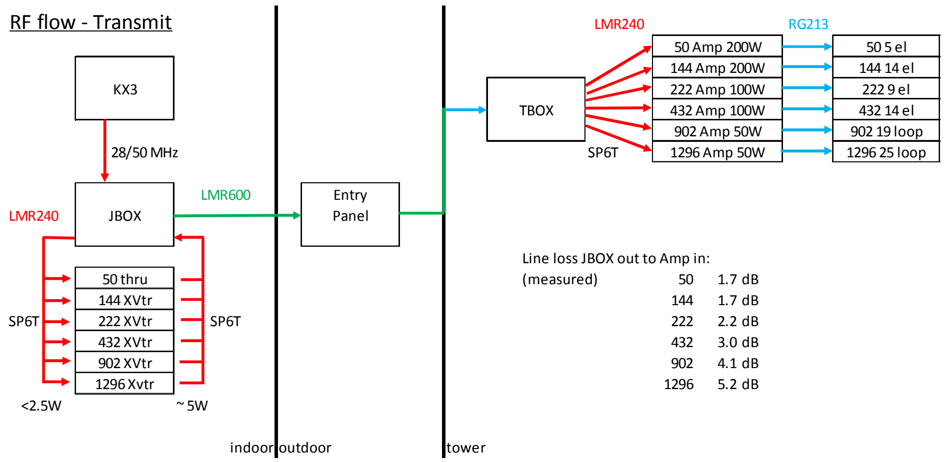
My goal in building this 50 MHz to 1296 MHz station was to achieve the typical power levels allowed by the contest “low power” category. The targets being 200W for 50 and 144 Mhz, 100W for 222 and 432 Mhz and 50W for 902 and 1296 MHz. I wanted the station to be fully integrated and simple to operate including “one button band changes”. My antennas are modest, so I wanted to minimize feedline losses where possible.

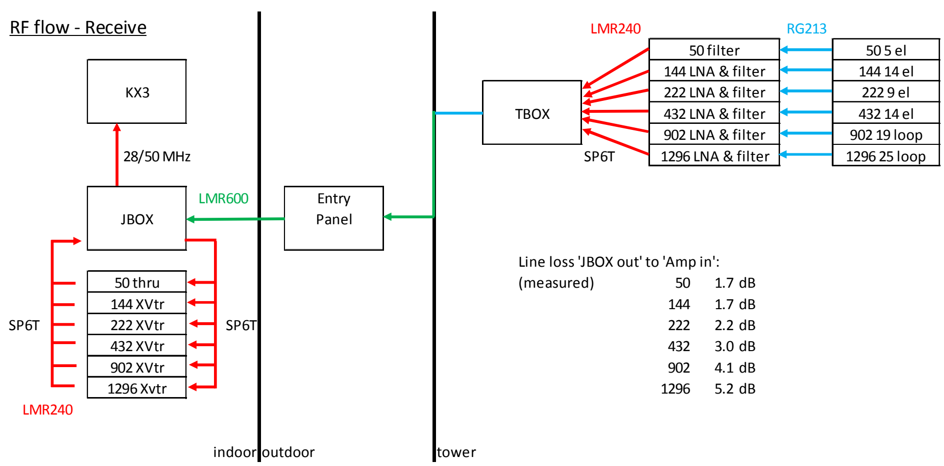
BASIC LAYOUT

A straight through feedline from my station to the antennas is 150 feet. Using LMR600 coax, the theoretical losses on 902 and 1296 MHz are 3.7 and 4.5 dB respectively. Add in connectors and relays and the losses are too great to ignore. At the very least I needed to have LNAs for these bands on the tower. Another issue is the potential receive noise from the cell tower that is less than ½ mile away – I wanted some filtering very close to the antennas. Rather than setting up a separate switching process for the higher bands, I chose to mount all the TX amplifiers and the RX LNAs and filters on the mast of the tower.

Antennas, amplifiers and LNAs for 50MHz thru 1296MHz at K1UU

Several years ago, I bought three new Teledyne SP6T relays on EBAY for $100 each. I could use them to switch one feedline from the station to the antennas. This would avoid having six feedlines going around the rotator. See the diagrams showing the RF flow during transmit and receive.





With the basic layout defined, I focused on the components I would need to build to fully assemble the station:

- Amplifiers for 50, 144, 222, and 432MHz
  - Including receive LNAs and filters
- Desktop junction box (JBOX) for switching transverter RF, DC, FWD/REF power, etc.
- Tower junction box (TBOX) for switching RF, 50V DC PTT, SWR, LNA power
- Power supply 12, 28, 50V

Amplifier, TBOX, JBOX and Power Supply

The picture shows the boxes that I built to complete the station. On the left is 1 of the 4 amplifiers. The TBOX is at center, top. The JBOX is at center bottom and the Power supply is on the right.

I used Front Panel Express (FPE) for all the sheet metal. FPE provides a straightforward CAD program that makes it easy to layout the pieces needed. They can do rectangular cutouts and popular connector holes. They offer fancy colors and designs, but I settled for some simple lettering. Their products and service are excellent, but their prices seem high.

All the sheet material is sold in metric thicknesses. I had them make one piece in each box with raw aluminum to allow grounding. All other sides are anodized. They sell small threaded angle brackets used to assemble the sides together.

The amplifiers and the TBOX are mast mounted. All the connectors are on the bottom of each box and the bottom plates are recessed to hide the connectors from the weather.   The sheet metal pieces overlap, and I used weatherproof tape to seal all the seams and the connectors.

AMPLIFIERS

Amplifiers for 50, 144, 222 and 432 MHz with key components mounted

The picture above shows the four amplifiers with the key components mounted. No wiring or shielding is in place yet. The upright panels in the photo will be the bottom panels when mounted on the tower. Each amplifier has a Tohtsu T/R relay and a circuit board on the bottom panel. The circuit board routes DC, the receive RF, PTT, FWD, REF and LNA control signals. The 50MHz amp on the far left will have a DEMI built 50 MHz filter using a Temwell 3 section helical filter. The other three amps have a DEMI LNA/filter mounted on their boards.

W6PQL Jim Klitzing sells a range of VHF+ amplifiers and components. I used a W6PQL low pass filter in each amplifier. They are mounted on the left side of each heatsink. These low pass filters also have couplers and components to measure forward and reflected power. I chose to use his 500W pallet in the 432 MHz amplifier on the right.

NXP sells “evaluation boards” for several frequencies including 50, 144 and 222 MHz based on their MRF300 LDMOS part. Each board is rated for 300W+ output, but the data sheet charts indicate about 220W maximum linear output. These boards meet or exceed my needs for contest low power levels. The evaluation boards for 50 and 144 MHz measure 2” x 3” (see the left two amps in the picture). The 222 MHz NXP board (center right) is 5” x 5” and it uses microstrip for impedance matching. The price for each of the NXP boards was $350 when I bought them in late 2021. As of this writing they sell for $950 each!

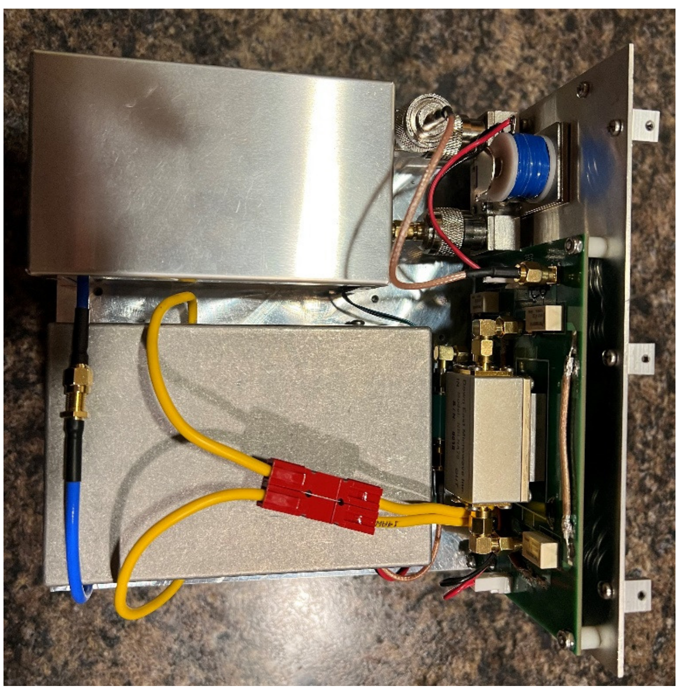
The heatsinks are from Heatsink USA (HUSA). They are 8” x 8” with 3” fins. I ordered the heatsinks by length and I sent a simple pdf file showing my desired hole locations, threads, fly cutting and specs to the company. HUSA was great to work with and they created a CAD drawing and sent it to me for approval. The price for the drawing and machining was reasonable.

The large heatsinks appear to be overkill especially when compared to the small NXP boards, but the amplifiers will be outside during summertime. The ambient air temperature and direct sunlight heatsink temperature will be much higher than room temperature. I assumed:

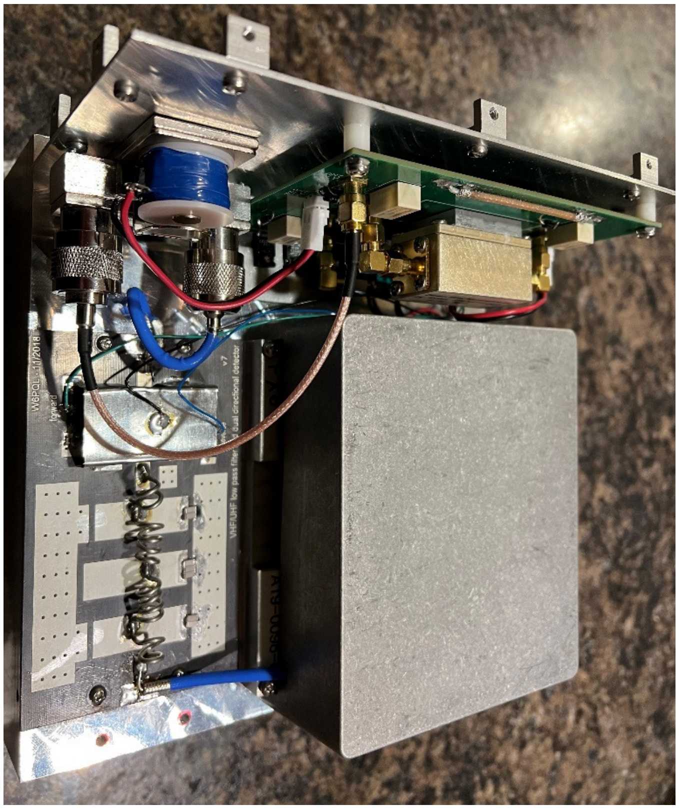
- 50 ^{0}C ambient temperature
- Continuous 200W output using FT8 (50% duty cycle)
- 65% efficiency (datasheet specifies 72%)
- 0.55 ^{0}C/W FET junction to FET case (datasheet)
- 0.5 ^{0}C/W FET to heatsink (guess)
- 0.375 ^{0}C/W heatsink (ARRL handbook chart)

Based on the above somewhat rare conditions, the FET junction would be at 143 ^{0}C verses a datasheet maximum allowed of 175 ^{0}C. I would not want to use smaller heatsinks.

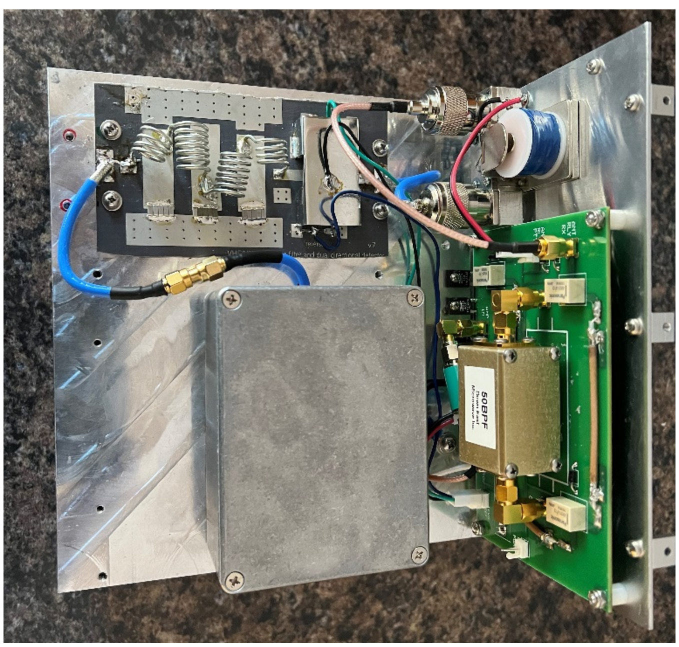
The following pictures show the amplifiers fully wired and with the shielding in place.



432 MHz amplifier



222 MHz amplifier



50 MHz amplifier (144 MHz amplifier looks the same)

DESKTOP JUNCTION BOX (JBOX)

I use a microHAM microKEYER III (MKIII) for CAT control and audio routing. It is connected between the Elecraft KX3 IF rig and the station computer. The MKIII also contains a sound chip for digital modes and a K1EL WinKeyer for CW.

I also use a microHAM STATION MASTER (SM) that takes band and PTT information from the MKIII and provides band switching along with KX3 / transverter / amplifier PTT sequencing to the JBOX.

The JBOX uses the band and PTT sequencing information to perform the following functions:

- Switch two 28V SP6T relays to route:
  - RF from the KX3 to the proper transverter input
  - RF from the selected transverter output to the antenna feedline
- Switch 28V SP6T RF relay and 12V relays in the TBOX
- Provide the sequenced PTT signals to the selected transverter and amplifier
- Manage FWD and REF power displays

The JBOX also contains a simple flip flop that disconnects PTT signals from the transverter and amplifier if the reflected power exceeds a 3:1 SWR threshold.

The JBOX rear panel

Top row of connectors pictured from left to right:

DB9 connector – band data in from Station Master
(6) phono jacks – PTT for the transverters
DB9 size, 15conductor connector – 12V and 28V band signals to TBOX
SP6T relay – (6) transverter out RF to feedline
SP6T relay – KX3 RF to (6) transverter in

Bottom row of connectors pictured left to right

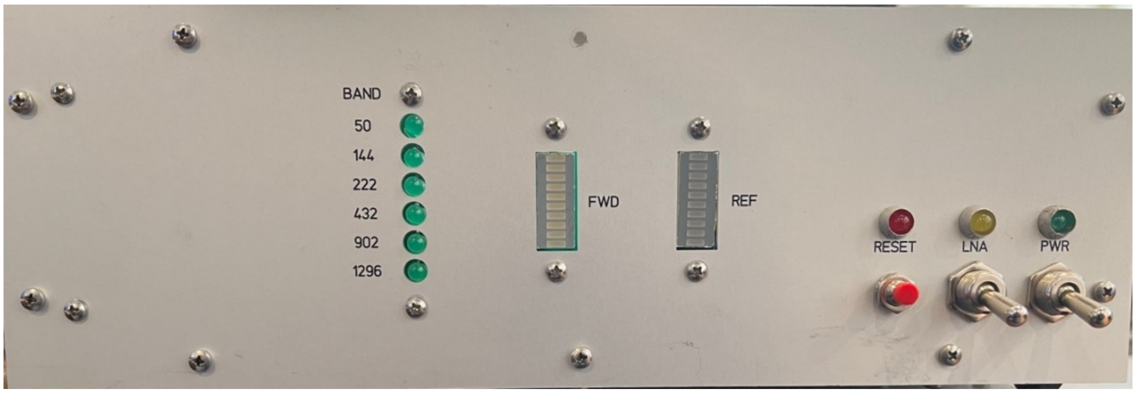
Red / Blk power pole connector – 13.6V in from power supply

Fuse

Yel / Blk power pole connector – 28V in from power supply

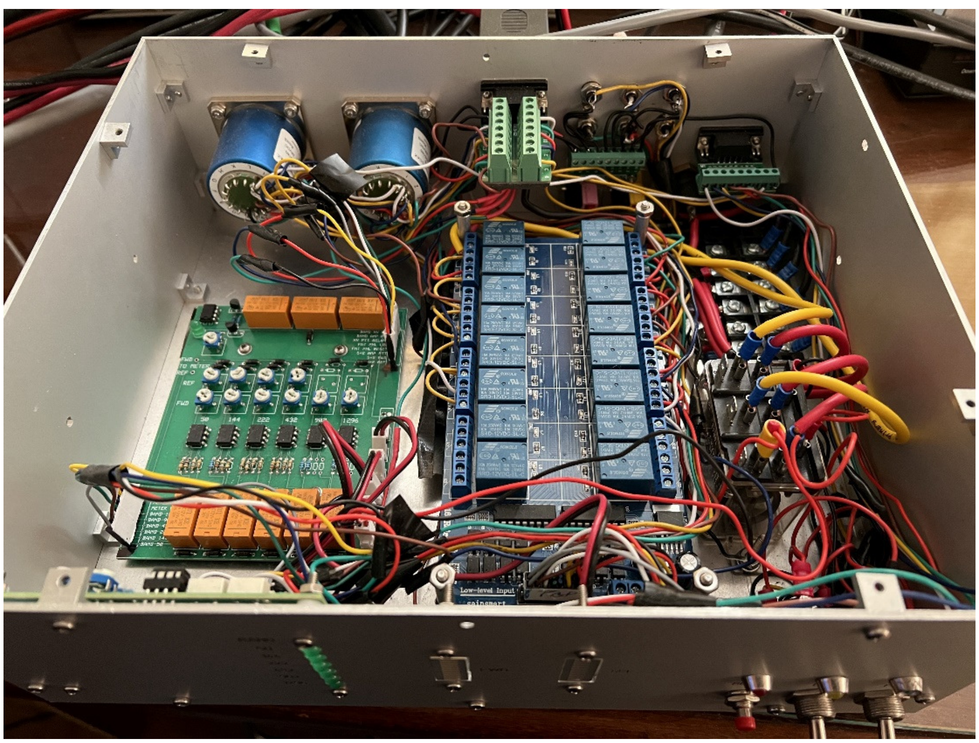
Pink / Blk power pole connector – 50V in from power supply

DB9 size 2 power pins, 5 signal pins – 50V, PTT, LNA, FWD, REF to TBOX



JBOX Front Panel

The JBOX front panel has LED band indicators, FWD and REF power bar graphs (W6PQL), LED high SWR indicator and reset button, switch to turn the LNA on or off, and the power switch.



JBOX internal view

Refer to the JBOX internal view photo. Across the top of the board on the left is the high SWR circuit. A potentiometer sets the comparator level. When the reflected power DC signal exceeds the comparator level, a simple two transistor flip flop energizes the relays to disconnect the PTT voltage from the selected amp and transverter.

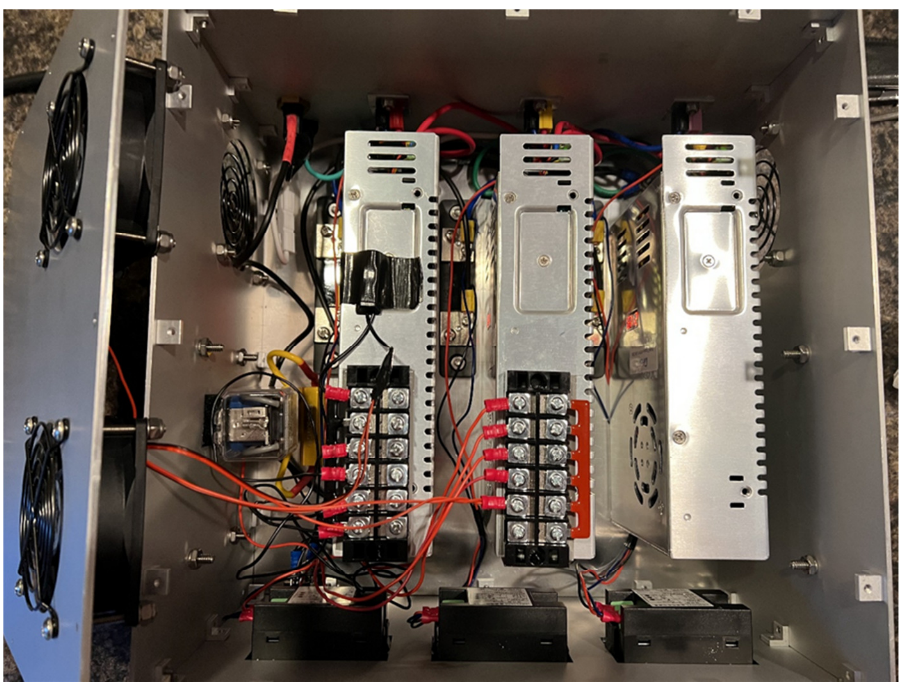
The mid-section of the board has op amps and potentiometers to calibrate the DC levels of forward and reflected amplifier power to drive the front panel LED bar graph displays. Across the bottom of the board are relays that select FWD and REF signals by band.

The boards (there are two) in the center of the box contain (16) 10-amp relays each. These boards only cost $15 each, but the downside of using them is all the point-to-point wiring.

I use 6 (one per band) relays on each side of each board, resulting in 4 banks of 6 relays.
The 4 banks are:

- 50V, 10-amp power for the amplifiers
- 28V to select the band on the SP6T relays
- 12V to select the band in the TBOX, the SWR management and the front panel LEDs
- Closure to ground to provide PTT for the transverters

POWER SUPPLY



Power supply

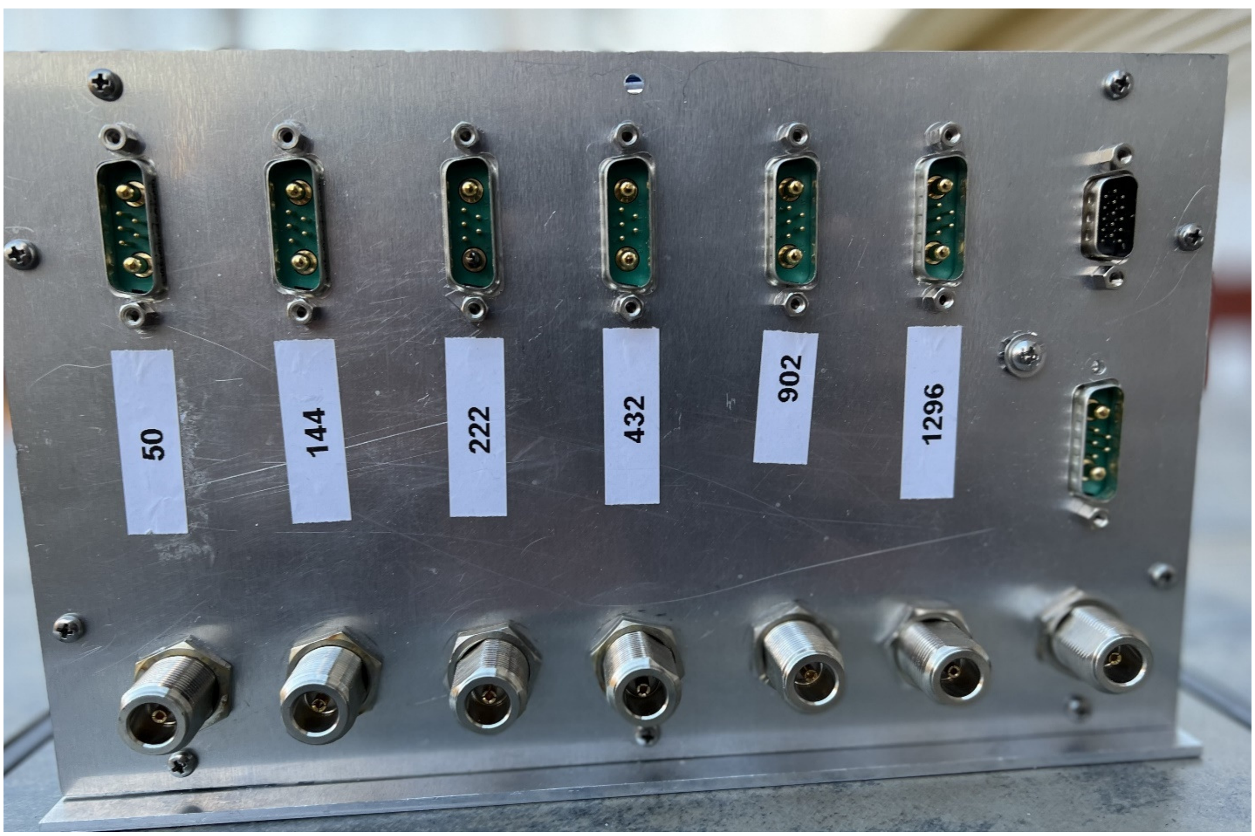
The power supply is a simplified version of the one described on W6PQL's website. I used three "DROK" ($39 each Amazon) 0V to 24V, 20-amp power supplies. They are connected in series with one set at 13.6V, the next at 14.4V (28V total) and the third at 22V (50V total).   They run on 120V AC. Included in the power supply box is a current inrush circuit and a temperature sensor that will turn on the two small fans in the top cover when the temperature exceeds 100 degrees F. In the picture, the leftmost unit is the 13.6V supply. Between the supplies are the shunts for the front panel amp meters.

TOWER DISTRIBUTION BOX (TBOX)

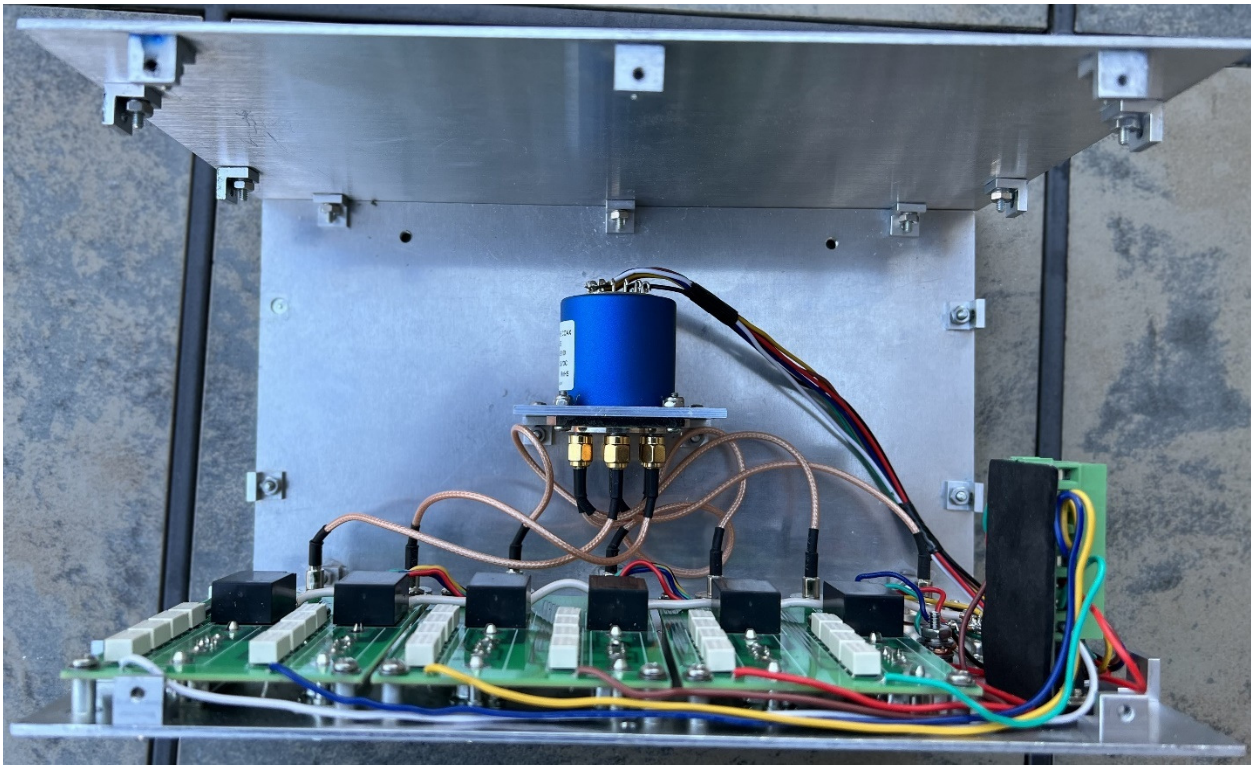
The TBOX has 3 input connectors:

N connector: RF from the selected transverter (less than 5 watts)
DB9 (15 cond): 24V and 12V band selection signals
DB 5+2power: 50V and PTT, LNA, FWD, REF signals

There are two output connectors for each band – an N connector for RF and a DB style 5+2power connector for 50V DC and PTT, LNA and SWR signals.



TBOX connectors



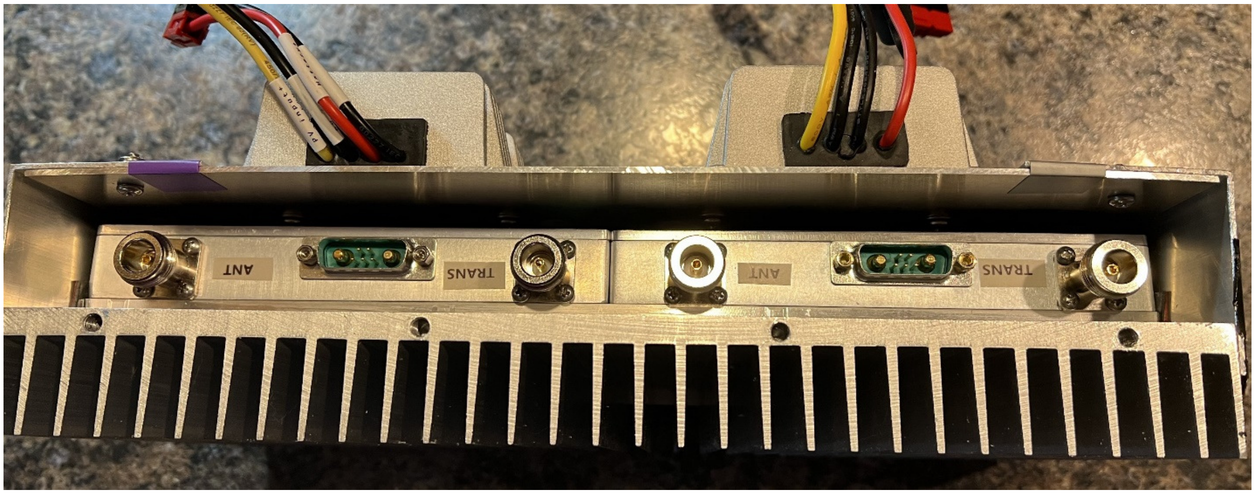
TBOX internal

I designed an ExpressPCB mini board to mount the relays needed for 50V power and the PTT, LNA, FWD and REF signals. I was able to lay them out with two bands per board. ExpressPCB sells mini boards in sets of three, so I was able to cover all six bands with one mini board order.

902 MHZ and 1296 MHZ AMPLIFIERS

It was necessary to modify the 902 and 1296 MHz amplifiers a bit to fit them into the station. First, they would be mast mounted without their normal heatsinks and fans. I designed a 10mm thick adapter plate to go between the amplifiers and a larger heatsink. Second, I needed to provide weather protection. See the picture below. Both amplifiers are mounted on the larger heatsink and are recessed into a cover. Lastly, I needed to convert the 50V available at the top of the tower to the 12V, 20A required by the amplifiers.

Powerwerx and HRO sell 300W 50V DC to 14.6V DC solar charge controllers. I tested the converters under “on the tower” conditions and they were able to support full power from the 902 and 1296 MHz amplifiers. You can partially see the converters at the top of the picture.



902 MHz and 1296 MHz amplifiers

<u>LESSONS LEARNED</u>

<u>YOU MUST READ THE SPEC SHEETS!</u> case1

When I was first mapping out the station, I was focused on the new amplifiers. I knew I needed 50V at less than 10A to power each of the 4 new amps. Thinking of house wiring, I decided that I needed 14-gauge zip wire to handle the current to the amplifiers. In my head I did a quick calculation for the 902 and 1296 MHz amps DC requirements:

50W RF output
50% efficient
12.5V
100W / 12.5V = 8 I need 8A

I was happy with my choice of 14-gauge wire and with my choice of 10-amp relays…

After everything was built, I tested the four new amps with the actual wiring I would use to mount everything on the mast. There were no (DC) problems with the new amps. When I started testing the 902 and 1296 amplifiers, I got a nasty surprise.

The amplifiers would not put ANY power out. Frustrated, I opened them up and started tracing RF at a few points in the circuit. There was RF present at the module inputs, module outputs, combiner output and at the input to the TR relay. I measured DC to the relay, and it was under 8 volts – too low for the relay to engage! How can this be?

I looked at the spec sheet that came with the amplifiers and was shocked to see a requirement of 12.5V at 20A! Turns out the amplifiers are much less efficient than my 50% assumption! Probably should have read the spec sheet. I'm lucky I didn't weld the 10-amp relays.

My power supply can provide 20A so why is the voltage so low? You guessed it…14-gauge wire is sufficient to handle the current, but the voltage drop over 100 feet (200 feet round trip) at 10 amps is 5 volts. I had no chance of getting the power required to the amplifiers!

At this point I changed the zip wire up the tower to 10-gauge and I no longer send 12V up the tower. Only 50V goes up the tower and I use the 50 to 14 volt converters described above to provide power to the 902 and 1296 amplifiers.

YOU MUST READ THE SPEC SHEETS! case2

One of the first components I bought were the LED bar graphs for forward and reflected power. I needed them early on so I could design the JBOX front panels. When they arrived, I wired them up to see how they worked. I could not get them to work. After re-reading the information on the W6PQL website, I discovered that the bar graphs are set up to respond to negative voltages. I was happy to see that by shorting two pads on the bar graph boards, they would respond to positive voltages. My 902 and 1296 amplifiers provide a DC signal of about 7 positive volts when producing full power. I assumed the low pass filter couplers in each of the four low pass filters would also provide a reasonably high positive voltage for both FWD and REF power. I assumed the voltage would increase as power increased.

Based on my assumptions, I had PC boards made that included traces for non-inverting op amps. I built up the boards and installed them into the four new amplifiers.

It wasn't until I was testing the completed amplifiers that I saw that the couplers on the LPF boards produce a negative voltage for FWD and REF power. Not only was it a negative voltage, but it was also very small. With the amplifier producing 200 watts into a matched load, the DC forward power signal was under -0.5 volts!

I went back to the W6PQL website and read the specs and data in detail. Sure enough, all the information was there. The bar graphs respond to the small negative voltages that the couplers produce. I ended up developing a new board to manage the SWR bar graphs.

NEVER TRUST THE SPEC SHEETS!

Look at the prior picture of the 902 and 1296 amplifiers. In the center of each unit is a connector the size of a DB9, but with 7 pins. There are two large outer pins designated as A1 and A2. These two pins are rated for 20 amps. In the center of the connector, there are 5 pins used for control signals.

When I was mapping out the station, I decided to use these connectors at the JBOX, TBOX and all the amplifiers. They conveniently will handle the power requirements and had enough signal pins for my needs. For consistency I wanted to use the same pin-outs throughout the station.

I grabbed the 902 MHz amplifier spec sheet and read that pin A2 goes to the red wire and handles the +13.8V. Pin A1 goes to the black wire and is ground. Perfect! I laid out and built the TBOX boards using A2 as 13.8V. I wired the JBOX to provide the positive voltage on pin A2. I made up the 7 required cables with two connectors on each – the red wire to A2. All consistent…nice.

I tested the amplifiers as part of the whole system. I had hundreds of feet of wire and coax around my desk so I could see what performance would be like. The test went (for the most part) well for the first four amplifiers – the newly built ones. When I switched bands to 902 MHz, I heard popping sounds and saw some smoke. Not good. I stupidly thought, okay, I have something screwed up on 902…I'll try 1296. More popping sounds and more smoke. Not good.

I opened the units up and saw that the bypass caps on the DC lines were all blown. I had the positive and negative connectors reversed based on the spec sheet!

I thought that the modules might be damaged also. I packed the amplifiers up and shipped them to the manufacturer to see if anything was salvageable. Only the bypass caps and one relay were damaged. The manufacturer was able to repair everything.

I looked closer at the 902-amplifier spec sheet – it incorrectly states in two places that A2 is positive. This is the spec sheet specifically for my unit – it has the serial number marked on the sheet. Then I looked at the 1296 amplifier spec sheet. Again, the spec sheet specifically for my amplifier. On the front page it says A1 is positive, matching the physical amplifier. On page 3 it incorrectly says A2 is positive.

Mapping the entire station layout based on a quick glance at one spec sheet was a mistake.

*__SOMETIMES IT **IS** THE TEST EQUIPMENT!__*

During the testing phase I had several tasks as follows:

- Adjust the KX3 output and the transverter output to achieve the target amplifier power
- Check intermodulation distortion using a two-tone test. I want the 3rd order peak 30 dB below the carrier per the ARRL standard.
- Check harmonics. The second order harmonic needs to be at least 60 dBc with each successive harmonic farther down.
- Check spurious emissions. They need to be at least 60 dBc.
- Measure and calibrate the forward and reflected power signals.

I started testing with the 6-meter amplifier. It performed nicely and hit the target output power with the expected drive. Then I looked at harmonics and the second harmonic was only 53 dB down…

This started me on a 6-week grueling ordeal. I investigated a dozen different things to get the harmonic down – to no avail - including:

- I measured the harmonics with no low pass filter in line – same result
- I thought the MRF300 quiescence current might be set for class C operation and tried 15 current levels between 50 mA and 1 amp…no change
- Maybe the filter required shielding – no change
- Maybe the amplifier board required shielding – helped some
- I put the cover on the unit and the harmonic got worse
- I cut a 100 MHz stub that had 27 dB dip – no joy
- I built a 50MHz / 100MHz diplexer - nothing
- W6PQL uses a "standoff" length of coax on his 50MHz amplifier between the amplifier and the filter – lots of connector soldering, no results

Frustrated, I put the 50MHz amplifier aside and tried the 2-meter unit. I saw similar problems. I had tested all the amplifiers at different stages of the build and developed matrices of test results that were not repeating.

In desperation, I put a different coupler into my test setup. All the harmonics were nicely 60 dBc! A couple days later my spectrum analyzer could not even find the USB connection – it was dead. I sent the unit for repair but I wasn't sure it could be fixed at a reasonable cost. I purchased a new analyzer and completed the project – harmonics were never a problem again!