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The MARC MoRIS and its Application to RFI Mitigation

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1. Introduction

A continual challenge of operating a radio observatory is monitoring and mitigating radio frequency interference (RFI). One very common source of RFI is emission from overhead power-lines. Components start out clean, but over time, wind, dirt and corrosion can lead to external problems that result in arcing. Lightning, or other factors, can cause internal failures in components that lead to arcing. Another common problem is improper grounding of components since induced voltages on neutral wires that are not properly grounded can lead to arcing. Either way these sparks produce pulses that are short in time and broad in frequency. Power-line noise is also modulated by the 60 Hz rate of AC in the US. Harmonics at 120 Hz or even as high as 480 Hz can also be quite strong.

Localizing RFI can be challenging even though the emission produced is often strong. Some of the difficulties are that the RFI is variable, especially during windy conditions, and can also be quenched by rain or high humidity. On more than one occasion knocking on a pole with a hammer caused RFI to disappear, only to re-emerge later. Furthermore the RFI from a single component can be broadcast by the power-line or from other components on power poles. Common tools like hand-held yagi antennas are direction dependent, but have strong sidelobes that can lead to confusion. And if other RFI is present then just looking at the power of the signal can confuse the source of the power-line noise. Below we describe a novel strategy developed at the Long Wavelength Array to localize RFI. The technique described may also be useful for identifying and localizing other sources of RFI as well.

Figure 1. LWA antenna mounted in the back of the LWA truck inside a wood frame that also houses the two 12V batteries. The GPS antenna is mounted on top of the wooden post on the passenger side of the truck bed. We refer to this setup as the Mobile Antenna for RFI Characterization and Mobile RFI Identification System (MARC MoRIS or just MARC for short).

2. Observations

On Friday, April 17, 2020 Jayce Dowell and Greg Taylor conducted an RFI survey at 74-76 MHz using an LWA antenna mounted in the back of the LWA truck, the Mobile Antenna for RFI Characterization and Mobile RFI Identification System (MARC MoRIS; see Figures 1 and 2). The antenna was connected to a USRP radio via an analog receive chain consisting of an amplifier (Mini-Circuits ZKL-2R7; +20 db), a low pass filter (Mini-Circuits SLP-90), a bandpass filter (Mini-Circuits SIF-70), and an attenuator (-3 dB). All electronics were contained within a Ramsey Electronics STE2900 Shield Test enclosure and powered by two 12V 110Ah marine grade AGM batteries. These batteries provide a total of 1.6 kWh and can power the equipment for up to 16 hours (power draw roughly 100 W). The USRP digitizer is calibrated such that an input voltage of 640 mV peak to peak corresponds to a reading of ~6000 in power.

We surveyed 38 locations on the VLA site for durations of 5 seconds each at 75 MHz with 3.125 MHz of bandwidth. We FFT each capture to generate spectra with 1024 channels and ~2.5 ms time resolution. The spectra are then averaged in frequency and we FFT this set of power as a function of time to get a secondary spectrum that allows us to isolate the 60 and 120 Hz variations (Figure 3). From the secondary spectrum the testing metric is the ratio of the peak at 60/120 Hz to the power in the DC bin and we try to maximize that. A map below (Figure 4) shows the location of the points sampled, colored by the strength of the 120 Hz signal. As is evident, there is one area of the map that shows a much stronger signal, to the west of the antenna assembly building (AAB). There is also some variability in the signal strength since some measurements in a similar location showed low, moderate, and high signals depending on the time. Winds were blowing at 10-20 mph and we suspect that this is just typical power-line variability as components on the pole are moved around by the wind.

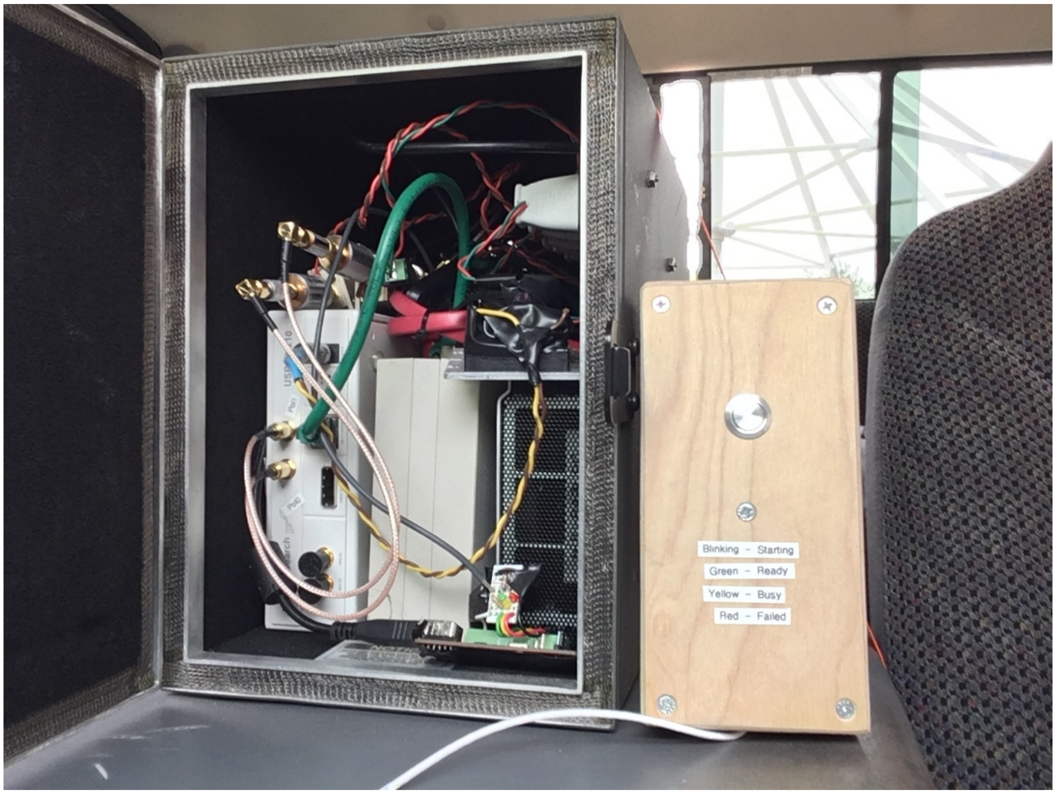

Figure 2. The shielded box containing the radio, computer and hard drive with the analog chain placed on top of the radio. Outside of the box is a button that initiates data captures with the unit closed up and no laptop connected. A laptop can be connected via ethernet for data retrieval and analysis.

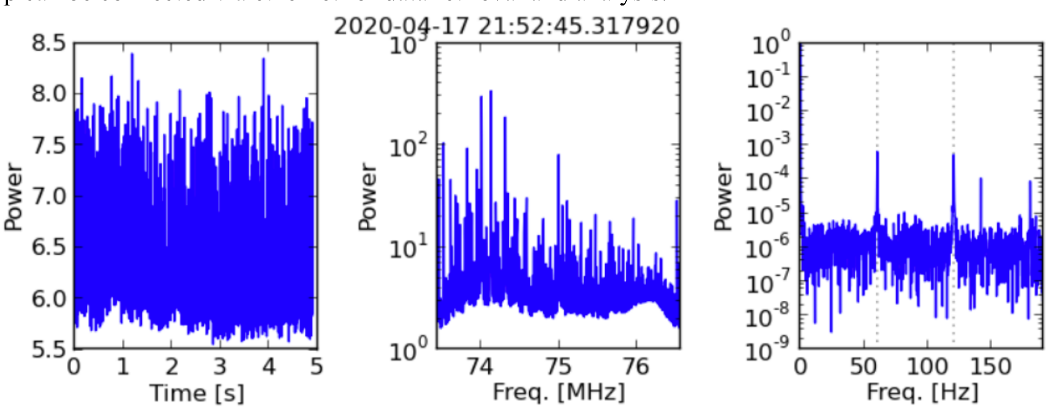

Figure 3. Plots of Power vs Time, average spectrum, and secondary spectrum for a capture on April 17 near the noisy pole. Note the strong signals at both 60 and 120 Hz (dashed lines).

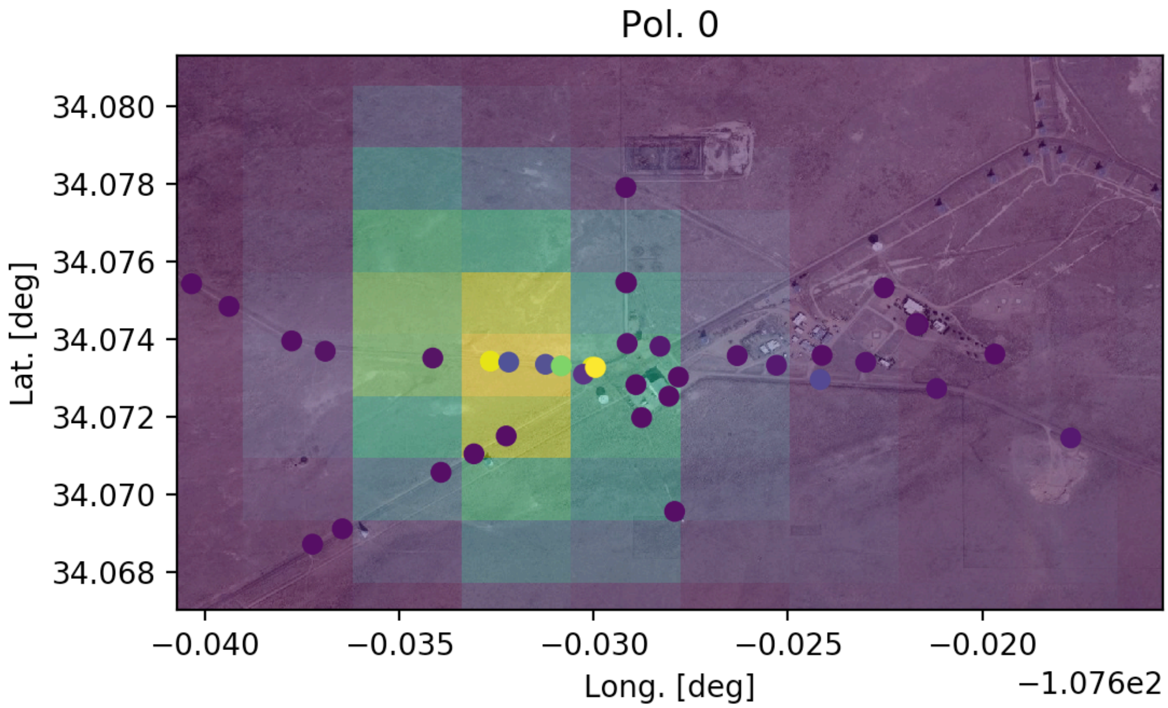

Figure 4. Image of the VLA site with 60 Hz power in color overlayed from the survey on April 17.

Our findings are consistent with LWA-TV observations that showed at the same time a strong 74 MHz RFI on the horizon to the North through NNW (Figure 5.). The AAB (due North) also appears to be radiating strongly at 120 Hz, but that might be a reflection from signals generated on the power line since we sampled on all sides of the AAB and did not detect it as a strong source of 120 Hz signals. Note that the RFI is strong enough to damage the image of the sky generated by the LWA. Considerably stronger RFI was evident in LWA-TV images over the previous several months.

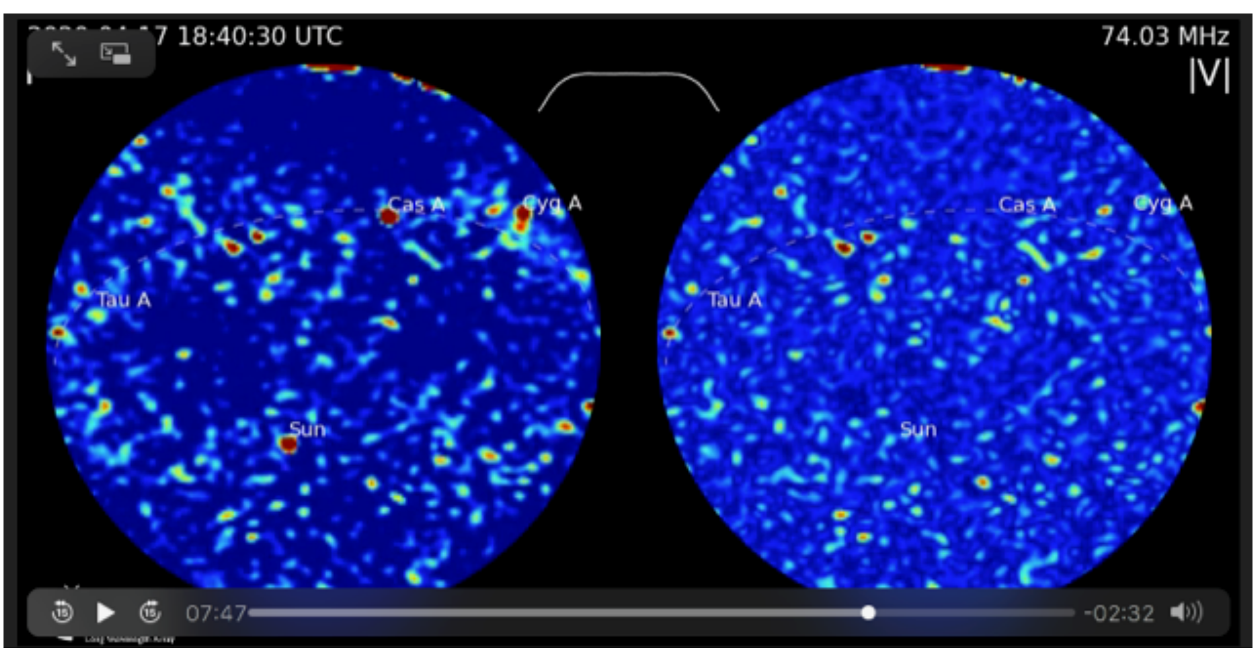

Figure 5. One frame from LWA-TV (5 second integration, 100 kHz bandwidth) showing strong RFI on April 17 from the direction of the AAB due north, and presumably powerlines NNW.


Figure 6. View of the suspected noisy pole with MARC in the foreground.

Our prime candidate for the RFI was a power line pole (Figure 6.) that is in the area with the strongest 60 and 120 Hz signals, and in line with the LWA-TV RFI signal. This power line pole is heavily loaded with various components. The location of the suspected noisy pole is indicted with the red pin in Figure. 7.

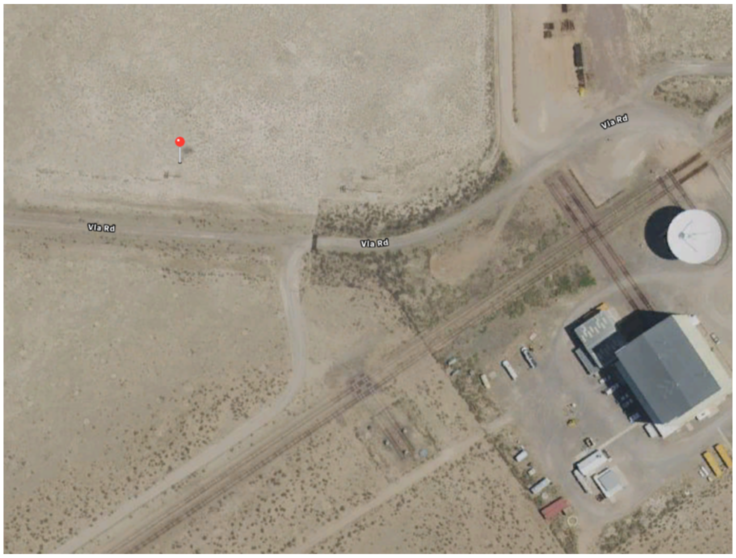

Figure 7. Google satellite image of the location of the suspected noisy pole. The AAB is in the bottom right corner. The red pin marks suspect pole with GPS coordinates:
Latitude: 34° 4’ 25.03” N
Longitude: 107° 37’ 50.868” W

3. Mitigation

On April 29 Greg Taylor and Chris DiLullo met with Emilio Orona and his crew from the Socorro Electric Company. We were joined by Dan Mertely from NRAO. Using bucket trucks and a hot-line sniffer, the linemen confirmed that the pole was quite noisy. Suspicion fell initially on the Versa-Tech reclosers (components mounted on the lower part of the pole) which are essentially large fuse breakers that can interrupt the current in the presence of a short down the line. These components were bypassed and the noise greatly abated but did not completely stop. After replacing a number of insulators on the pole, it was decided to also replace the grounding wires. Replacing the grounding wire, and in particular a strand with multiple aluminum connections (see Fig. 8) solved the problem. RFI emissions fell below detectable levels from both the handheld yagi antenna, and the LWA1 station. Some faint 60 Hz signals were still present in the MoRIS captures, but since this antenna is omni-directional it was decided to conduct a new survey (Fig. 9).

The survey conducted on April 29 at the VLA site showed more uniform 60 Hz emission with the strongest emission in the vicinity of the entrance gate to the VLA, East of the Visitor Center (Fig. 9). This RFI is not visible to LWA-TV but could possibly be harmful to VLA and LWA observations (Fig. 10). There are few components on these poles suggesting that mitigation should be fairly straight forward.

Figure 8. SEC line manager Emilio Orona (left) follows social distancing while Dan Mertely (NRAO) holds the faulty piece of ground wire. This ground wire can also be seen as part of the collection at the LWA RFI museum at LWA1.

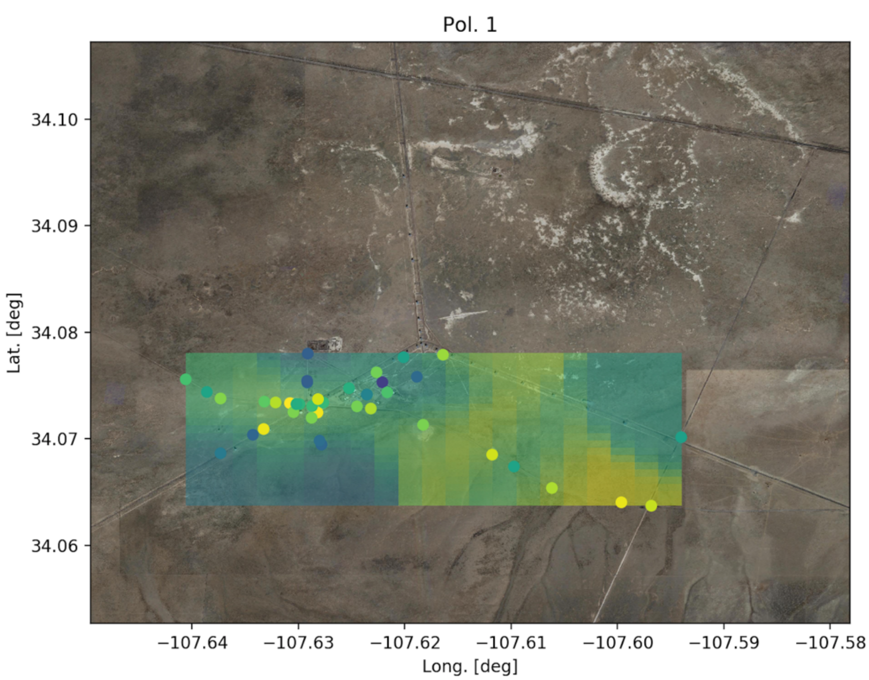

Figure 9. Image of the VLA site with 60 Hz power overlayed in color from the survey on April 29. Points have been auto-scaled and indicate a more uniform distribution.

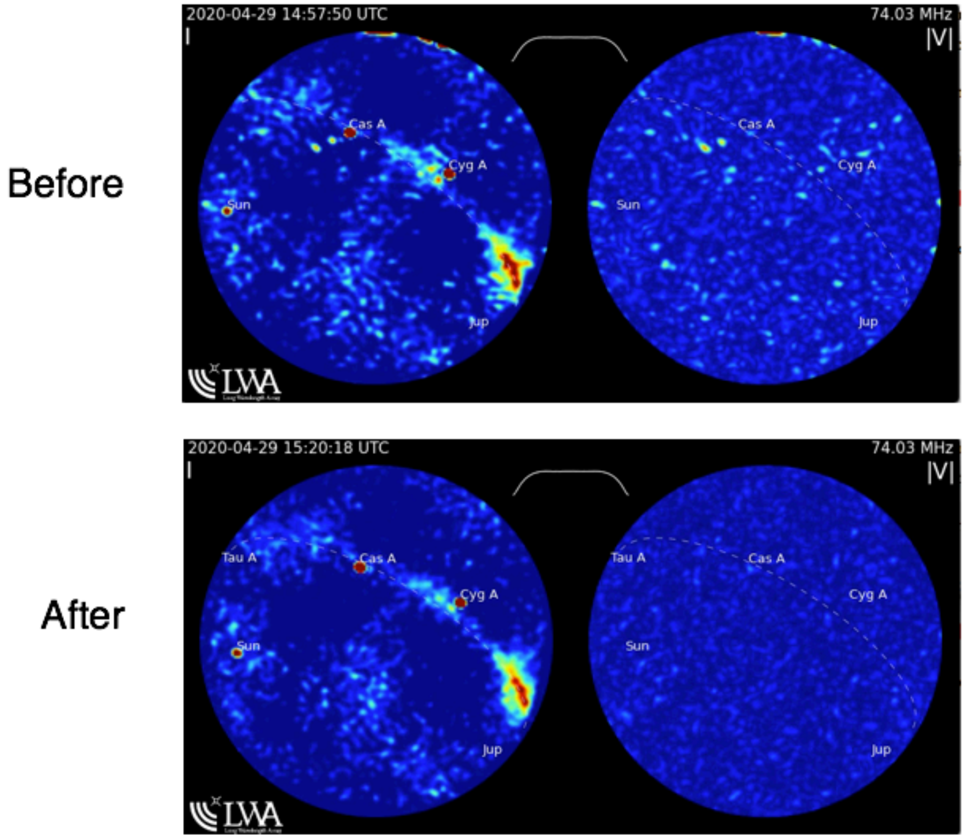

Figure 10. Before and after images from LWA-TV from April 29. SEC work concluded at 15:15 UTC.

4. Conclusions and Future Work

The new methodology using the MARC MoRIS to conduct surveys is an effective method to identify noise from power lines. A survey with an appropriate density of points (30-40 for the VLA site), takes approximate 2 hours. Major advantages from conventional techniques using directional antennas are (1) that the 60 Hz signal is fairly independent of power levels, (2) the data is automatically time and location stamped; and (3) maps can be generated quickly following data collection in order to identify RFI sources. A survey has also been collected in the vicinity of the LWA-SV station in the hopes of mitigating power-line noise there. It may be desirable in the future to conduct a survey of the VLA in B-configuration in order to check for interference generated by electronics in the VLA antennas.

5. Appendix A: Update as of July 1, 2021

Several new changes have been made to the design of the MARC MoRIS, as seen in Fig. A1. The analog components have been removed from the inside of the shielded test enclosure and instead placed in a separate, sealed metal box (shown in Figs. A2, A3).

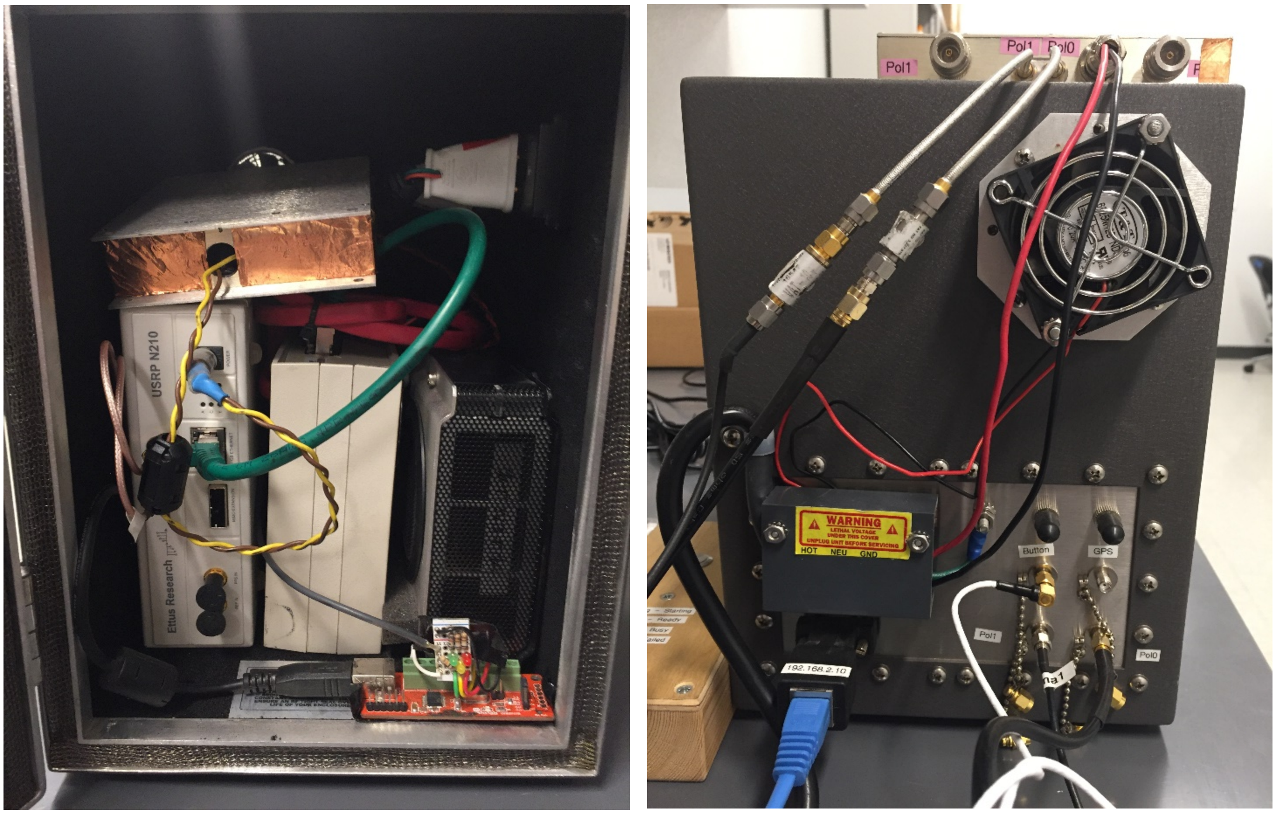

Figure A1. (Left) The reworked inside of the shielded box. The analog components have been removed and the voltage converter (12V to 6V) for the USRP has been placed in the metal box perched atop the USRP. (Right) The reverse of the shielded box. The analog components are now in the small metal box at the top of the image.

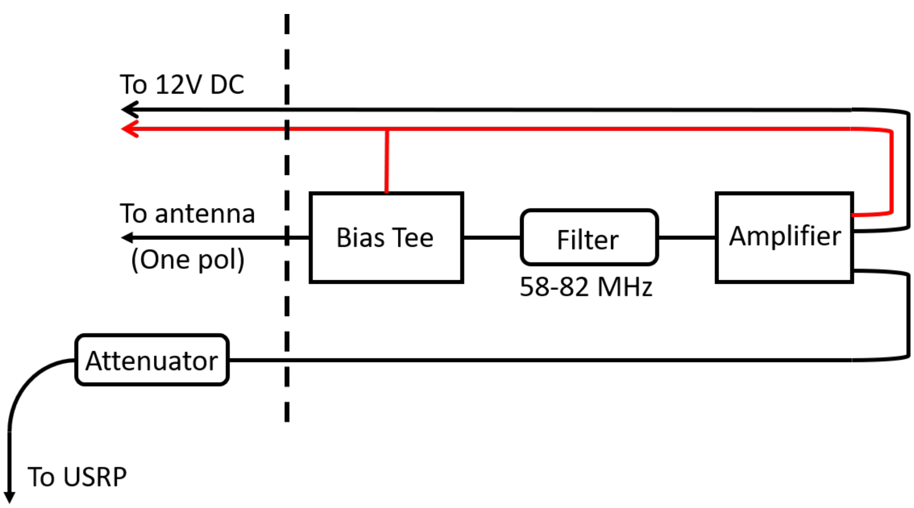

Figure A2. The schematic of the analog chain inside the sealed box. There are two such chains in the box, one for each polarization. The filter shown is appropriate for observing at 74 MHz. The attenuator is placed outside the box to allow for easy access.

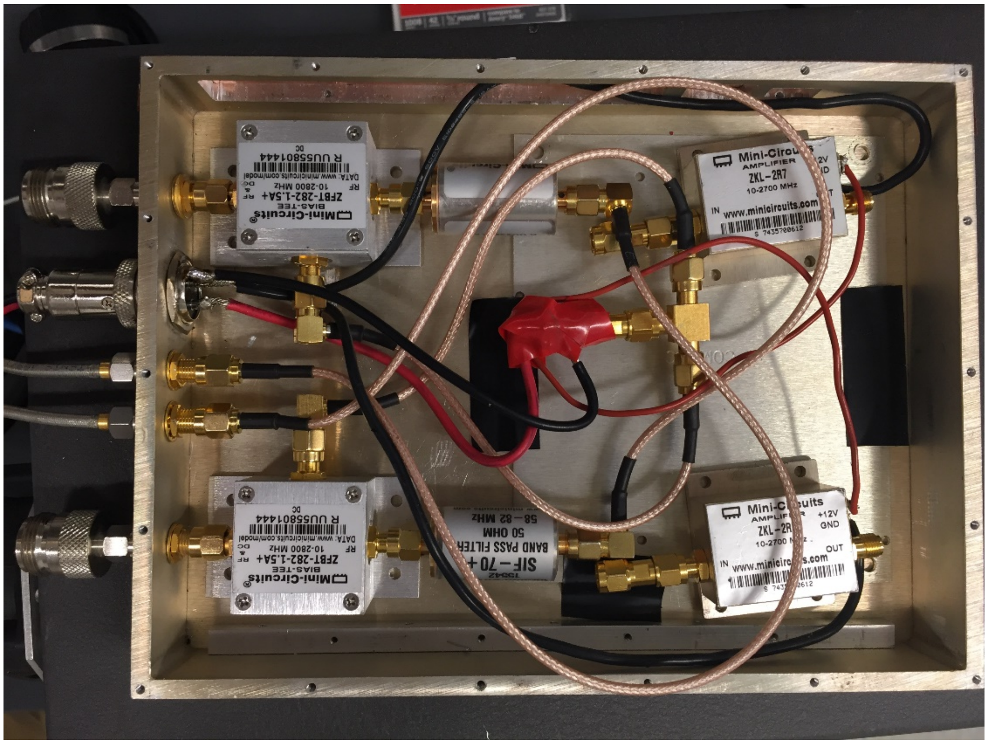

Figure A3. The internals of the analog box diagrammed in Figure A2. In this image, the output wires are connected directly after the filters; the amplifiers are unconnected and are free floating in the box.

The signal from the antenna enters the analog chain at the bias tee which provides DC power to the antenna front end. From there it is passed through a band pass filter – either a 58-82 MHz filter for 74 MHz observations or a 48 MHz low pass filter for 39 MHz observations. Initially it was sent to an amplifier, however since the amount of attenuation needed to get the signal back to a good power level exceeded the amount of amplification, the amplifier was subsequently removed prior to the 74 MHz observations. Despite this, some amount of attenuation was still needed to get the power into recommended 5 – 50 range. In general, it was found that somewhere between 10 – 30 dB worth of attenuation was needed.

In addition to this, the voltage converter for the USRP, which converts from the 12V shielded box outlet to the 6V USRP plug, was encased in its own metal box to limit the amount of potential noise present inside the shielded box (refer back to Fig. A1). As a comparative test, this converter device was replaced with a rechargeable 6V battery which fed directly into the USRP – there were no substantial differences between the two setups in terms of the resulting spectra. In light of this, the voltage converter device seems to be suitably quiet for continued use. It should be mentioned, however, that the 6V battery needed to be partially discharged (to around 6.6V) before the USRP would turn on.

The first field survey with the updated design occurred on May 26, 2021 around the LWA-SV station and the nearby community of La Joya. The system was set up for observing at a frequency of 39 MHz. The results were broadly encouraging, with good agreement between the two polarizations and decent repeatability between the captures. However, there were some problems with the observations such as inconsistent or spiking power levels and intermods from suspected low frequency external signals. An example of a good and less good capture can be seen in Figs. A4 and A5, respectively.

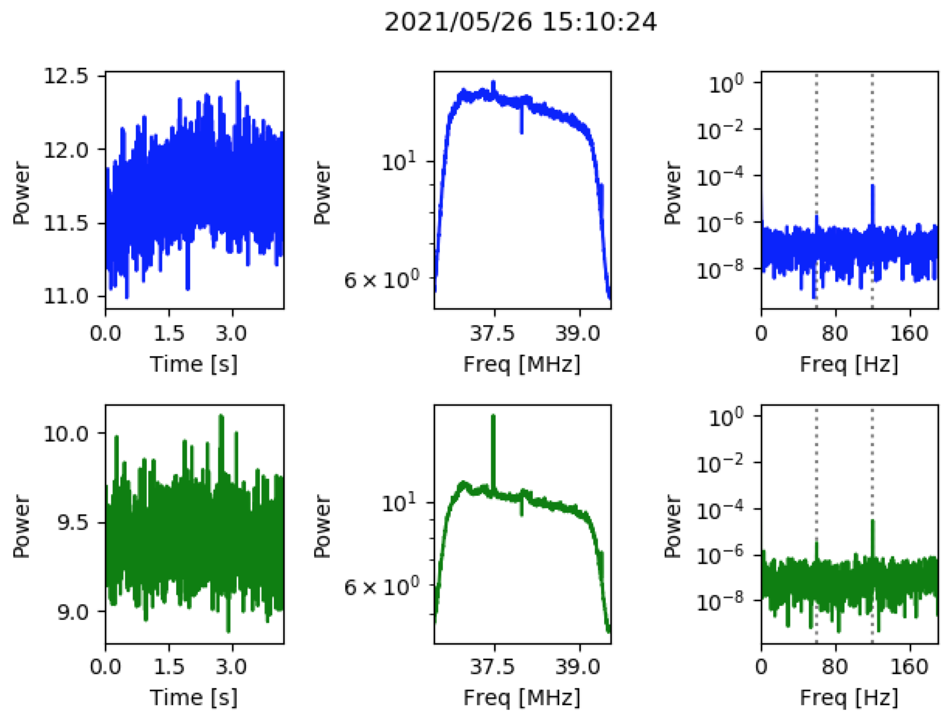

Figure A4. An example of a good capture, with decent power levels, a good band pass shape, and clear indications of a 60 and 120 Hz signal. Note also the good agreement between the top and bottom set of plots, which represent the two different polarizations.

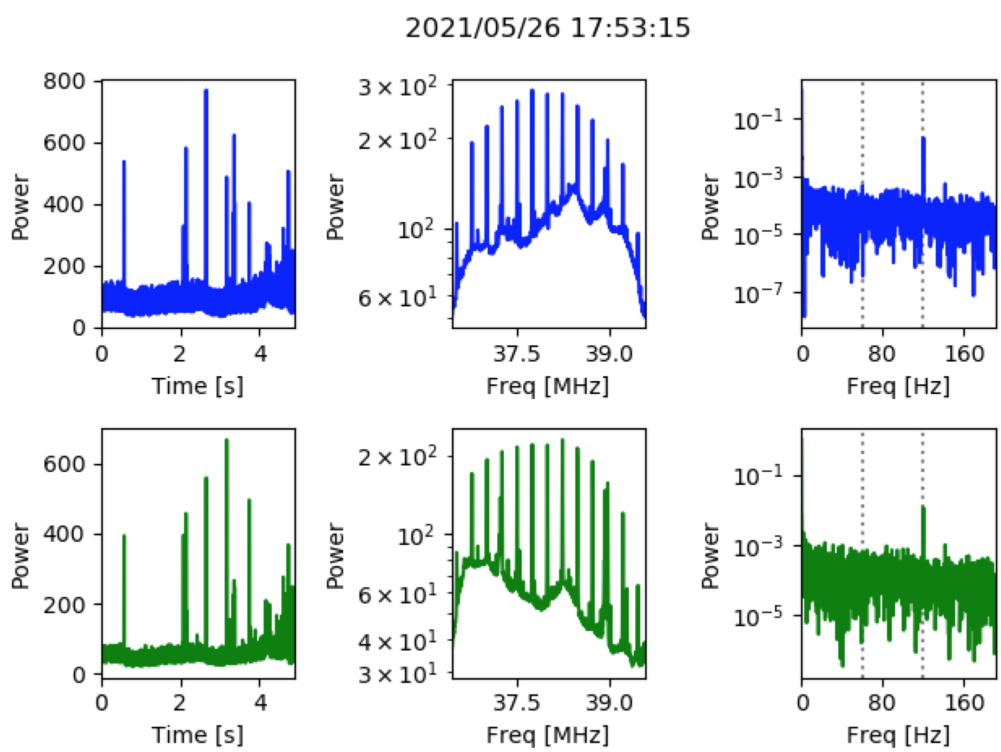

Figure A5. An example of a less good capture, with spiking power levels and rampant intermodding in the frequency plots.

The resulting map of captures for each polarization can be seen below in Fig. A6. The intensity of each dot is related to the strength of the 60 Hz signal. Though the heat map alone did not seem to suggest any localized region of interference, a couple of poles were manually identified as being slightly noisy using the handhold antenna.

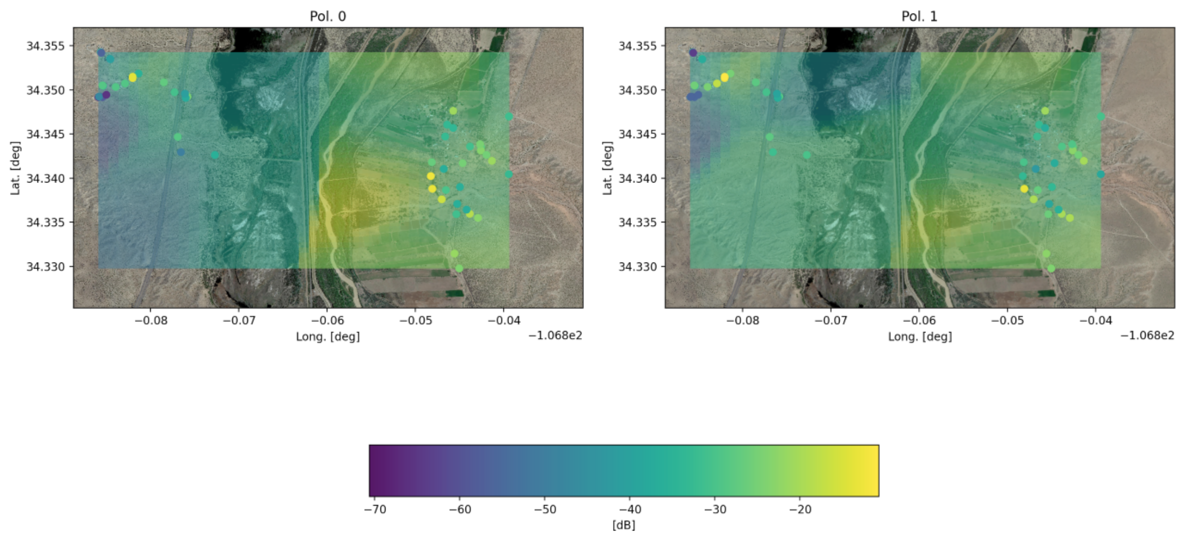

Figure A6. Image of the LWA-SV (left of highway) and La Joya (right of highway) with 60 Hz power in color overlayed for each polarization for the 39 MHz survey on May 26, 2021.

Due to the occasional intermodding issue, it was decided to switch the MARC MoRIS over for 74 MHz observations. This involved switching out the filter in the analog component box, adjusting the attenuation, and editing the capturing software.

The next field test was conducted on June 16, 2021 at approximately the same locations at LWA-SV and La Joya, however now at 74 MHz. There was some initial difficulty getting the correct attenuation while on-site at Sevilleta – while trying to get the power levels correct, the signals would occasionally revert to their null values despite being in the correct range in the previous capture. This problem was resolved by power cycling the MARC MoRIS. It is recommended to try this solution for similar problems in the future. The results of this survey were generally in agreement with the previous one, though without the intermodding issues. Instead, the power levels seemed to be less well behaved, exhibiting spikes and large swings in power, the latter of which is shown in Fig. A7. Despite this, the resulting area map, Fig. A8, still bears a strong resemblance to the previous survey as expected.

One of the problems still present in the MARC MoRIS is the occasional fluctuation in power. By using a signal generator connected to the attenuator and into the USRP through one polarization while the other polarization was left open to the air, the spectrum of a known signal was examined. In one test, the signal started out as expected, however after 4 captures (over a 20 minute span), the power began to vary inconsistently and remained that way for several captures. This was ultimately resolved by power cycling the electronics. Additional attempts to replicate this problem were not successful. Therefore, due to the intermittent nature of this problem, the current best solution seems to be doing a power cycle of the system.

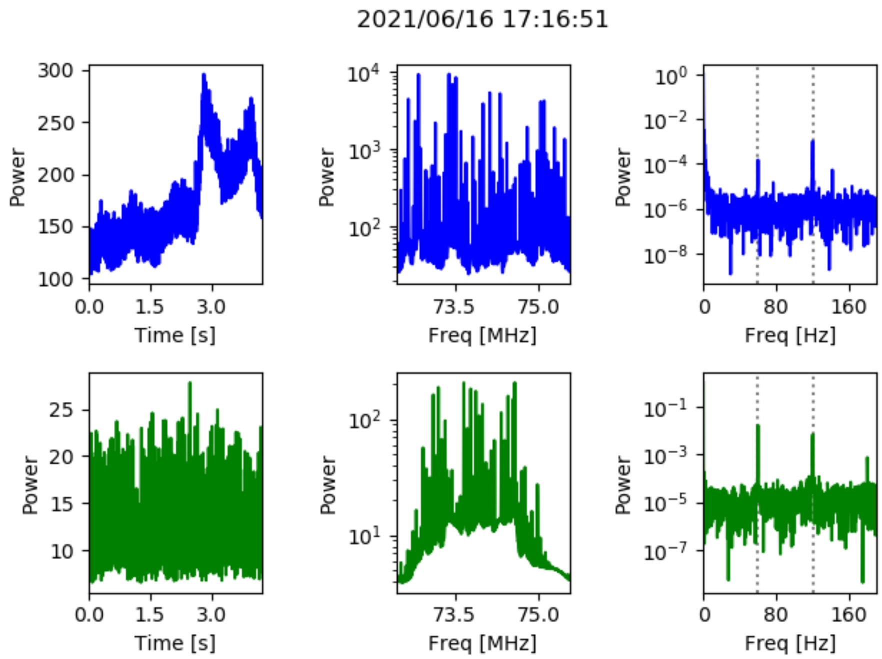

Figure A7. The blue series of graphs are representative of the power swings seen during the June 16, 2021 survey. Note that the 60 and 120 Hz signals are still very prominent.

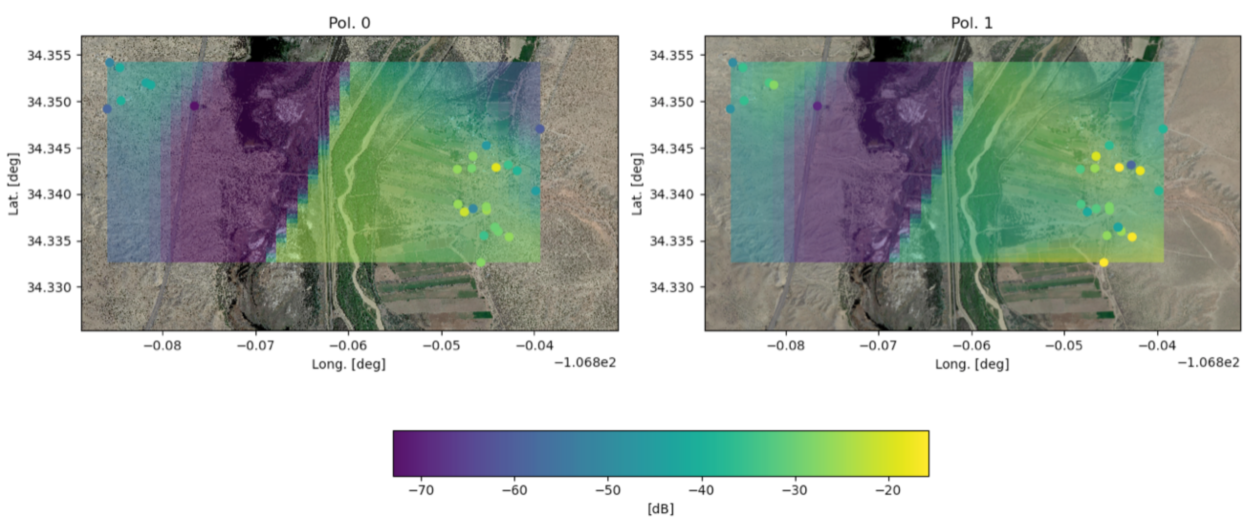

Figure A8. Image of the LWA-SV (left of highway) and La Joya (right of highway) with 60 Hz power in color overlayed for each polarization for the 74 MHz survey on June 16, 2021.