HYPERION Memo #4: Testing the Radio Environment in Rangely, CO

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1 Abstract

Radio environment is an extremely important aspect of Epoch of Reionization studies, as the signals are so much quieter than even most celestial sources. This memo aims to lay out the results of some initial radio environment testing in and around Rangely, Colorado. It also aims to lay out some analysis of what these results mean for the HYPERION instrument and suggests some new ideas for mitigation of environmental factors. These tests conclude that the radio environment around Rangely, CO makes it an ideal candidate for deployment for HYPERION. It also finds that local topological features can be used to effectively attenuate RFI signals.

2 Background and Theory

One aspect of the HYPERION instrument that has yet to be finalized is its location – where the instrument will be deployed to do the science it is designed to accomplish. Since its inception, there has been frequent discussion of using a site near Rangely, Colorado – a tiny town in northwestern Colorado, far removed from most typical sources of radio transmission and peppered with convenient topology. With low RFI and a somewhat quieter radio sky, it seemed like an ideal candidate in theory. So, we put it to the test – what does the radio environment around Rangely actually look like in the HYPERION frequency band? And, assuming it's a good starting point, how can we optimize it to our particular needs?

To answer these questions, a series of four tests were conducted: one in the driveway of Professor Aaron Parsons' parents house, one up a box canyon with limited N-EW exposure a short drive northeast, one mobile experiment with the antenna mounted in the back of a pick-up truck, and one in another box canyon with limited exposure in all directions about 15 miles southwest of Rangely. This changing directional exposure allowed us to begin investigating the effects of geological structure on the radio environment – in particular, to see if rock formations around our antennas could serve as attenuators of ground-based sources of RFI.

2.1 Receiver Noise and System Temperature

In order to determine the overall system temperature of the Rangely, CO deployment system, we will first need to know the receiver noise temperature, T_{rx}, i.e. the noise that would be added at the amplifier's input in order to account for the added noise observed following amplification. However, it would be too easy for the manufacturer's to simply provide T_{rx}, so instead we'll start from a noise figure NF. Using Eq. (1), we can calculate the noise factor F. For a single amplifier, we can then find the noise temperature using Eq. (2) with T_0 typically being set to a room temperature value of 290 K.

$$NF = 10\log_{10}(F) \tag{1}$$

$$F = \frac{T_0 + T}{T_0} \tag{2}$$

In the case of the Rangely testing, two amplifiers were used in a chain. In this scenario, a final equation is needed to calculate the full receiver noise temperature, which accounts for the gain of the first amplifier on the effect of the amplifier noise contributions of the second amplifier.

$$T_{rx} = T_1 + \frac{T_2}{g_1} \tag{3}$$

The Rangely signal chain featured two identical amplifiers, each with a noise factor $NF = 11$ dB and a gain $g = 23$ dB. This led to a final receiver temperature of 3377 K across the band.

As discussed in Kundert (2016), we would like for our overall system temperature $T_{sys} = T_{rx} + T_{sync}$ to be dominated by a known term, such as the galactic synchrotron emission, T_{sync}, which can be calculated using Eq. (4) using a value of $\beta = 2.5$.

$$T_{sync}(\nu) = T_{sync}(\nu = 150\ \text{MHz}) \left(\frac{\nu}{150\ \text{MHz}}\right)^{-\beta} \tag{4}$$

With the receiver temperature calculated in Eq. (3) and the sky temperature calculated with Eq. (4), we can find the difference between the total system temperature and the known sky temperature using Eq. (5).

$$\text{dB} = 10\log\left(\frac{T_{sys}}{T_{sync}}\right) \tag{5}$$

From this, we find that the system temperature T_{sys} is approximately 5 dB brighter than the sky temperature T_{sync} at 70 MHz, as can be seen in Fig. 1. This indicates that the receiver system used during this round of testing will be inadequate for observations, as it will be difficult to properly calibrate the system with such a high level of noise being generated by our system.

3 Method

In each of these tests, a broadband dipole was hooked up to the FieldFox spectrum analyzer and used to record all that it picked up in a given frequency band (either 80-110 MHz or 0-300 MHz). Each spectra held 1001 points and was averaged for approximately 1 minute, collecting a maximum, minimum, and average spectrum for each recording.

In the first experiment, the observations were taken in the driveway at Professor Parsons' parents' house. There was an RFI source around 193.5 MHz, which was assumed to be emitted from the nearby oilfield towards NE. So, the observations were done with on-axis (i.e. in the beam null) and off-axis (i.e. in the beam peak) alignment of the antenna with respect to the oilfield.

In the second experiment, measurements were taken up the canyon where the place was shielded by the landscape towards the north, east, and west (with a horizon altitude of 57° to the W). The southern direction was most exposed, with a horizon altitude of only 4° degrees.

In the third experiment, the antenna was mounted onto the back of a pickup truck and observations were taken at various locations, starting at the house and ending well up Cottonwood Canyon.

Finally, after traveling up Cottonwood Canyon into a shallow box canyon, the antenna was dismounted from the truck and placed in a creek bed with rock walls raising the horizon in all directions. There, observations were taken in both frequency bands in both E-W and N-S dipole orientations.

4 Data and Analysis

Rangely, Colorado is already an attractive candidate for low-frequency radio astronomy, as there are only a handful of known emitters in the FM band. As can be seen in Fig. 3, even when standing in the driveway of Professor Parsons' parents' house, there's only about 13 visible sources of RFI within the HYPERION science band and all have a maximum amplitude of less than -20 dBm. However, by being strategic, we can get even better results.

Table 4 shows the visible FM sources from the box canyon up Cottonwood Canyon, the site we found to have the minimum amount of RFI contamination. At a maximum, these five FM stations have a power level of -50 dBm. These kinds of contamination rates make Rangely, CO competitive with other hallmark radio observatory sites, such as the Karoo Desert in South Africa.

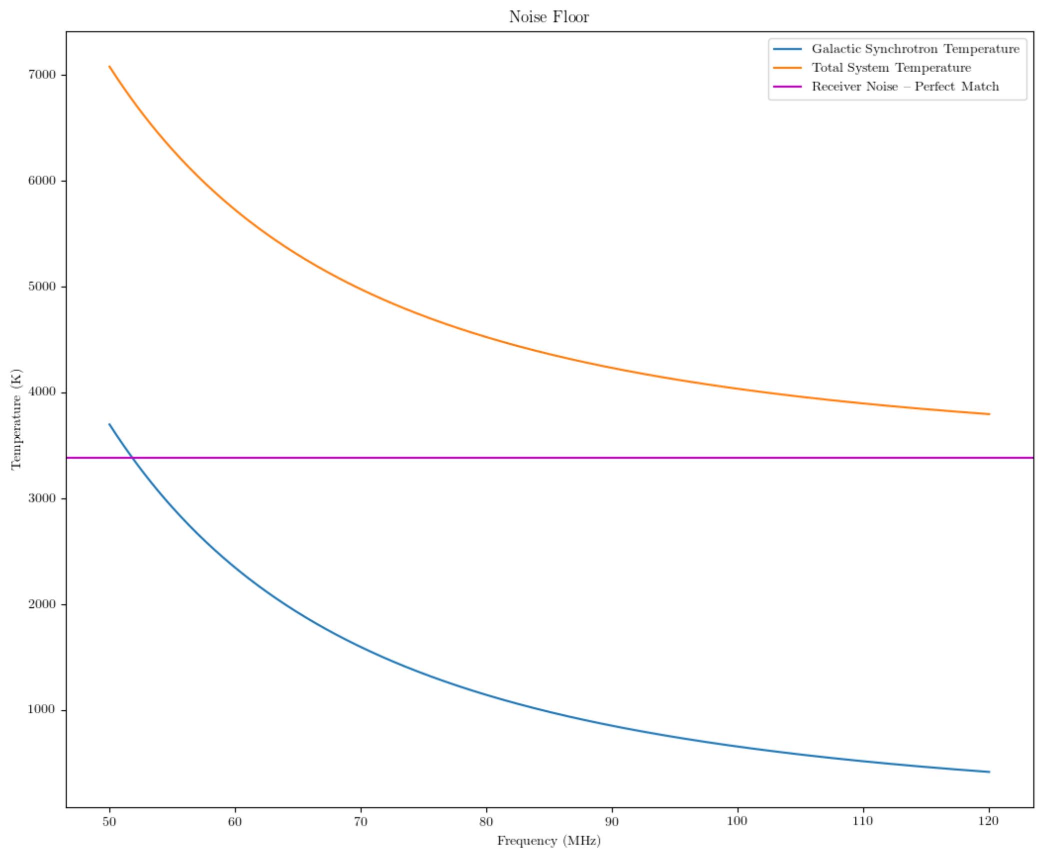

Figure 1: In this figure, we can see how the receiver temperature contributed to the overall system. Ideally, we would like to be able to lower the system temperature to the point where the synchrotron sky is the main term across the band. However, as is evident above, the receiver chain used in this particular testing trip introduced about 3400 K in noise temperature, drowning out all but the absolute lowest frequencies of the synchrotron sky. All in all, the synchrotron sky is approximately 5 dB down from the overall system temperature at 70 MHz. In future testing, we will need to develop a lower temperature signal chain to mitigate this effect.

FM station	Frequency(MHz)	Power Level (dBm)
KXRQ Roosevelt	94.3	-50
KIFX Vernal	98.5	-50
KCUA Naples	92.5	-57
(Undefined)	106.4	-57
KMZK Clifton	106.9	-57

Moreover, our data indicates that local topology can have a strong effect on the visibility and strength of RFI sources. In comparing Figs. 4 and 5, we see that in changing the orientation of the antenna and therefore the beam relative to the point of maximum exposure in the south, we change the what RFI sources are seen and their amplitudes. More exposure translates to more visible sources and more power in that direction.

This has huge consequences to HYPERION, which is built upon our ability to modify the "horizon" of the sky using absorbers to impose an artificially tall horizon and force the sky into higher order spatial Fourier modes. The effects of these rock faces in these initial results shows that it's possible to generate this kind of effect naturally by using local geological structures to our advantage. While these natural structures won't replace our need for high-performance, low-frequency absorber entirely, they could help attenuate the bright galactic sky signal in those directions and therefore lower our overall system temperature.

5 Conclusions

In this round of field testing, we hoped to gain some insight into the overall RFI environment of Rangely, CO and to learn whether it would be a good candidate site for the HYPERION experiment. The data acquired is very promising, indicating that even the worst conditions (those in the driveway of Professor Parsons' parents' house) in Rangely are pretty clean for our purposes. Moreover, the best conditions (those from the secluded box canyon to the southwest) are superior to even those in the nationally protected radio reserves in the Karoo Desert in South Africa.

One remarkable feature observed in the data is the strong effect that local topology can have on our observations and RFI environment. In limiting our exposure to different directions using naturally occurring geological features, we were able to reduce the number of visible RFI sources from approximately 13 with amplitudes between -60 and -20 dBm to only two with amplitudes below -45 dBm. That's a very strong and valuable effect, and one that is unique to the geology in the area.

While there is still quite a bit that would need to be determined before planning a deployment in CO, this site remains our best candidate for the final HYPERION experiment.

References

Kundert, K. 2016, The Relationship Between System Temperature and Sky Beam Coverage, Memo 1, HYPERION

A Data from Driveway Observations

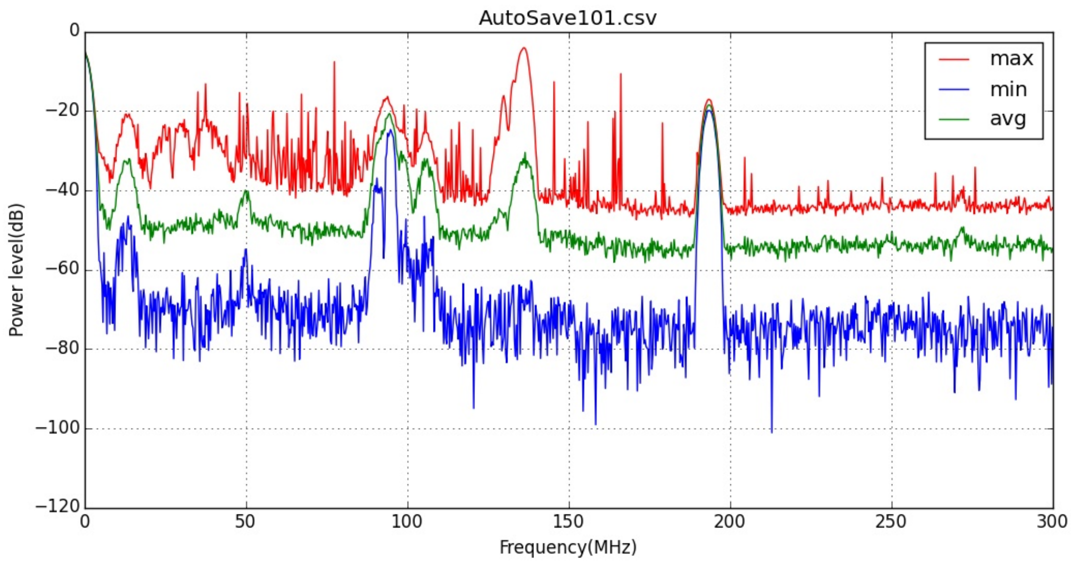

Figure 2: Pictured above is the radio environment from 0-300 MHz as measured from the driveway of Professor Parsons' parents' house, with the antenna axis aligned with the oilfield in the northeast. This puts the oilfield transmission at 193.5 MHz in the null of the beam.

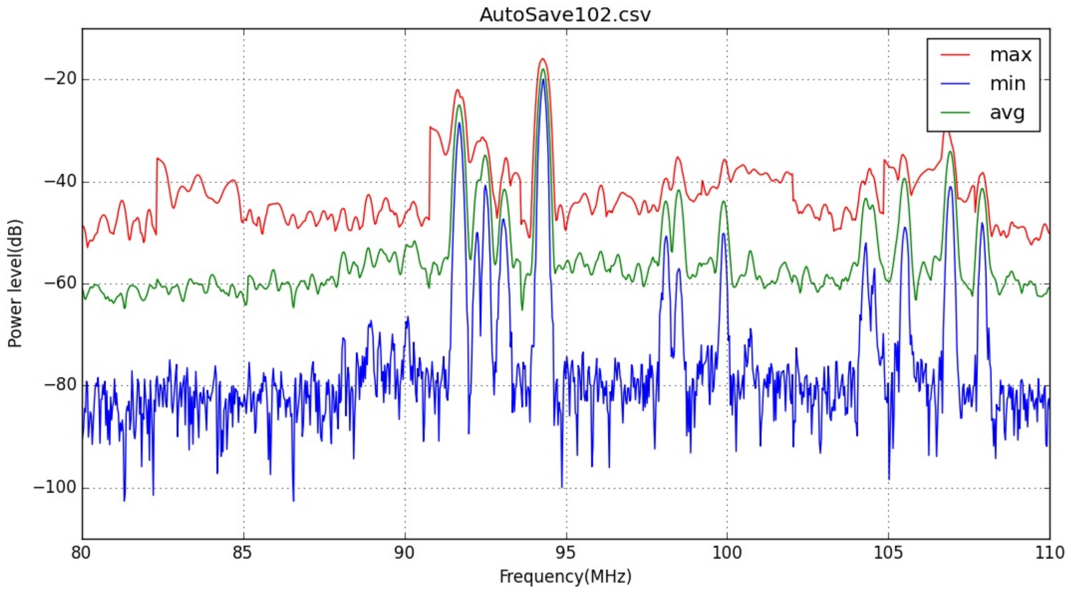

Figure 3: Pictured above is the radio environment from 80-110 MHz as measured from the driveway of Professor Parsons' parents' house. As can be easily seen, there are approximately 13 unique and strong sources of RFI with amplitudes between -60 and -20 dBm.

B Data from Northeastern Box Canyon

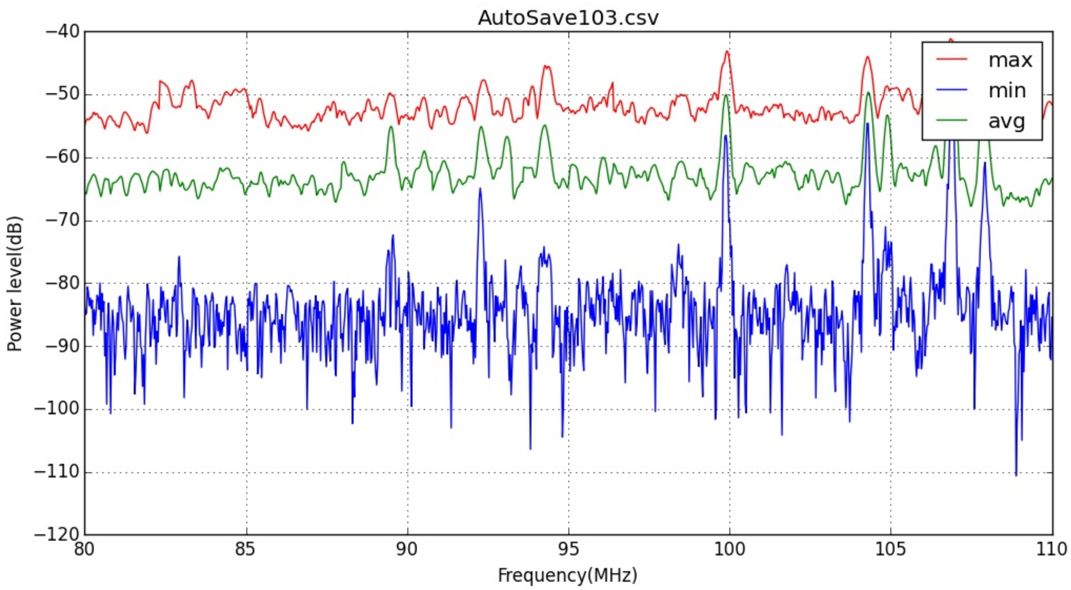

Figure 4: Pictured above is the radio environment from 80-110 MHz as measured from a box canyon to the northeast of the house, with the dipole axis aligned N-S. This alignment points the null of the antenna beam towards the point of the lowest horizon altitude (4°), and the peak of the beam towards the most geologically sheltered part of the canyon. Already much of the RFI from the environment has been strongly attenuated, and there are only five remaining sources with amplitudes between -70 and -45 dBm.

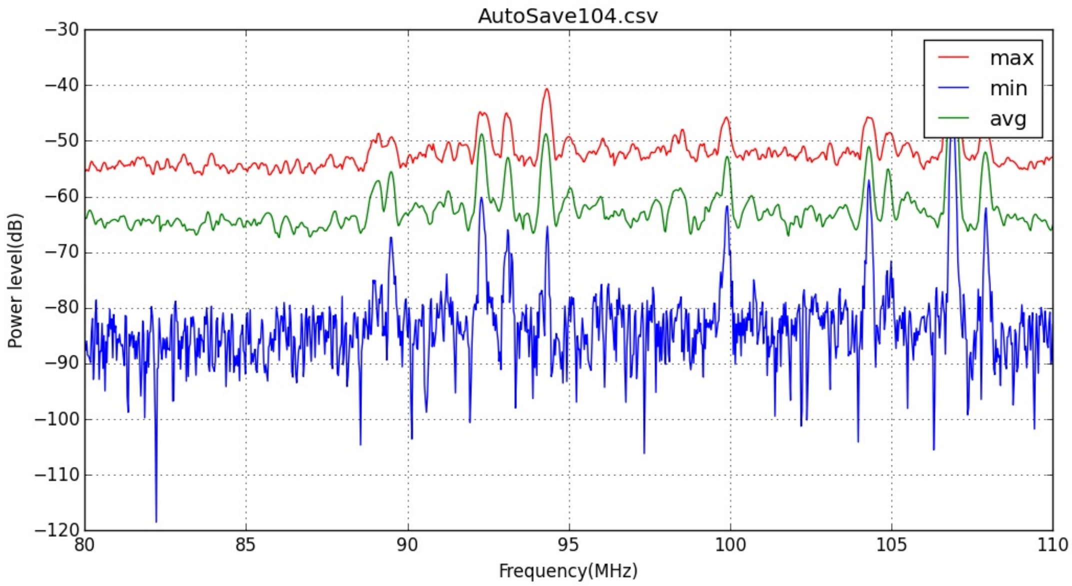

Figure 5: Pictured above is the radio environment from 80-110 MHz as measured from a box canyon to the northeast of the house, with the dipole axis aligned E-W. This alignment points the peak of the antenna beam towards the point of the lowest horizon altitude (4°), and the null of the beam towards the most geologically sheltered part of the canyon. This arrangement is visibly worse than the previous one, with eight sources of RFI now visible in the spectra with amplitudes between -70 and -35 dBm.

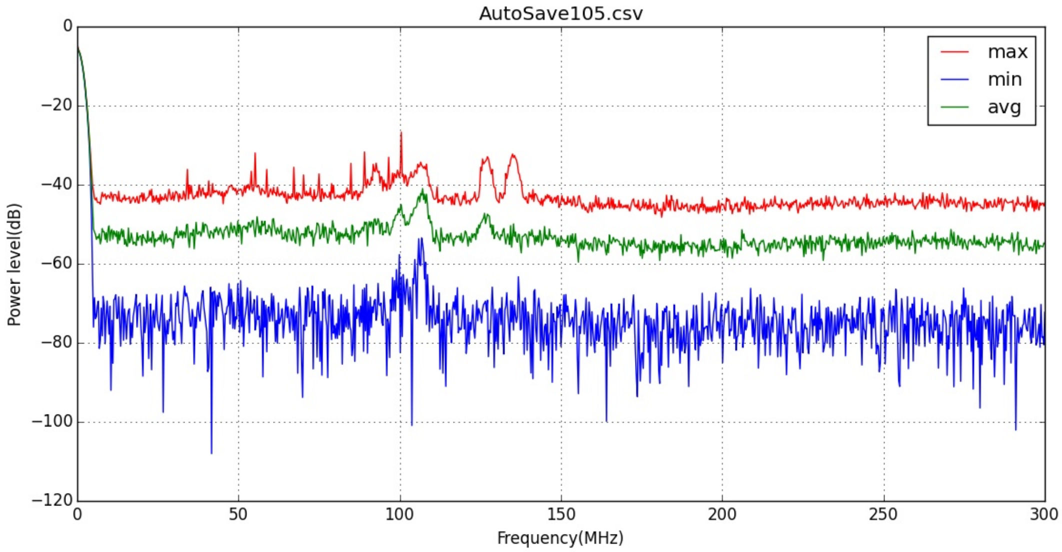

Figure 6: Pictured above is the radio environment from 0-300 MHz as measured from a box canyon to the northeast of the house, with the dipole axis aligned N-S. This alignment points the null of the antenna beam towards the point of the lowest horizon altitude (4°), and the peak of the beam towards the most geologically sheltered part of the canyon. Most of the RFI contamination is contained within the FM band, with no strong signals appearing beyond approximately 140 MHz. All sources of RFI have an amplitude of less than -25 dBm, and there are two new bright sources with peaks around 125 MHz and 135 MHz.

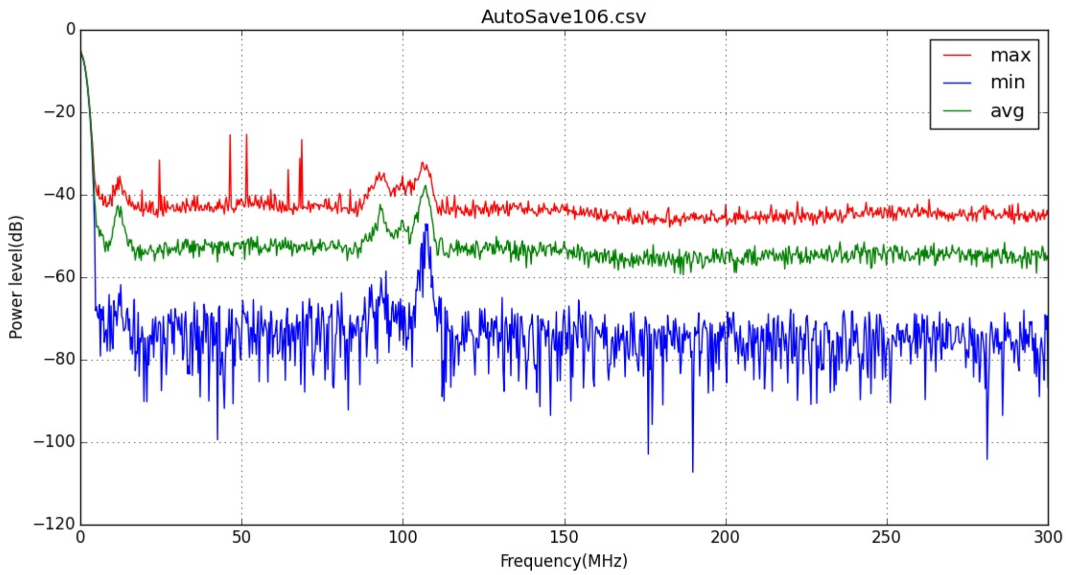

Figure 7: Pictured above is the radio environment from 0-300 MHz as measured from a box canyon to the northeast of the house, with the dipole axis aligned E-W. This alignment points the peak of the antenna beam towards the point of the lowest horizon altitude (4°), and the null of the beam towards the most geologically sheltered part of the canyon. Most of the RFI contamination is contained within the FM band, with no strong signals appearing beyond approximately 110 MHz. All sources of RFI have an amplitude of less than -25 dBm, though the ones that are present have higher power levels than in the N-S alignment. The sources seen at 125 and 135 MHz are no longer visible, indicating that they were being transmitted from somewhere in the E-W directions of the canyon.

C Data from Mounted Truck Observations

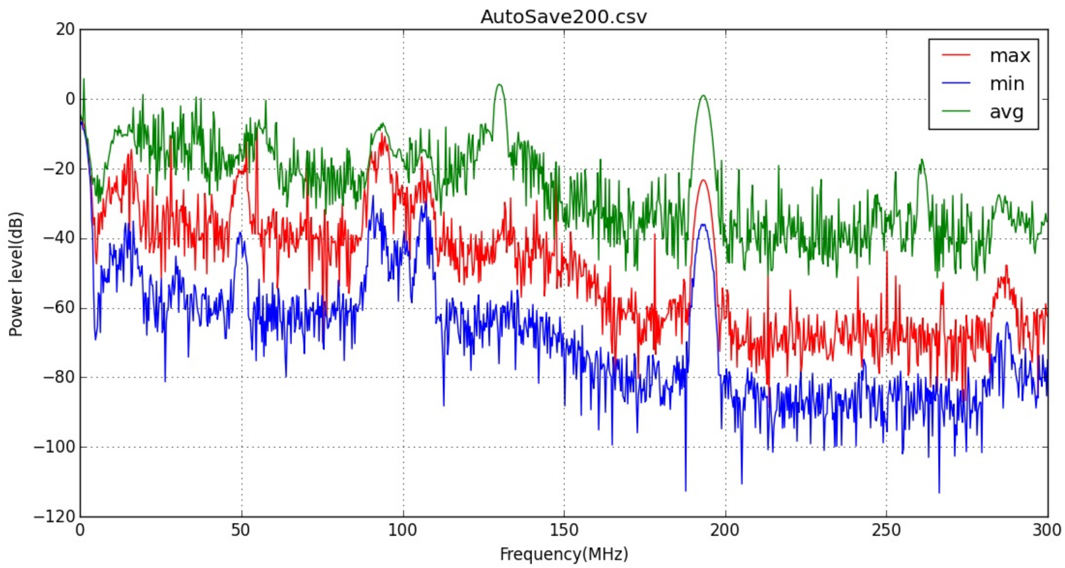

Figure 8: Pictured above is the radio environment from 0-300 MHz as measured from the house, with the dipole mounted in the back of a pick-up truck. This arrangement, while convenient for mobility, clearly introduces a fair amount of reflections and other spectral features. The strongest RFI sources in this spectrum have amplitudes of more than 0 dBm and a maximum noise floor ranging between -40 and -20 dBm, making this the loudest and noisiest spectrum measured in this set of experiments.

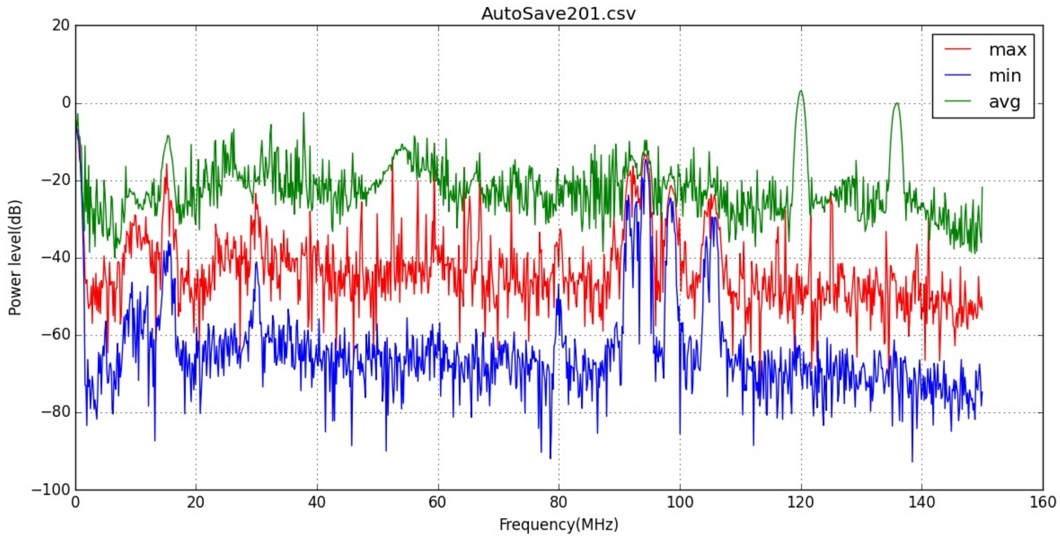

Figure 9: Pictured above is the radio environment from 0-150 MHz as measured from City Road 2, with the dipole mounted in the back of a pick-up truck. The strongest RFI sources in this spectrum have amplitudes of more than 0 dBm and a maximum noise floor ranging between -30 and -20 dBm, making this a marginally better spectrum than the data set shown in the previous figure.

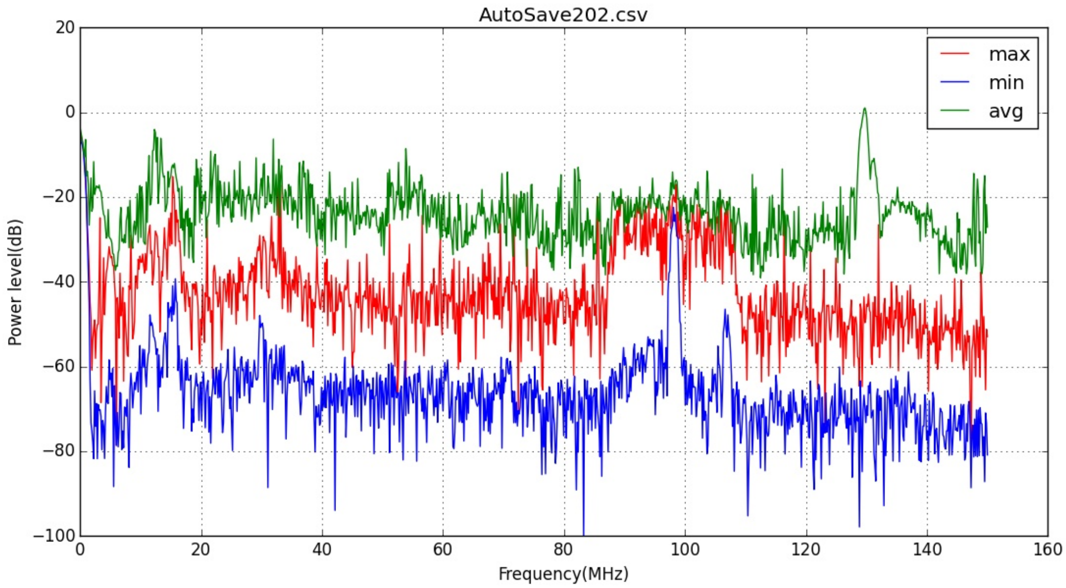

Figure 10: NOTE: I CAN'T READ THESE NOTES, I DON'T KNOW WHAT THIS MEASUREMENT IS

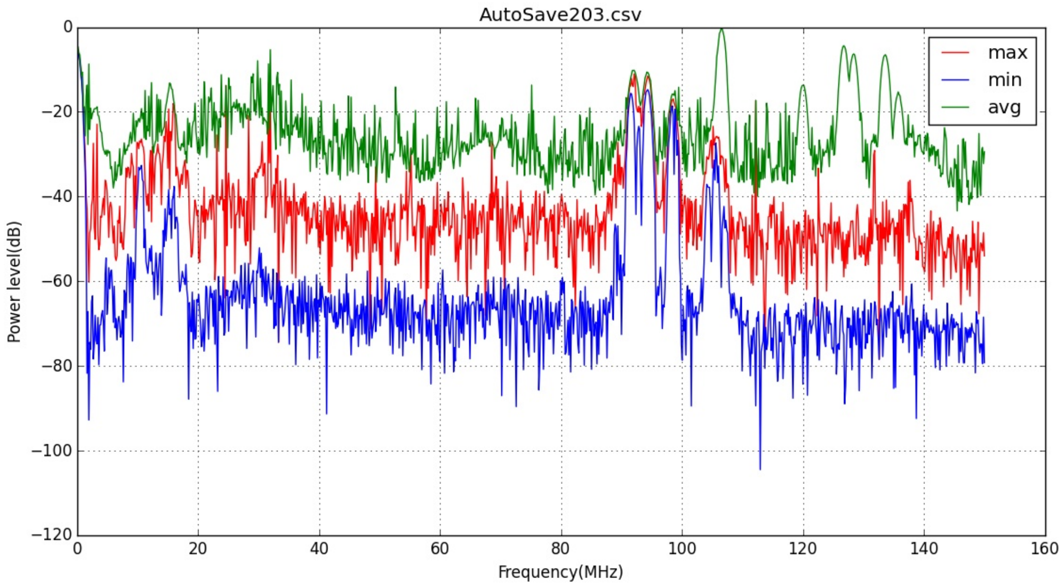

Figure 11: Pictured above is the radio environment from 0-150 MHz as measured from a shallow hollow at the entrance to Cottonwood Canyon, with the dipole mounted in the back of a pick-up truck. The spectrum has a maximum noise floor ranging between -30 and -20 dBm, and approximately seven consistent sources of RFI between 90-110 MHz. Most of the higher frequency RFI sources between 120-138 MHz appear to be transient, only appearing in the maximum spectrum and not the average or minimum spectra. All RFI sources have an amplitude of less than 0 dBm in this observation, and the consistent sources only have a max amplitude of approximately -10 dBm. Even in this very noisy data set, it's already apparent that Cottonwood Canyon could be a promising deployment site. NOTE: ALSO STRUGGLING TO READ THIS

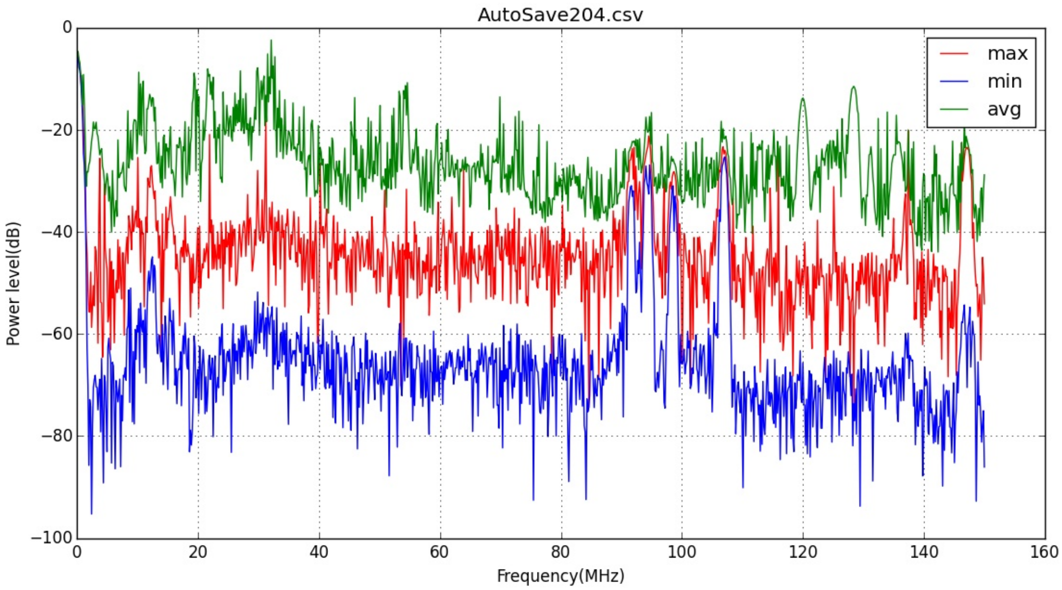

Figure 12: Pictured above is the radio environment from 0-150 MHz as measured from three miles up the road into Cottonwood Canyon, with the dipole mounted in the back of a pick-up truck. The spectrum has a maximum noise floor ranging between -30 and -20 dBm, and approximately four consistent sources of RFI between 90-110 MHz. Most of the higher frequency RFI sources between 120-138 MHz appear to be transient, only appearing in the maximum spectrum and not the average or minimum spectra. All RFI sources have an amplitude of less than -10 dBm in this observation, and the consistent sources only have a max amplitude of approximately -25 dBm. Going deeper into the canyon and using the shallow rock walls as natural attenuators to local RFI is proving to be an effective method.

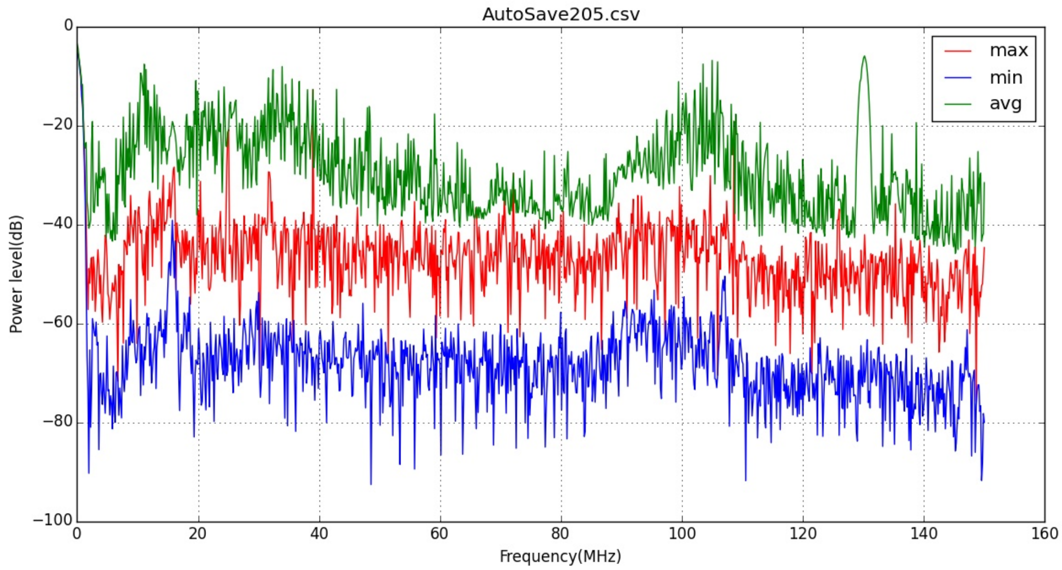

Figure 13: Pictured above is the radio environment from 0-150 MHz as measured from a small box canyon approximately five miles up the road into Cottonwood Canyon, with the dipole mounted in the back of a pick-up truck. The spectrum has a maximum noise floor ranging between -40 and -20 dBm, an average noise floor of -45 dBm, and no visible consistent sources of RFI. There is one higher frequency RFI source centered at 130 MHz that appears to be transient, only appearing in the maximum spectrum and not the average or minimum spectra, with an amplitude of approximately -10 dBm. This is the best candidate site yet, and is further explored in the next round of testing upon being removed from the back of the truck.

D Data from Cottonwood Road Box Canyon

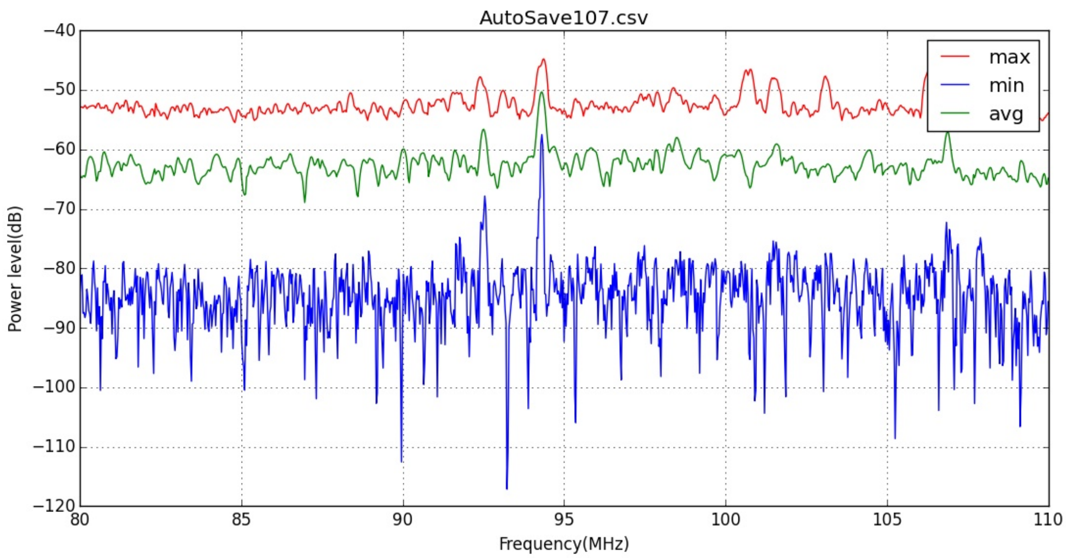

Figure 14: Pictured above is the radio environment from 80-110 MHz as measured from the creek bed in the box canyon off of Cottonwood Road, approximately 15 miles southwest of Rangely, with the dipole axis aligned E-W. This is the cleanest radio sky that we observed, with only two visible sources of RFI and both with amplitudes of less than -45 dBm. This was also the most sheltered testing location, where the box canyon had faces on all sides of the antenna.

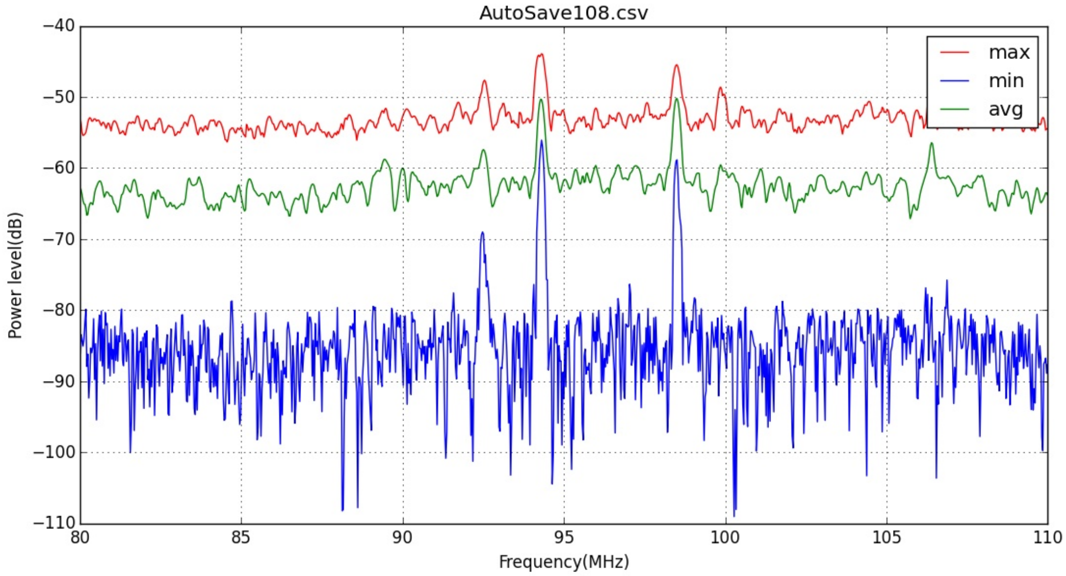

Figure 15: Pictured above is the radio environment from 80-110 MHz as measured from the creek bed in the box canyon off of Cottonwood Road, approximately 15 miles southwest of Rangely, with the dipole axis aligned N-S. Although not quite as impeccable as the previous figure, there are still only three visible sources of RFI in this spectra and all have amplitudes of less than -45 dBm.

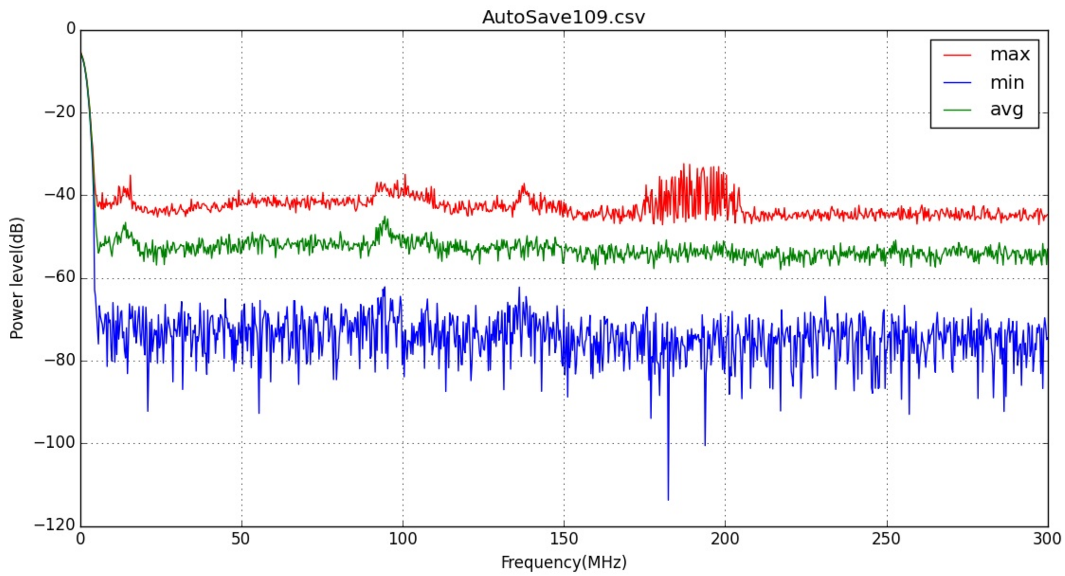

Figure 16: Pictured above is the radio environment from 0-300 MHz as measured from the creek bed in the box canyon off of Cottonwood Road, approximately 15 miles southwest of Rangely, with the dipole axis aligned E-W. Overall, this is a very clean radio sky, with some fuzz appearing intermittently between 175-205 MHz. We believe this originates from the local oilfields. This was also the most sheltered testing location, where the box canyon had faces on all sides of the antenna.

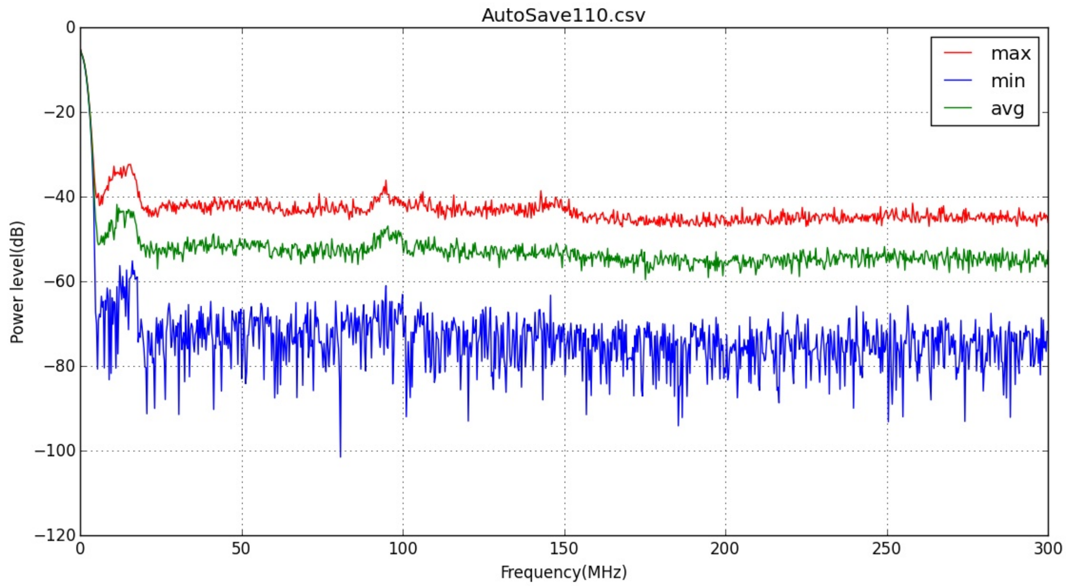

Figure 17: Pictured above is the radio environment from 0-300 MHz as measured from the creek bed in the box canyon off of Cottonwood Road, approximately 15 miles southwest of Rangely, with the dipole axis aligned N-S. All RFI sources are very attenuated here, and the high frequency fuzz seen between 175-205 MHz in the previous figure is no longer visible, as the oilfields are now in the null of the dipole beam.