Morocco Site Evaluation for 21cm Cylindrical Radio Telescope

Dave McGinnis
Ralph Pasquinelli
January 26, 2009

Introduction

Fermilab is a member of the 21 cm Cylindrical Radio Telescope collaboration. Possible sites in Morocco for the 21 cm CRT were measured for radio frequency interference during January 6-8, 2009. The site visit was hosted by Al Akhawayn University located in Ifrane, Morocco.

Equipment

Two antennas were used for the measurements

1. D-130J Super Discone Antenna from Diamond Antenna with a frequency range of 25-1300 MHz, a gain of 2dBi and vertical polarization. The antenna is shown in Figure 1
2. CLP5130-2 UHF Log Periodic Antenna from Creative Design Corp. with a frequency range of 105-1300MHz, a gain of 11-13dBi, and horizontal polarization. The antenna is shown in Figure 2.

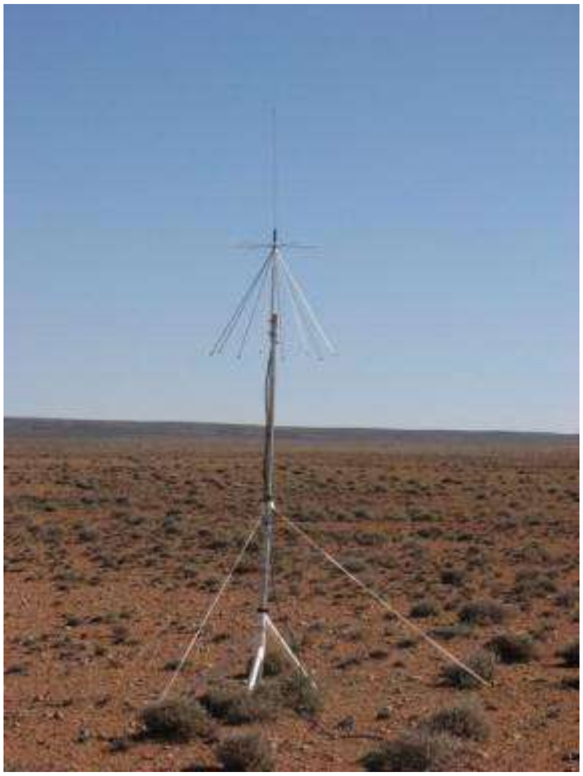

Figure 1. D-130J Super Discone Antenna from Diamond Antenna with a frequency range of 25-1300 MHz, a gain of 2dBi and vertical polarization.

Figure 2. CLP5130-2 UHF Log Periodic Antenna from Creative Design Corp. with a frequency range of 105-1300MHz, a gain of 11-13dBi, and horizontal polarization.

The antennas were mounted to a mast that could extend to 7 meters in height although it as extended only about to 3 meters during the measurements. The antenna output was connected to a Miteq low noise amplifier (AMF-3F-0050010-10-10P) which has a frequency range of 500-1000MHz, a gain of 45 dB, and a noise figure of 0.5 dB. The useable frequency band extended from 100 MHz to over 1500 MHz.

The amplifier was connected to an Agilent 9020 MXA signal analyzer with approximately 30 meters of Times Microwave LMR-200 3.5 mm flexible cable. The cable is low loss and is designed for short antenna feeder runs. The cable has a multi-ply bonded foil outer conductor and is rated for 90dB of isolation. The long length was chosen to reduce RFI generated by the signal analyzer from feeding into the antenna. The measured gain of the amplifier and cable is shown in Figure 3. The measured noise figure is shown in Figure 4.

The signal was analyzed with an Agilent 9020 MXA signal analyzer. The analyzer can perform vector signal and swept spectrum analysis. The measurements were done in the vector signal mode. In this mode, the analyzer measures the spectrum via an FFT. Because the FFT can be done extremely fast, many averages of the FFT can be done. The drawback of using the vector signal analyzer mode is that the instantaneous bandwidth cannot be greater than 10 MHz. to measure a spectrum greater than 10 MHz of span, the measurements must be broken up into discrete steps. To step through the spectrum, a Java program was written to control and collect data from the analyzer. Because the Agilent 9020 MXA signal analyzer runs Windows XP, the controlling program can be resident on the analyzer. This eliminates the need for an external computer to control and collect data. Reducing the amount of computers during the site test is highly desired because of the amount of RFI that high speed computers produce. A screen shot of the Java data acquisition program is shown in Figure 5.

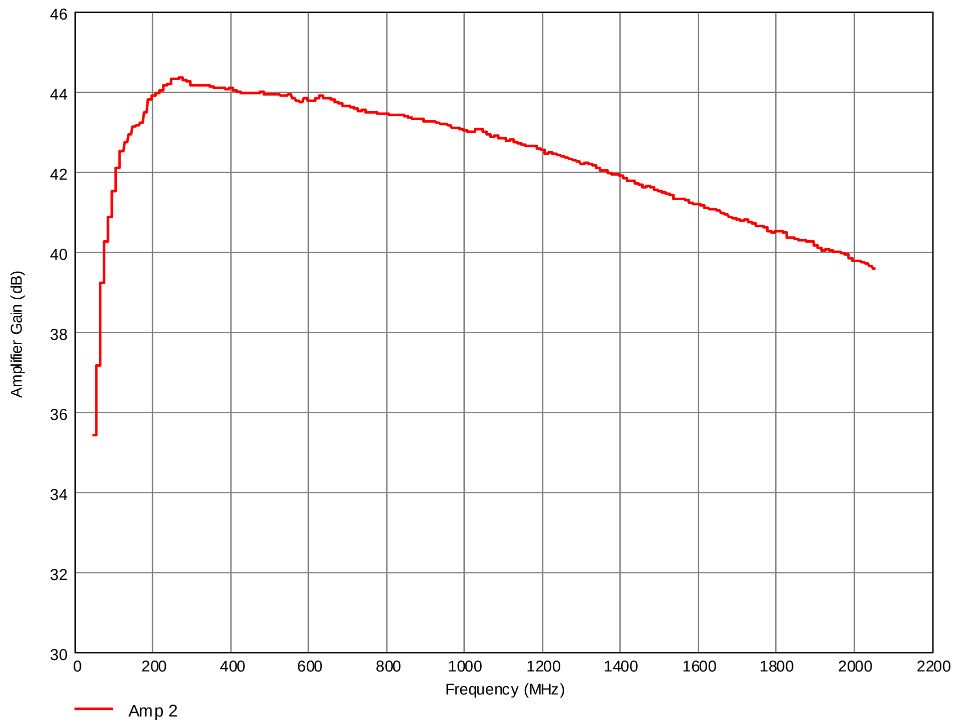

Figure 3. Measured gain of Miteq low noise amplifier (AMF-3F-0050010-10-10P) and 30 meters of Times Microwave LMR-200 3.5 mm cable.

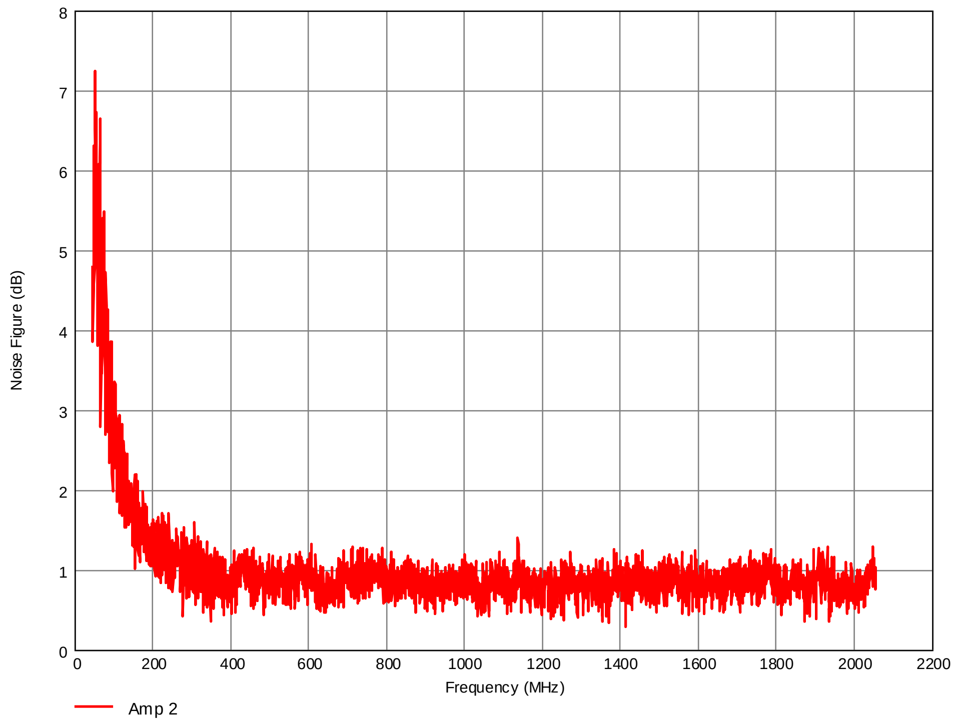

Figure 4. Measured noise figure of Miteq low noise amplifier (AMF-3F-0050010-10-10P) and 30 meters of Times Microwave LMR-200 3.5 mm cable.

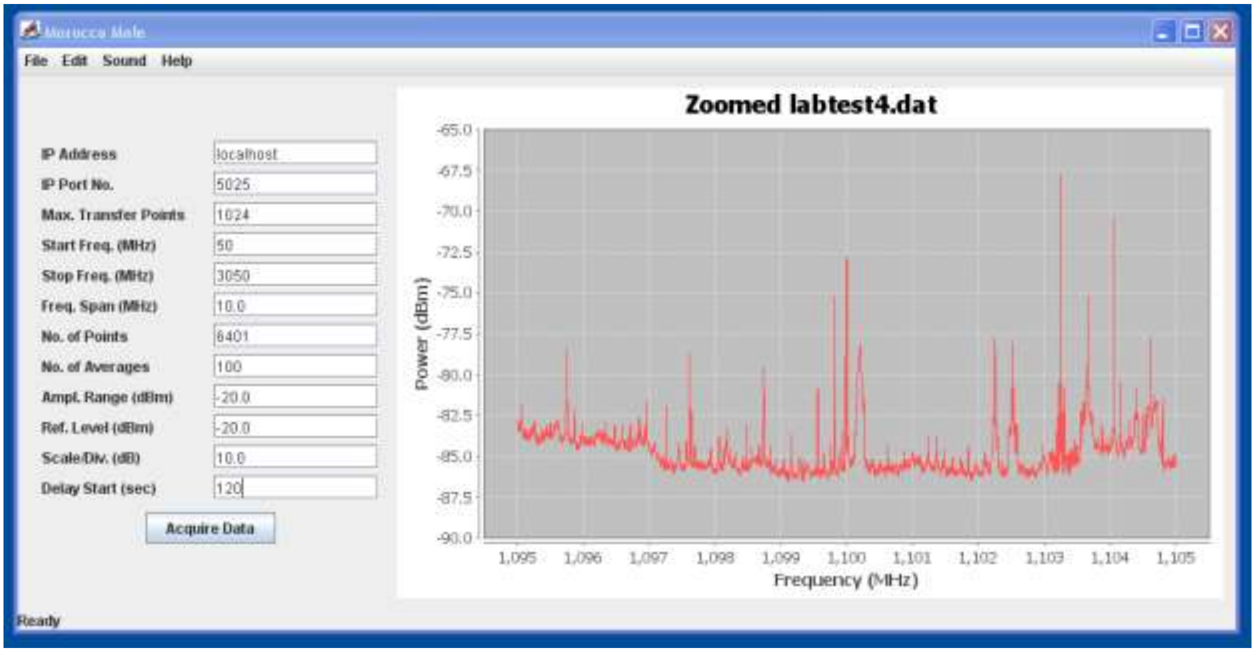

Figure 5. Screen shot of on-board Java control and acquisition program for the Agilent 9020 MXA signal analyzer.

Even still, since the MXA contains a computer, the MXA also produces RFI that can feed into the measurements. The MXA was shielded from the antenna by means of a "screen bag". A photograph of the screen bag is shown in Figure 6. The screen bag is much lighter and transportable than a shielded box. The screen bag was made from fine mesh aluminum mosquito screen. The closed edges of the bag were sealed by a row of stables followed by a layer of copper tape, followed by a layer of duct-tape which again was sealed by a row of staples. After the equipment was inserted into the bag, the open end of the bag was sealed by clips placed a few centimeters apart. It is important that the power supply ground and the signal cable ground are in good ohmic contact with the screen bag.

Figure 6. Photo graph of a "screen bag" for RFI shielding.

The MXA consumes energy at a rate of about 175 Watts. This power would drain a typical 12 Volt car battery in about two hours so battery power over many hours and days would not be practical. To supply power, a light-weight Honda 4 cycle gasoline generator was purchased. The generator can supply as much as 900 Watts. At 200 Watts, the generator could run for eight hours on 2 liters of gasoline. The gasoline powered generator uses a spark plug which could generate substantial amount of RFI. To test the amount of RFI the generator produced, the generator was placed 1 meter away from the discone antenna shown in Figure 7. The antenna was connected to the low-noise amplifier and the measurements were made inside a screen room. Figure 8 shows RFI measurements at three different frequencies with the unshielded generator. The measurement is the ratio RFI produced with the generator on to the generator off. The generator clearly produces broadband RFI. Figure 9 shows the same measurements except the generator shielded with a screen bag. The screen bag removes all trace of RFI.

Figure 7. RFI measurements of the generator

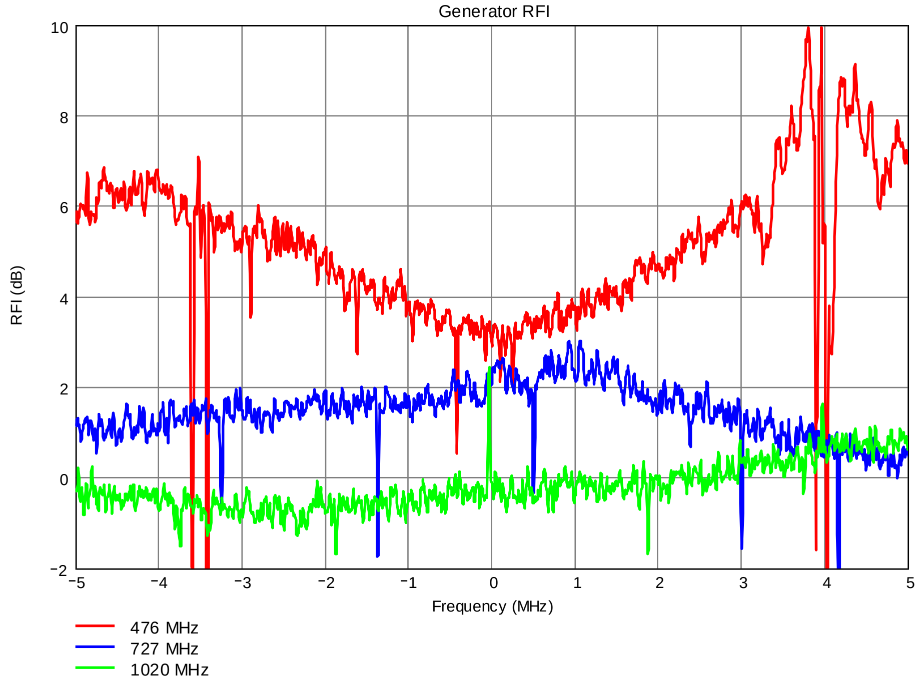

Figure 8. Measurements of an unshielded generator RFI at three different frequencies. The measurements are the ratio of with the generator on to generator off. The spikes or glitches in the data is due to external RFI leaking into the screen room

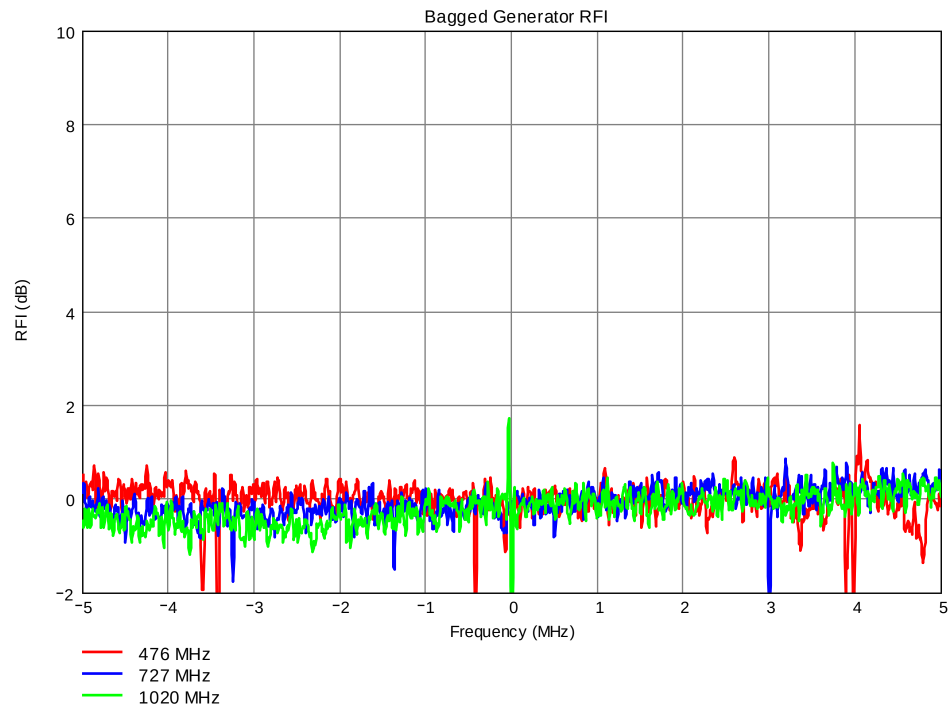

Figure 9. Measurements of shielded generator (using a screen bag) RFI at three different frequencies. The measurements are the ratio of with the generator on to generator off.

Measurements

The collaboration picked eight possible sites to investigate in Morocco. These sites are shown in Figure 10. After some discussion, it was decided that sites 4, 5, and 8 would be the first sites to test. Travel to Site 8 was relatively straightforward because the site was close to the town of Talsint. The data taken with the discone antenna at Site 8 is shown in Figure 11 and Figure 12. The raw data was normalized to a flux density by the following:

$$N\left(\frac{dBW}{m^2Hz}\right) = 10log_{10}\left(\frac{P_{raw}(mW)\frac{1W}{1000mW}}{G_{amp}G_{cable}\Delta f_{rbw}(Hz)A_{ant}(m^2)}\right) \quad (1)$$

where P_{raw} is the power measured by the signal analyzer, G_{amp} is the power gain of the amplifier measured by a network analyzer, G_{cable} is the power attenuation of the cable, Δf is the resolution bandwidth of the vector signal analyzer and A_{ant} is the effective area of the antenna. The effective area of the antenna is determined from the gain or directivity of the antenna.

$$A_{ant}(m^2) = \left(\frac{c}{f}\right)^2 \frac{10^{\frac{D(dBi)}{10}}}{4\pi} \quad (2)$$

where c/f is the wavelength of radiation an D is the antenna directivity relative to an isotropic source. The resolution bandwidth of the measurements shown in Figure 11 and Figure 12 is 25kHz. Because Site 8 was so close, a large amount of RFI was seen around 938 MHz. This signal is from cell phone towers that can be seen near Talsint. The integrated power of the largest peak is over 1μW/m^2. Because of the large amount of interference, it was decided not to measure the site with the log-periodic antenna.

Figure 10. Moroccan Site Map

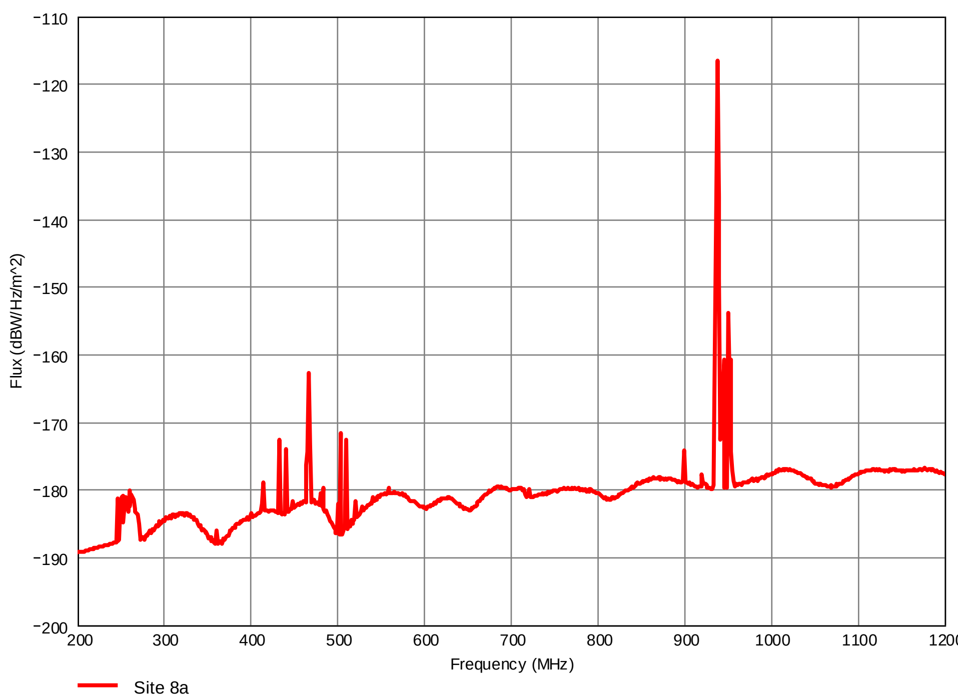

Figure 11. Normalized measurements at Site 8. The resolution bandwidth of the measurements is 25kHz.

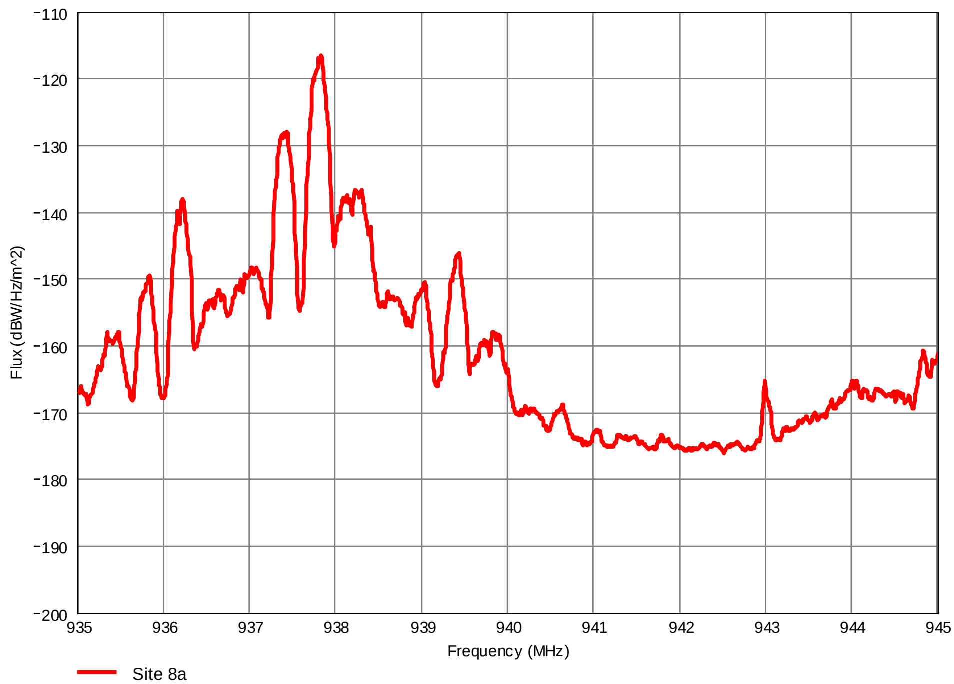

Figure 12. Zoomed in normalized measurements at Site 8. The resolution bandwidth of the measurements is 25kHz. The integrated power of the largest peak is 1uW/m^2.

The travel off-road in Morocco proved to be more difficult than expected so it was not possible to make it from Talsint to Site 5 in a single day. The route travel is shown in Figure 13. It was decided to make measurements at a site south of the intended Site 5. This site was designated Site 5a as shown in Figure 13. The discone measurement of Site 5a is shown in Figure 14. The RFI near 940MHz is still present but substantially reduced from the amount of RFI present at Site 8a. There were also some other signals detected. It was assumed that the RFI present around 1.5 GHz was due to GPS satellite, the RFI present below 250MHz was due to TV and radio stations. There were also some signals observed near 470 MHz.

The site was deemed quiet enough so that detailed measurements with the log-periodic antenna should be done. The log-periodic measurements were with the antenna pointing at the east, north-east, north, north-west, west, south-west, south, and south-east. Each measurement spanned from 50-2050MHz with a resolution bandwidth of 25 kHz and 1000 averages. Each measurement took about 50 minutes to complete. The strongest signals came from the south-west which is the direction towards the town of Anoual. The south-west measurement is shown in Figure 16. The integrated power of a number of the RFI peaks as a function of direction is shown in Figure 17. The beam width of the log-periodic antenna is about 60 degrees. The strongest signal is about 20 pW/m^2, which is about four orders of magnitude smaller than was seen at Site 8a. As a comparison, the integral of the noise power into the log-periodic antenna from an ideal 300K sky from 500MHz to 1400 MHz is about 40pW/m^2. There was just enough time left in the trip to travel to the intended Site 5 (now designated 5b) and make a discone measurement. The measurement is shown in Figure 18. Even though Site 5b was much more remote and less populated than Site 5a, the amount RFI present at Site 5b was about the same as Site 5a. There was not enough time to make a series of log-periodic measurements at Site 5b. Table 1 gives a summary of the measurements taken during the site visits.

Figure 13. Travel route to Sites 5a and 5b

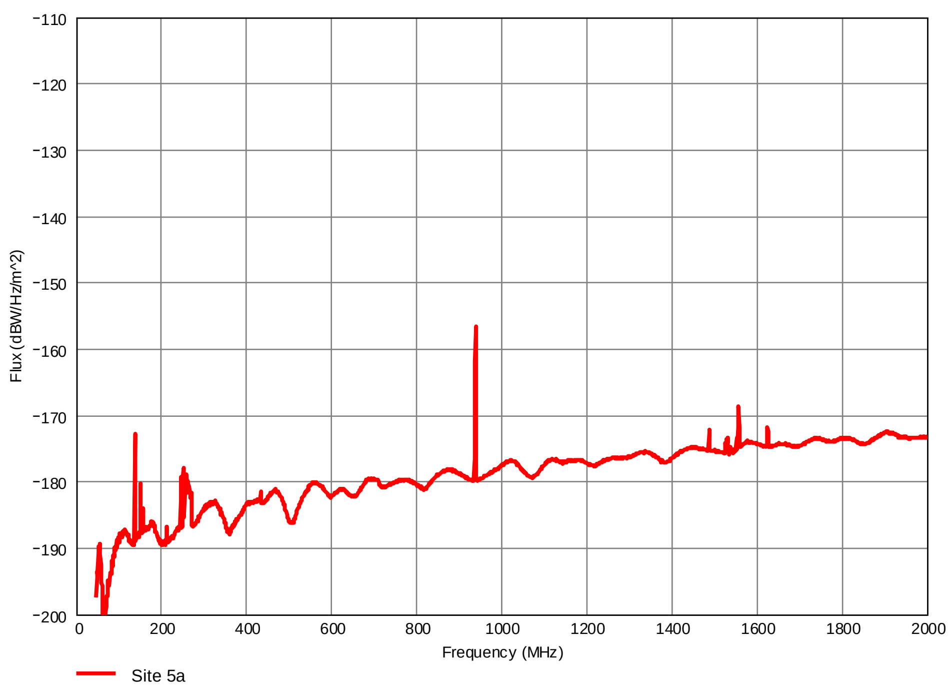

Figure 14. Discone measurements at Site 5a. The resolution bandwidth of the measurement is 25kHz.

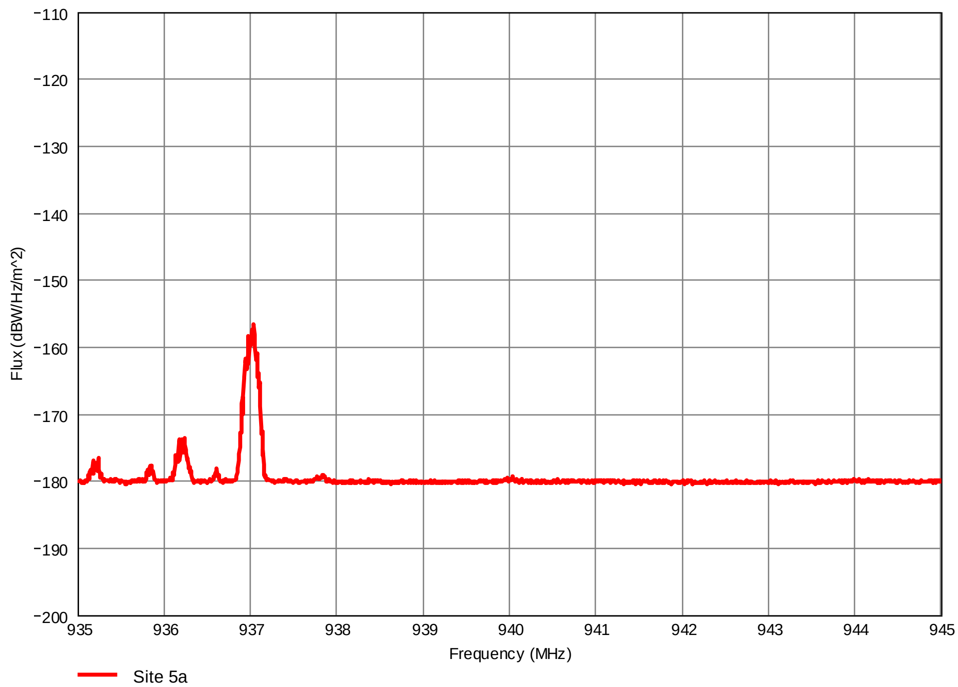

Figure 15. Zoomed in normalized discone measurements at Site 5a. The resolution bandwidth of the measurement is 25kHz.

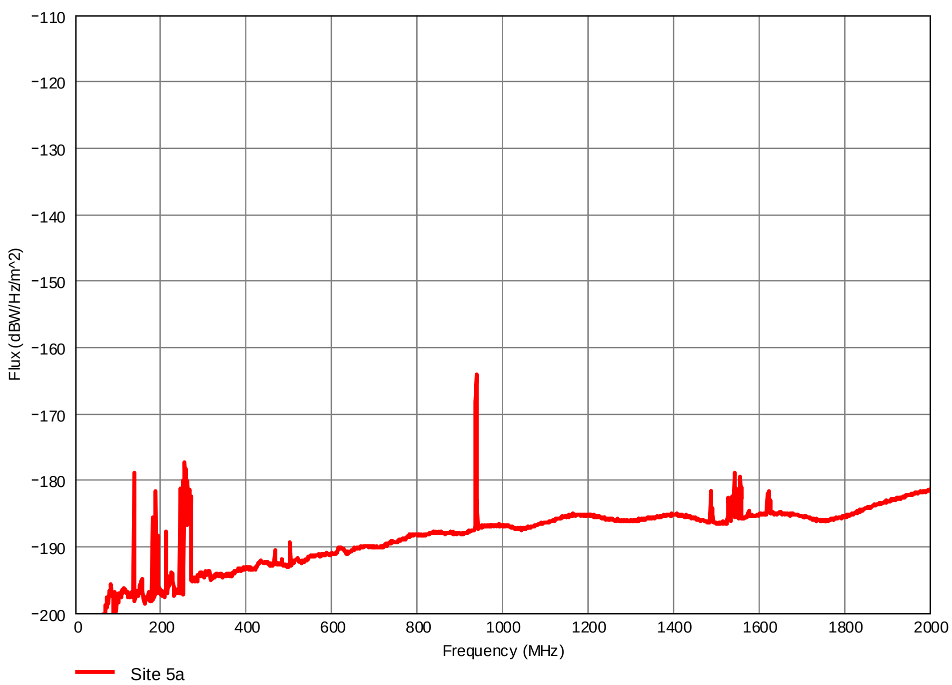

Figure 16. Normalized log-periodic measurement of Site 5a with the antenna pointed towards the south-west. The resolution bandwidth of the measurement is 25kHz.

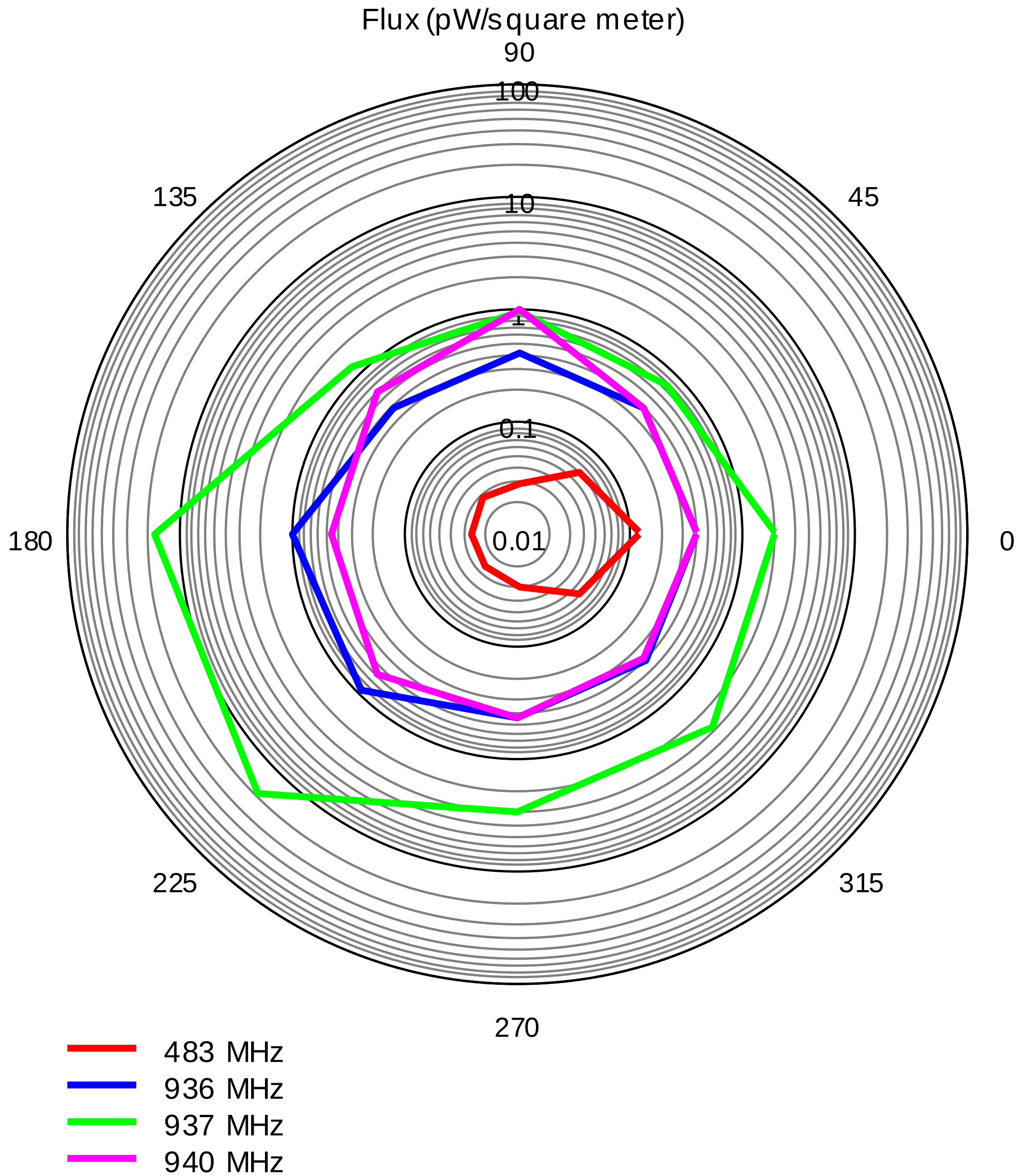

Figure 17. Directional plot of signal flux at Site 5a using the log-peridic antenna. The antenna has a beam width of about 60 degrees. The north direction is pointing up, the east direction is pointing to the right. The units of the plot is pW/m^2.

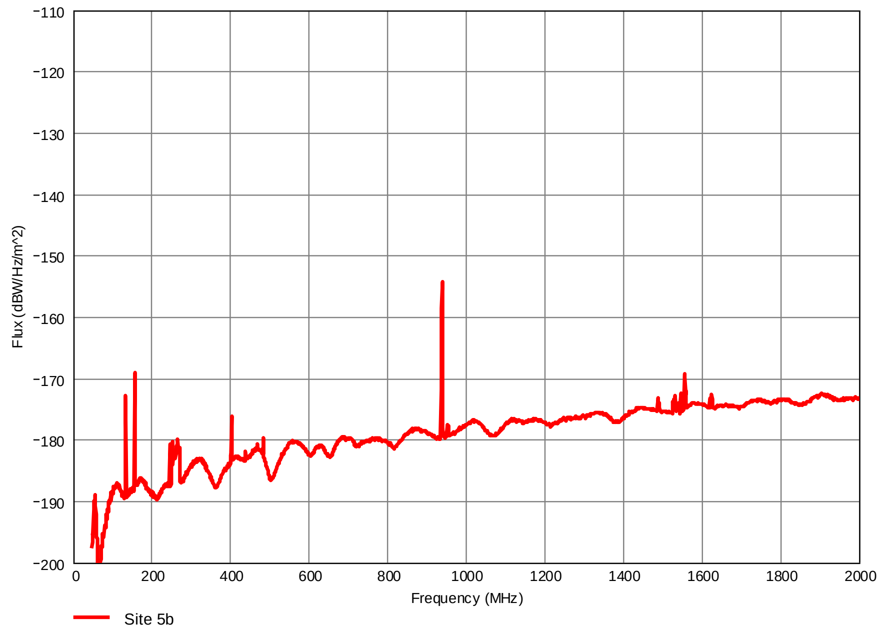

Figure 18. Normalized discone measurement at Site 5b.

File Name	Date	Latitude degees N	Longitude degrees W	Elevation m	Antenna	Pointing	Start Freq MHz	Stop Freq MHz	Step Freq kHz
pp8a	1/6/2009 16:55	32.60925	3.32593	1360	Discone	All	245	1255	6.25
pp5a	1/7/2009 16:54	32.79833	2.93024	1303	Discone	All	45	2055	1.5625
pp5aSS	1/7/2009 18:15	32.79833	2.93024	1303	Log Per	South	45	2055	6.25
pp5aWW	1/7/2009 19:28	32.79833	2.93024	1303	Log Per	West	45	2055	6.25
pp5aNN	1/7/2009 20:29	32.79833	2.93024	1303	Log Per	North	45	2055	6.25
pp5aEE	1/7/2009 21:23	32.79833	2.93024	1303	Log Per	East	45	2055	6.25
pp5aNE	1/7/2009 22:15	32.79833	2.93024	1303	Log Per	North East	45	2055	6.25
pp5aSE	1/7/2009 23:08	32.79833	2.93024	1303	Log Per	South East	45	2055	6.25
pp5aSW	1/8/2009 0:00	32.79833	2.93024	1303	Log Per	South West	45	2055	6.25
pp5aNW	1/8/2009 0:51	32.79833	2.93024	1303	Log Per	North West	45	2055	6.25
pp5b	1/8/2009 12:04	32.92462	2.87838	1465	Discone	All	45	2055	6.25

Table 1. Summary of data taken.

Noise Performance

During the data analysis performed upon returning from Morocco, it was noted that the normalized noise floor of the measurements seemed higher than expected, especially at the low end of the frequency band. Figure 19 shows the comparison between the normalized discone measurements at Site 5a compared to a theoretical 300K sky feeding the discone antenna with no amplifier noise. The difference in the traces is much larger than would be expected with an amplifier that has a noise figure of less than 1 dB. The gain of the amplifier was measured upon the return from Morocco and compared to the spare amplifier on the same plate. Before the Morocco trip, the difference in gain between the amplifiers was less than a dB. After Morocco, the difference in gain was over 4 dB as shown in the network analyzer measurement displayed in Figure 20. The loss in gain for the amplifier used in Morocco changed the noise figure drastically from the 1 dB noise figure measured before the Moroccan trip. The noise figure measurement performed after the Moroccan trip is shown in Figure 21. Comparing the raw data of the Moroccan site measurements as shown in Figure 22 with the raw amplifier noise measurements, indicate that the test amplifier was broken during transport to Morocco.

In retrospect, a 4dB change in gain out of 47 db of total gain would have been difficult to detect in the field. In the future, the gain of the amplifier should be checked frequently in the field. However, network analysis in the field would be cumbersome. The best way to check if the amplifier is functioning properly is to measure the output noise spectrum and compare it to a save spectrum

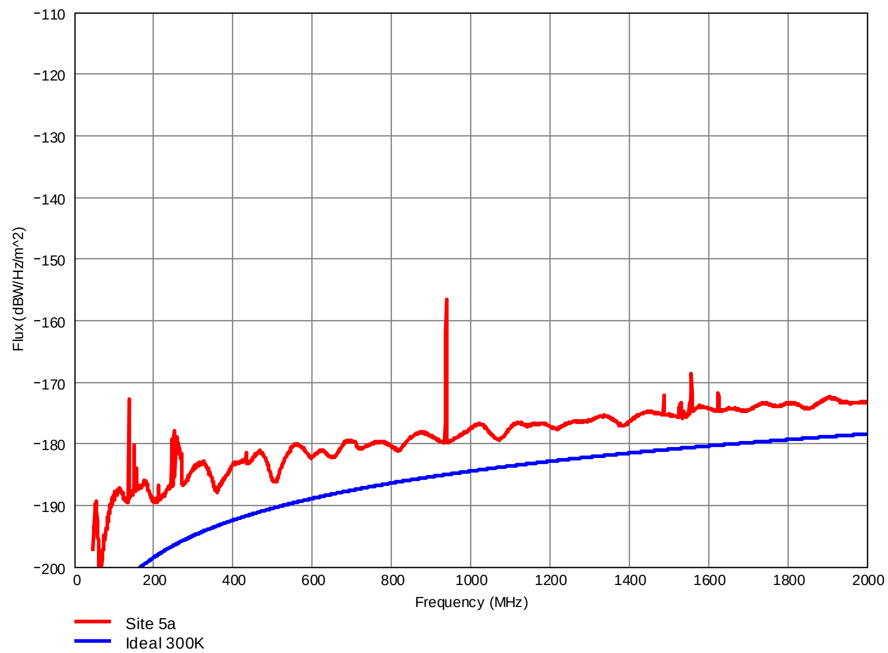

Figure 19. The red trace is the normalized discone measurements at site 5a. The blue trace is the theoretical noise floor of a 300K sky.

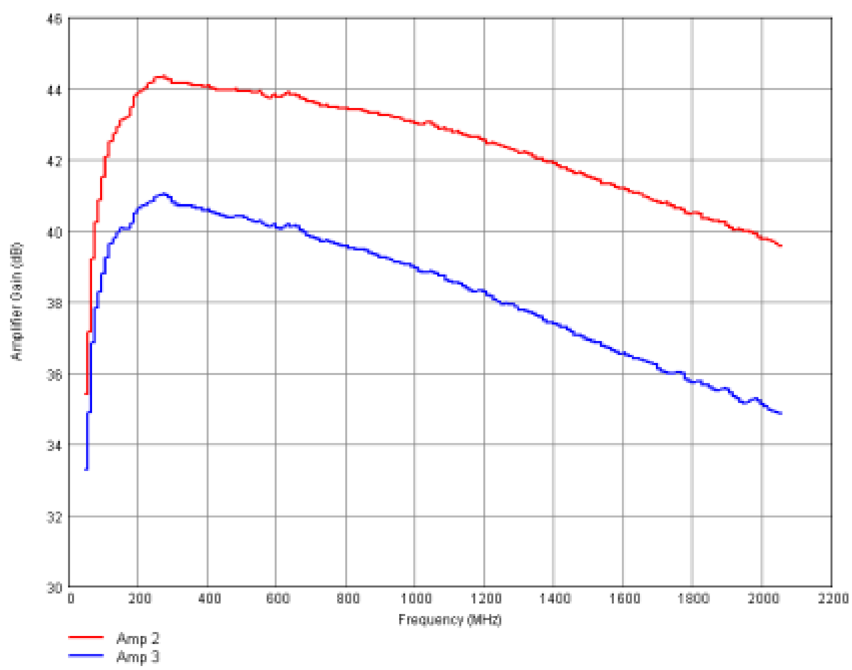

Figure 20. Amplifier Gain and cable loss network analyzer measurement for the spare amplifier (Amp 2) and the amplifier used during the Moroccan site visits (Amp 3). Before, the Moroccan trip, the gain difference between the two amplifiers was less than 1 dB.

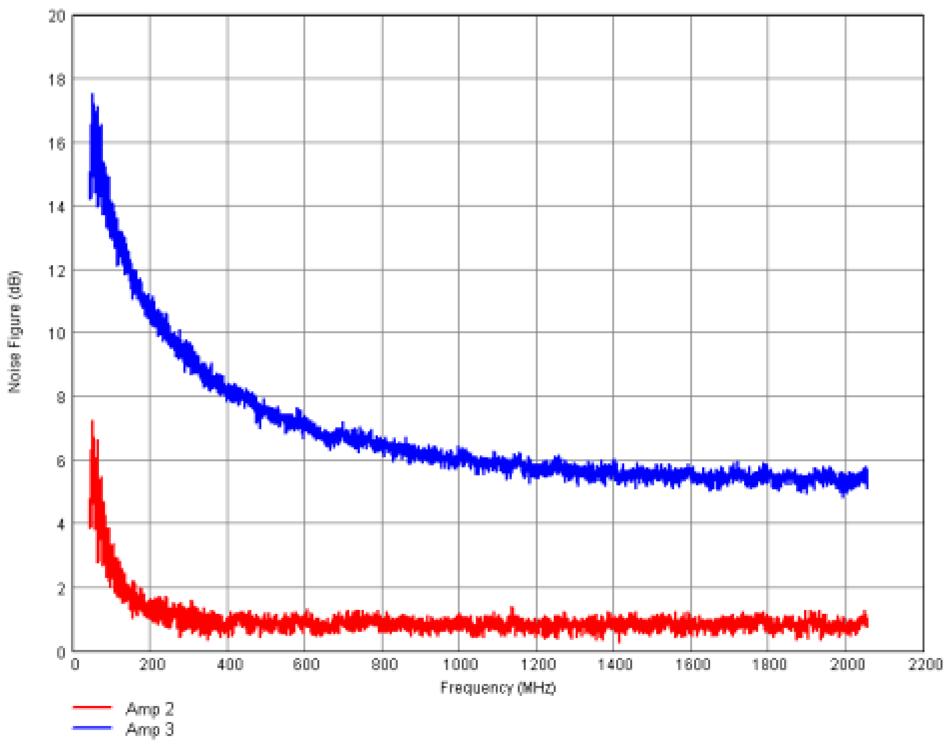

Figure 21. Noise Figure measurements for the spare amplifier (Amp 2) and the amplifier used during the Moroccan site visits (Amp 3). Before, the Moroccan trip, the noise figure of Amp 3 was less than 1 dB.

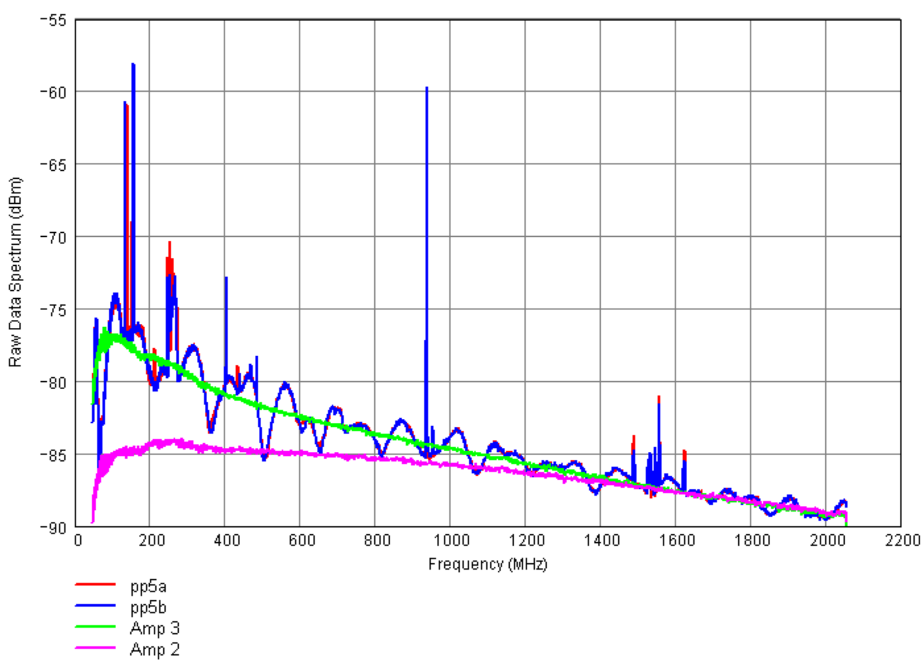

Figure 22. Comparison of raw data measurements of the Moroccan sites 5a and 5b (pp5a and pp5b) compared to raw data of the amplifier noise floor measurements.

Although, the unanticipated increase in amplifier noise was disappointing, small signals can stilled be distilled from the data because of the large amount of averages that were taken for each measurement. The number of averages for each measurement was 1000. Since the sweep time for every 10 MHz chunk of data with a resolution bandwidth of 25 kHz was 160μS, the total integration time was 0.16 S. Figure 23 shows the gain normalized noise signal of the log-periodic antenna pointing at the north-east centered at 750 MHz. The running average of the noise floor is given by the blue trace. Figure 24 shows a histogram plot of the deviation of the noise floor from the average noise floor. The standard deviation of the distribution is 45 Kelvin. This implies that a signal with a temperature of 45 K could be detected in the measurements.

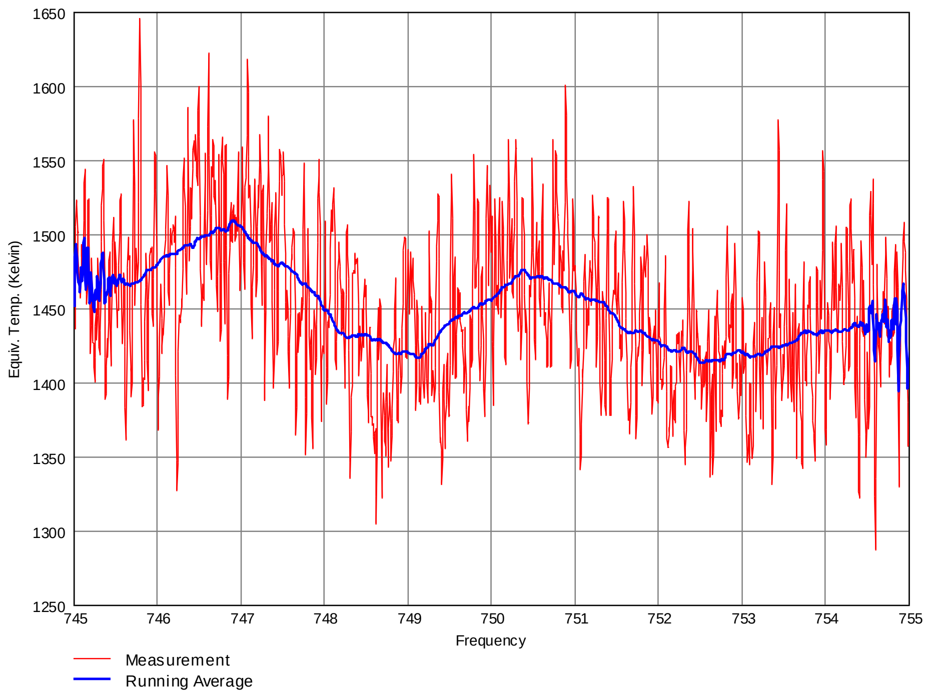

Figure 23. Gain Normalized noise floor for at 750 Hz for the north-east antenna pointing using the log-periodic antenna. The red trace is the data of which 1600 points cover a 10 MHz span. The blue trace is 200 point running average.

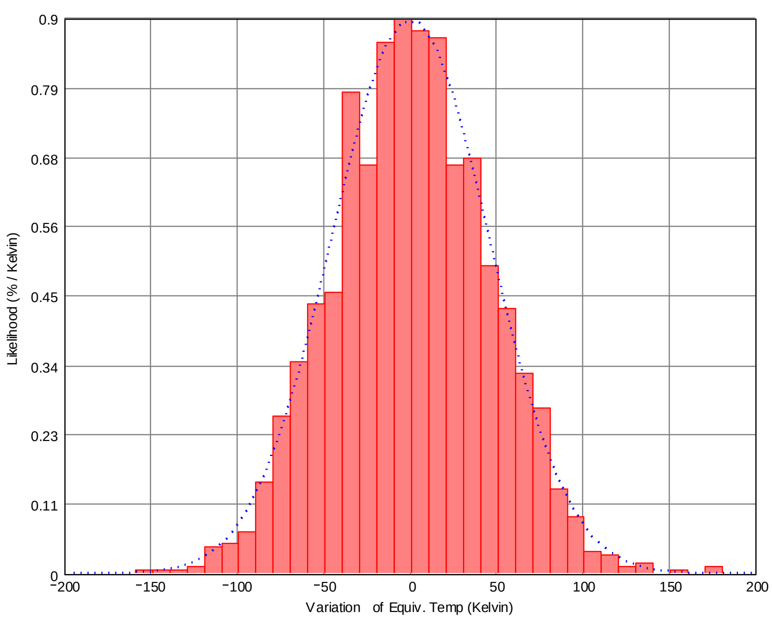

Figure 24. Histogram plot of the variation in noise. The standard deviation of the distribution is 45 Kelvin.

Summary

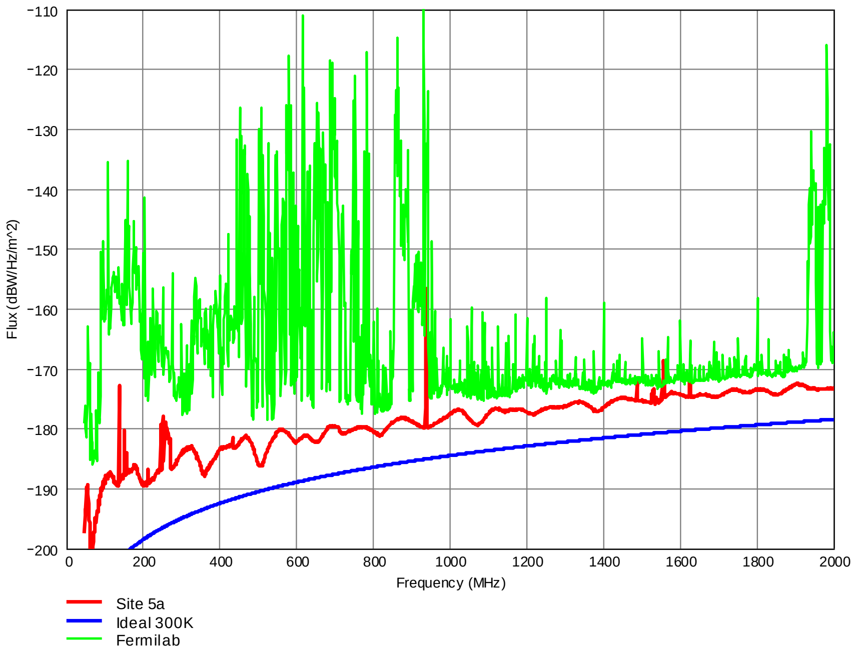

Figure 25. Comparison of RFI at Fermilab and Morocco Site 5a.