A Minimum Discernable Signal Comparison Signal Generator for the

NEWS Group Annual Meeting and Picnic

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Background

Purpose – to have a group of hams do comparative sensitivity (and transmit power) measurement on microwave bands 10 GHz and above. Minimum Discernable Signal or MDS is a well-defined signal to noise ratio in a fixed bandwidth – typically 3 dB and some narrow and appropriate bandwidth for the signal type. This test, however, is a combined radio and operator ability to determine the presence of a CW signal. So, very good ears might get a few more dB of "NEWS Group MDS". The original purpose for this testing was to help hams in our club figure out if their radios were great, good, or poor by simple comparison to others. It's not meant to be a competition, but rather a radio check-out. We conduct this at our annual club meeting in July where there is a pretty good layout for such testing. See Figure 1. Hopefully, if anyone discovers a weakness in their radios they have enough time before the summer contests to effect improvements.

Figure 1 A photo of the setup of many of the members of the NEWS Group at the K of C pavilion in Enfield, Connecticut, readying equipment for the MDS testing and enjoying burgers, hot dogs and good times as part of the annual club meeting.

How the Test is Performed

To perform this test we have a remote setup, some 330 ft. away from the pavilion where all participants ready their stations. That remote setup has RF signal sources and a keyer, along with attenuators. One person assists at the Pavilion by listing every call and radio details on a clip board. Sufficient power is transmitted from the remote site so that all can hear it. Then, using HT's the remote operator and the Pavilion assistant communicate while the power is dropped in steps until some station no longer hears

it. The amount of attenuation (in dB) used at the remote site is marked next to that station, and the process continues until the last station hears the signal no longer. That completes the MDS for that band. To find relative signal strength each station transmits a carrier while the remote measures the received power level, and that level is also recorded by the pavilion assistant. Then the next band is activated and the process repeats. The results are compiled and the list shared.

Basic Requirements

- Use IF away from standard e.g. 145.1 MHz instead of 144.1 MHz
- Be on frequency (within 1 kHz at highest frequency)
- Must be easy to carry, set up and use, battery operated for a full day
- At least 4 bands 10, 24, 47, 78 GHz
- In addition to some gross attenuation, 1 dB steps of 60 dB
- Determine relative received power as well
- Would like to have remote control (eventually)

System Design

Hardware

Earlier versions of the NEWS MDS system were combinations of sources, attenuators, mixers and switches. This was effective and over the years bands were easily added as the club members also added capabilities to their portable stations. At some point Don, W1FKF decided that it was too much effort to keep on doing it and I raised my hand. I tried to learn from all that Don had done when designing my own solution. I saw that almost everything he used had some ability to control by computer, so I felt that I had a chance of redesigning with a computer at the heart of the system.

By back-of-the envelope figuring, I needed about 15 to 20 bits of control. I also wanted a computer which was affordable, fairly well known in the commercial market for hobbyists, and reasonably low power. I also needed to make a user interface and write software in some easy to learn language.

I found that there were several sources for 31.5 dB digitally controlled attenuators which were variable to 0.5 dB steps. I only needed 1 dB steps, so could just ignore the least significant bit. I needed to build two attenuators, each in its own metal box to keep signals from leaking, especially when the attenuation levels were high. With two in series I could achieve the requirement of 60 dB in 1 dB steps.

Eventually, I would like to be able to remote control this system from the Pavilion so that even I could be testing my own equipment while running the tests. Most operating systems provide some sort of remote desktop function, including LINUX.

The Raspberry Pi (Linux) plus Python in Pi-400 form factor was chosen as the computer. It is basically a keyboard with a Raspberry Pi 4 inside, and presents HDMI monitor output, and has USB outputs useful for keyboards and a mouse, and takes power in through a USB C connector a 5 V about 1 A. There are many breakout terminators available for the ribbon cable that plugs directly into the Pi-400.
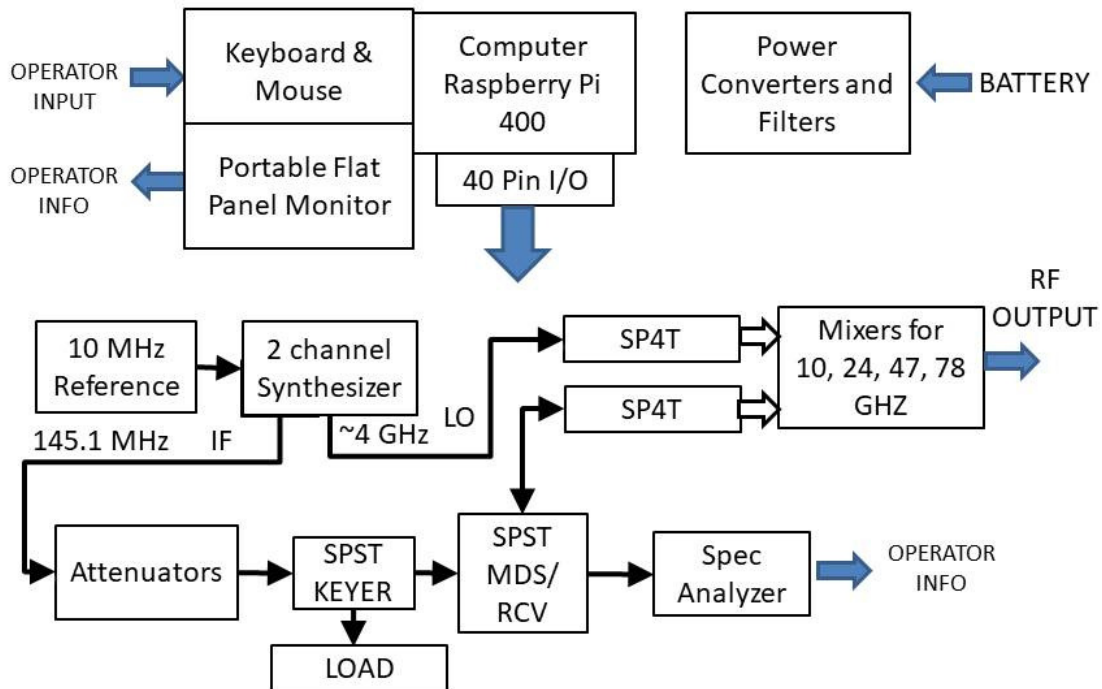
Figure 2. Block Diagram of MDS system.

Software

I had familiarity with UNIX from my career that included software development, so LINUX was immediately usable to me. The language Python is easy to learn, and the Python Projects type book I used had many examples to control individual bits on the interface cable.

I created a simple interface with one letter commands for B(band) and A(attenuator) followed by numeric values. A special band number such as 48 instead of 47 told the system to go into receive mode and stop keying. This mode turned off the IF from the synthesizer so as not to interfere with reception of the signal being transmitted from the Pavilion under test. It also directed a switch to connect the mixer IF to the Spectrum Analyzer (a "Tiny SA" centered on 145.1 MHz) instead of the (attenuated) Synthesizer IF output. Other commands included C(commands) to print help for the commands, and S(status) to give the status of all switches/attenuators and E(exit) to, um, exit. Every command results in a response. To simplify the beacon keying operation, that function was written as a stand-alone program, which was executed separately from the main MDS interface.

Component Selection

Raspberry Pi 400, with USB for Keyboard and mouse, HDMI for monitor, and 40 pin ribbon connector for control of the RF system. This convenient computer is built into a keyboard.

Portable monitor, runs off USB power and HDMI. The brand I use is Arzopa, but there are others.

Mixers: I used HP 11790 series (K, Q and W) MMW frequency extenders, up to 600 MHz IF, LO in 4 GHz range. For 10 GHz I just used standard connectorized mixer running on 3rd LO harmonic with a WR90 coax to WG adapter.

RF switches:

- 1x SP4T at 4 GHz range for LO Band
- 1x SP4T at 145 MHz for IF Band
- 2x SPDT at 145 MHz, 1 for Keying, 1 for Xmt/ Rcv

Attenuators:

- 2x 31dB each in own box, in series 145 MHz

Synthesizer:

- The Valon 5009 requires 6V, and has nearly enough output power for the LO, but needs a boost to get through cables and switches and still deliver +15dBm to Mixers LO port, so I added a Minicircuits ZX60-V83 and a small pad to get it "just right"
- 2 outputs, one at 145, other at 4 GHz range
- Internal table of frequencies, and change with parallel interface on fly
- Takes 10 MHz to lock

Reference:

- Q5 Signal 10 MHz, 4 output – this one happens to be about 10 ppb off frequency after 10 minutes, so within 780 Hz on highest frequency (78 GHz) which is very acceptable.

Construction

Control Cables

Ribbon cables need connectors, and there are a wide variety of them. I purchased a ribbon connector tool in order to make connections that were always good.

I decided to make a ribbon connector interface board. Directly from the computer a commercially available 40 pin connector breakout was convenient as it showed all signal names and has LEDs to show their state. From there I hand wired to a breakout board of my own which divided the signals into 4 ribbon cables. These ribbon cables had the functions of 1) 4 position LO and IF multiplexer switch including Key and Spectrum Analyzer switches, 2) Attenuator#1 binary dB value, 3) Attenuator#2 binary dB value, 3) Synthesizer control by selection from internal frequency pair table.
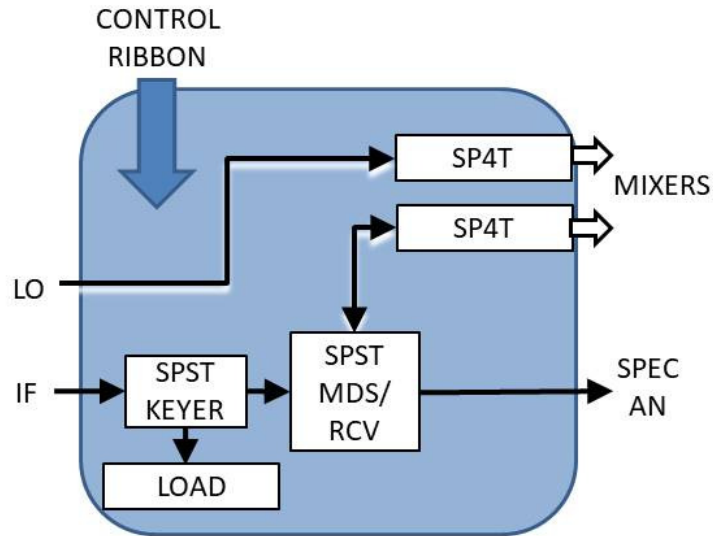
Figure 3 Block Diagram of the contents of the Multiplexing Switch Box

Each ribbon cable had ferrites. In two cases the ferrites were only on one end of the cable, but for the attenuators there were ferrites on both ends of the cables. Fortunately, the only switching transients on the cables were present during changes of configuration, not while actually performing tests.

RF Subsystem

Perhaps the most complicated part of construction (beyond mapping software bits to hardware functions) was the LO, IF Multiplexer plus Key and Spectrum Analyzer switch box. Doing it reminded me of a Star Trek movie *Wrath of Kahn* where they were in battle, barely able to tell where the other ship was. Spock, looking into his scanner said "his (Kahn's) pattern indicates TWO DIMENSIONAL THINKING". Well, to fit things in boxes, one has to think in 3D. (Thanks, Spock)
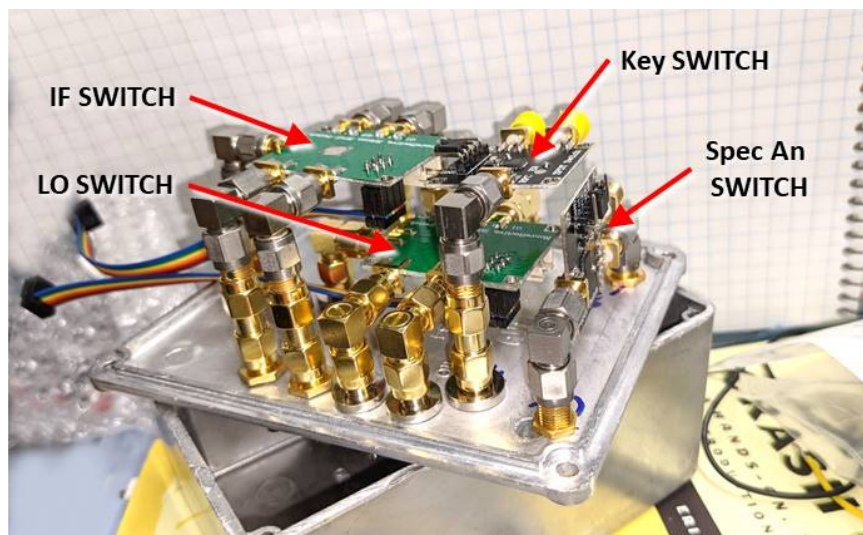

Figure 4. The internals of the Multiplexing switch box – certainly a 3D thinking task

As can be seen in Figure 4, switches are mounted with right angle and straight adapter SMA's. These had less loss than short connectorized flexible cables, and were equal to connectorized hard line, so this is how I did it. The 145 MHz signals were not particularly sensitive to loss, and could have been done with cables, but it would have taken more time and effort and probably not have been as neat (considering my lack of finesse with connector installation). I checked out the switch types available and the HMC7992 served well as a 4-way directing the 4 GHz LO and were more than adequate for the IF. Most of the 2-way switches I tested were quite adequate. I chose boards that used the HMC849. These were far superior to what was needed for the IF, operating from DC to 6 GHz with only 1 dB loss at the high end. Anyway, I have some spares for future needs. These SPST were only used on the IF.

The inside of the Attenuator boxes were very simple. Most of these use Analog Devices HMC 472A. I preferred that part. Nice easy parallel inputs – no clocks or data to format. Some boards use the '542B or the '109. I put just one board in each box with SMA in and out. I fed the ribbon out through a slit and immediately through a ferrite on the outside to prevent any ingress or leakage of 145 MHz IF.
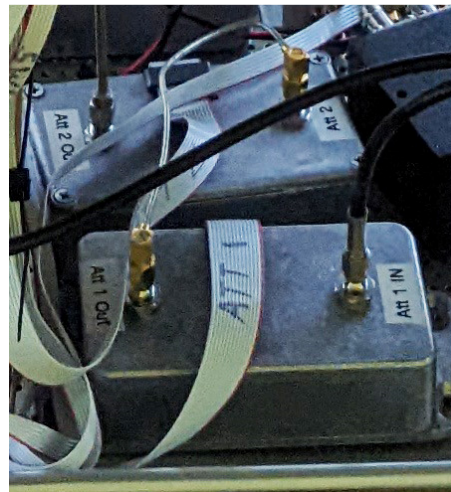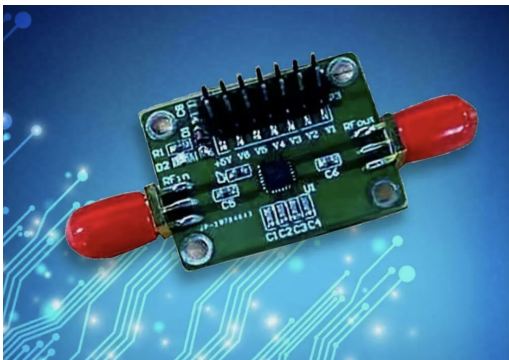

Figure 5. Left, a 30 dB digital Attenuator board. Right, these were put into individual boxes and connectorized with SMA to reduce leakage as much as possible.

With the Multiplexer box finished it was possible to perform some RF testing. First the switches were tested through the box by running a signal at an appropriate frequency for each function and measuring the outputs with a power meter. All seemed OK. Then, for a more complete RF system test, the mixers were connected to the RF portion of the system and wiring for each digital selection was set manually (hi and lo bits with alligator clips) while listening to each band with radios in the shack. This process found only one error which was easily corrected. See Figure 6.
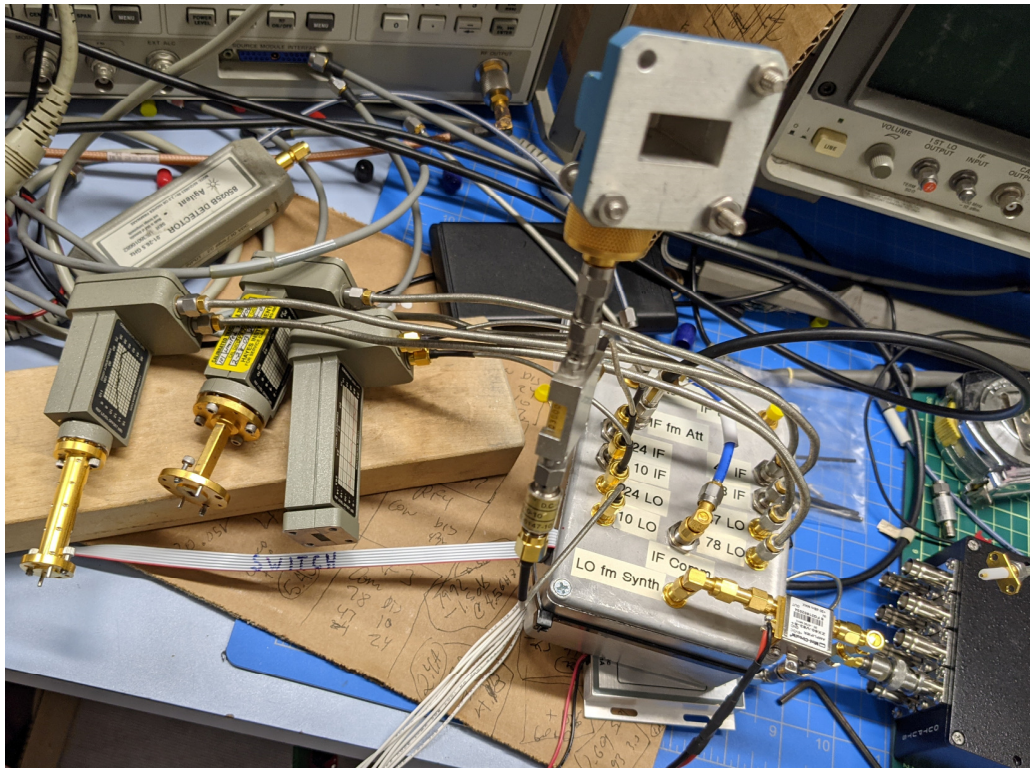
Figure 6. Here the multiplexer switch is being tested when connected to RF system components. The LO if fed in through a small Minicircuits amplifier ZX60-V83 to overcome all the cable and switch losses to still provide sufficient LO drive to run the mixers at their maximum performance. In this photo the synthesizer is beneath the multiplexer switch, almost hidden. The 10 MHz reference is off to the right with all the BNC connectors. The three mmw mixers are to the left and the 10 GHz mixer is standing up between the WR90 flange and the multiplexer.

DC Power

DC power is supplied to the system from a LiFePo4 battery, nominal 13.3V. There is a 6V switching power supply for the Synthesizer, and a 5 V power supply for the Computer and Spectrum Analyzer (both via USB) and 5 V is supplied to the LO Amplifier. The computer supplies 5V to the attenuators along the ribbon cables. The 13V is also sent to the fan that cools the whole box. To reduce or eliminate switching frequency (and brushless fan pulses) incursion into the RF circuits, each switching supply and the fan has its own input filters. The 5V and 6V supplies also have output filters. A filter was constructed to handle the battery input using three ferrites. See Figure 7. The battery input is a PI filter and the two outputs are common mode rejection ferrites. For individual supplies and the fan, several copies of a commercially available filter were employed. This resulted in very low ripple at all loads and the battery.

Additionally, voltage trimming was provided along with metering. There are voltage drops across cables, so trimming the voltage a bit higher at the supply was necessary to keep things in spec at the destinations. See Figure 8. Fortunately, that slightly higher voltage was still within spec, so that if some load went away everything should survive OK.
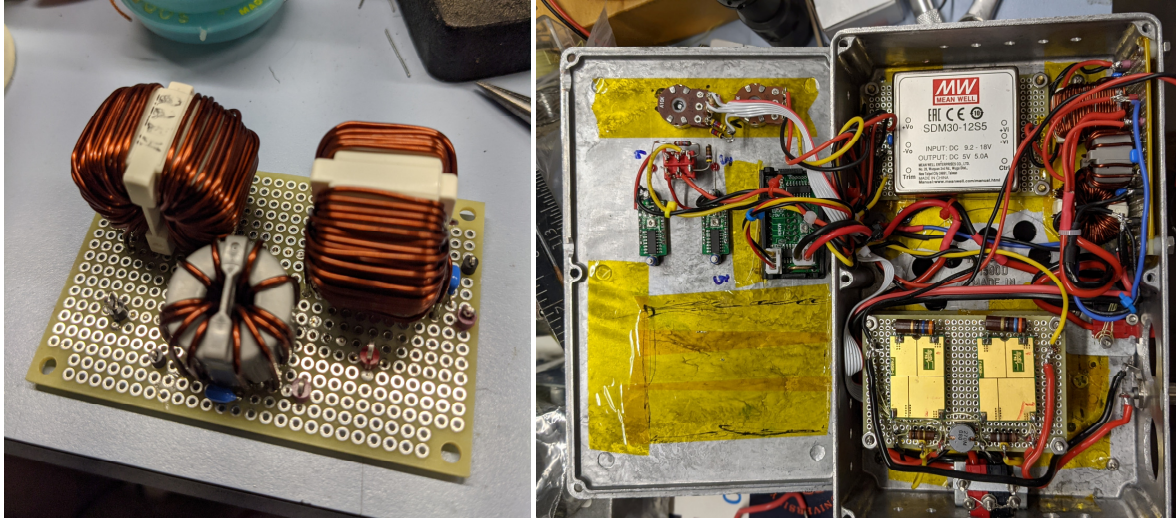
 Figure 7. Power supply subsystem. On the left is the primary battery input noise filter. On the right is the power supply box with the lid to its left. The lid has switches, meters and adjustment controls. The top of the inside shows the 5 V supply and the bottom shows some filters beneath which is the 6 V supply. The USB ports are holes to the lower right which will have USB sockets installed.

Figure 8. The photo above shows the DC subsystem in test. Total input voltage and current draw are indicated at the top while individual 5 and 6 volt meters along with trim pots are beneath and to the right.

System Integration

Various configurations were explored. In the end the unit was built on two levels, with the computer, Ribbon connector boards and power system on the top and the RF components on the bottom with the mixers bunched together presenting a common plane of open waveguides. Each level consisted of a "ventilated baker's sheet". These easily obtained (Amazon) aluminum pans offered sufficient strength along with holes that assisted in mounting with both screws and cable tie wraps. A wood pillar of 2x2 or similar size was placed in each corner and lag screws fastened to form a sufficiently stiff structure to be easily lifted in and out of the car without damage. See Figure 9.
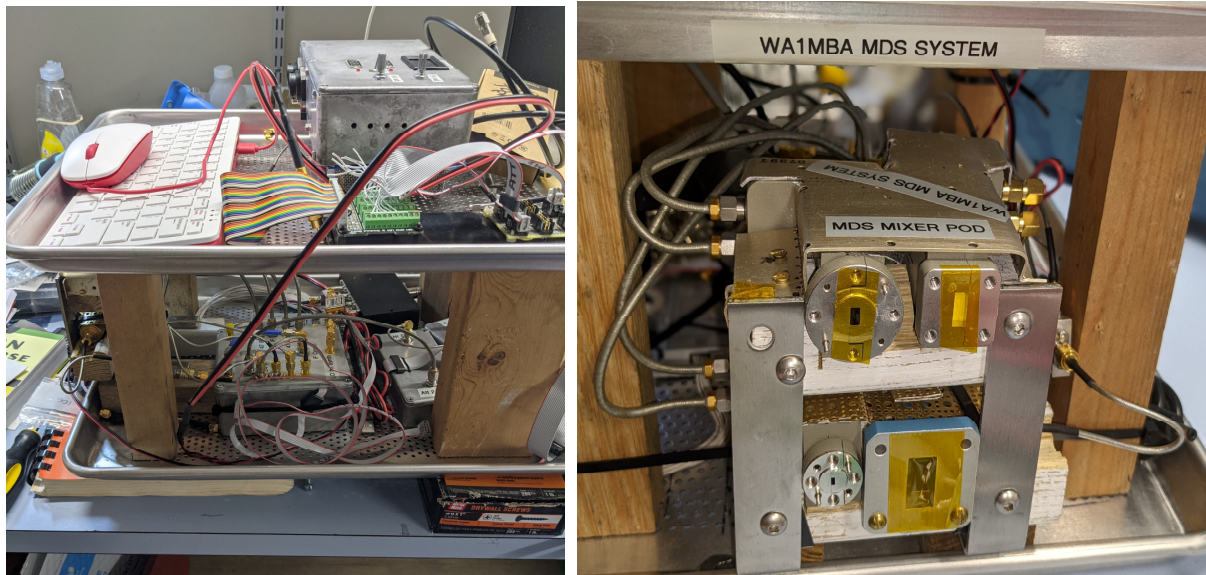

Figure 9. Here we see the entire system. On the left the computer control and power are on top and the RF components are on the bottom. On the right we see the waveguide ports which are pointed at the Pavilion when in the field during MDS testing. Kapton tape prevents moisture or dust from getting in. The 78 GHz tape had been removed to try a small horn. This tape does not present any attenuation on transmit or receive.

Results

The first time, everything worked except for 78 GHz

The second time I had fixed 78 GHz, but could not receive on any band. See Figure 10.

- I discovered operator error, forgot how to switch to receive (different band number)
- I changed interface to tell me how to do that in case I forget in the future
- (Following the W1GHZ principle of "nothing is fool-proof, so make it fool-resistant")
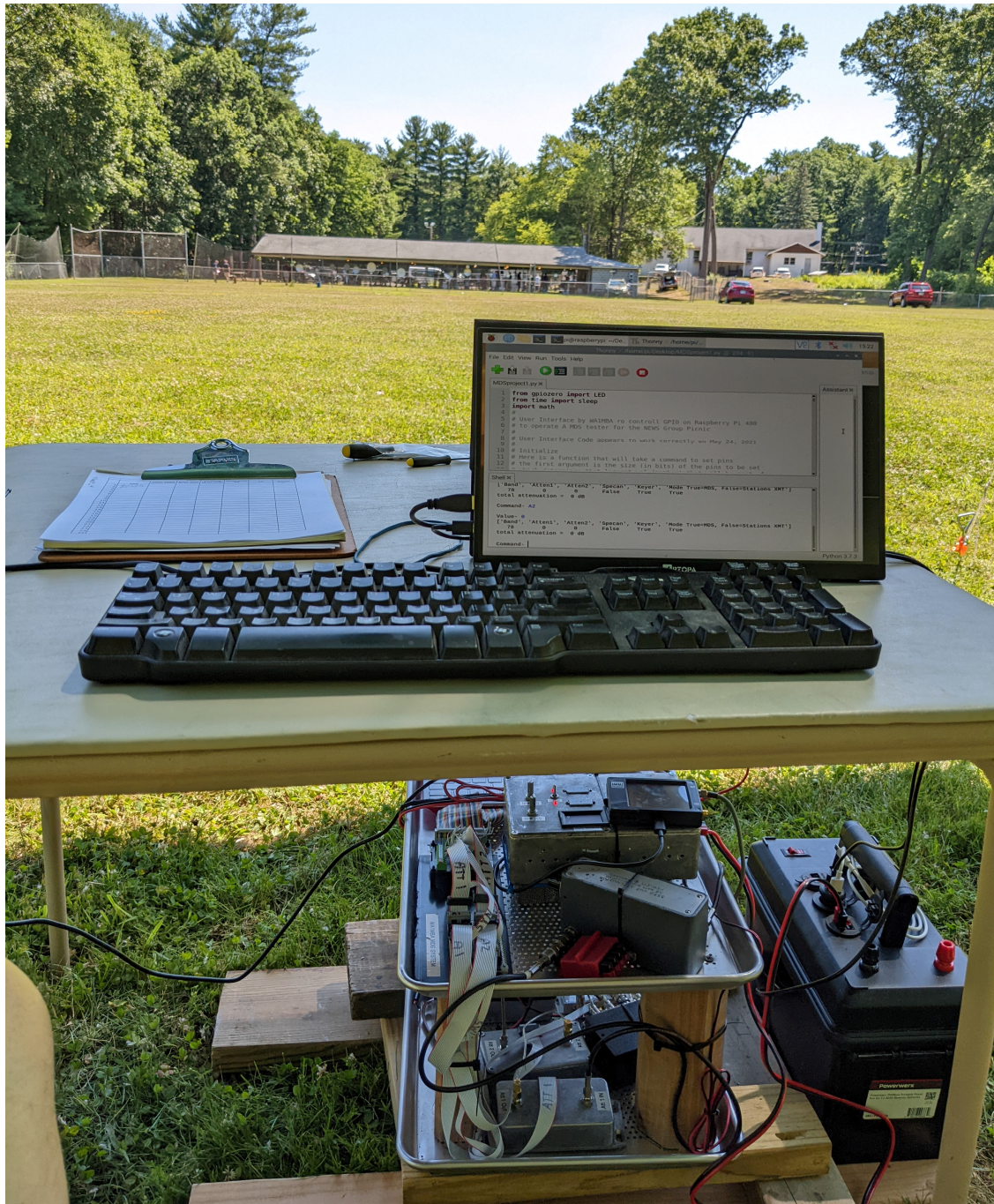
Figure 10. Photo of operating position during use at the 2022 NEWS Group Meeting and Picnic. The stack of short 2x4s on the ground bring the unit up to a height which appears to provide fairly good coverage of the Pavilion setups. The black "Tiny Spectrum Analyzer" can be seen sitting on top of the DC Power subsystem. That has long enough cables to be taken out to the table top during the Pavilion transmitting portion of the testing. A 40 AH battery lasts all day with less than ¼ discharge. Because our picnic meeting is in July, a small "Gazebo" style tent is used to provide shade.