ALMA Memo 470

RFI Survey at the ALMA Site at Chajnantor

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Abstract: A Radio Frequency Interference survey covering 10 MHz – 18 GHz was conducted at Chajnantor, Chile, the site of the ALMA project, on 2002 December 6 – 9. The survey provides a “snapshot” view of existing RF activity in the area. The detected signals fell into these categories: noise from nearby electronic equipment, broadcast TV and FM radio, and terrestrial and satellite radio services.

Introduction

Extensive measurements of atmospheric transparency and stability since 1995 have demonstrated exceptional conditions for millimeter and submillimeter astronomy prevalent at the ALMA site on the high (5000 m) plateau near Cerro Chajnantor in northern Chile. Because the area is remote and sparsely populated, the expected level of Radio Frequency Interference (RFI) is low, but there have been no systematic RFI measurements to date. The intent of this report is to summarize the findings of a RFI survey conducted at Chajnantor on 2002 December 6--9 to characterize the local spectrum. Although the survey range, 10 MHz -- 18 GHz, is below the ALMA observing frequencies, 30--950 GHz, the survey frequencies do overlap the ALMA IF frequencies.

Interest in conducting the ALMA RFI survey was initiated by a suggestion from the previous Director of NRAO that an effort should be made to characterize the spectrum at the ALMA site. Such a survey had not been done previously and since some level of regulatory protection against harmful interference is being sought, he felt baseline data on existing, strong, persistent RFI might be useful for identifying blatant changes in the spectrum, should such protection be granted. At a minimum, it certainly makes good sense to have some idea what the spectrum "looks like" for planning purposes. With this in mind, the Green Bank RFI group, in support of the project ALMA, set out to develop an executable plan that would characterize the spectrum at the ALMA site. In this report, only a small portion of the collected data is presented. The extensive amplitude vs. frequency data that was collected is available for detailed future analysis as requirements warrant.

Methods

1. Equipment

1.1 Configuration

The measurement system consisted of an antenna, a preamplifier, and a spectrum analyzer (Figure 1). The antenna was mounted on a rotor, affixed to a tripod, and secured to the top of the NRAO instrument container (Figures 2 and 3). A PC provided data storage and test sequencing in communication with the spectrum analyzer (Figure 4).

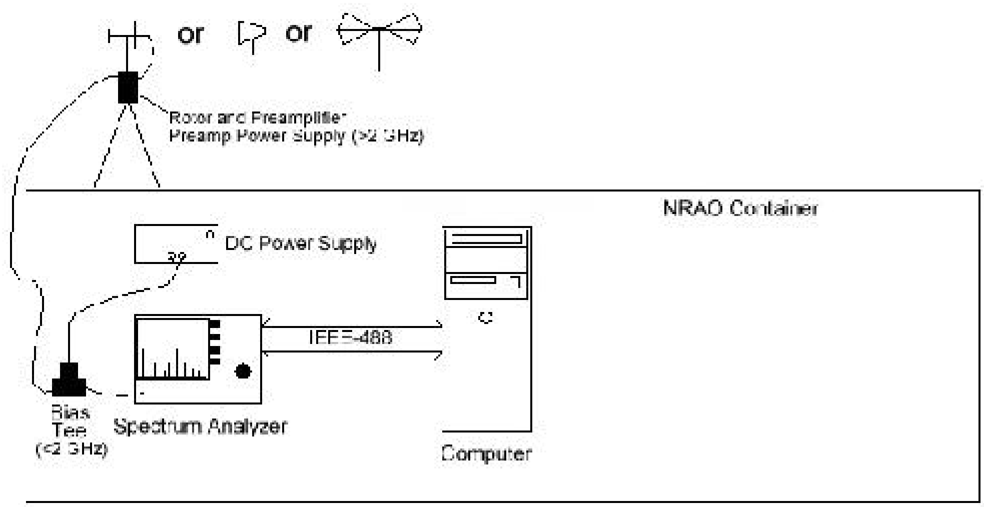


Figure 1: System Configuration

Figure 2: NRAO instrument container at Chajnantor with the biconical antenna for the RFI survey.

Figure 3: Biconical antenna with preamps, rotor, and tripod.

Figure 4: Spectrum analyzer and data collection software.
Note bias tee providing 15 VDC to preamps via the RF cable.

The following table shows the antennas and preamplifiers used for the different frequency ranges:

Frequency Range (MHz)	Antenna	Amplifier
10-200	EM-6912 (Biconical)	AU-1519-N-1306/E
200-300	EM-6950 (Log Periodic)	“
300-1000	”	AM-4A-0000110-N-1306/E
1000-2000	EM-6961 (Ridged Guide Horn)	AM-5A-1020-N-1306/E
2000-8000	“	AWT-8036
8000-12000	“	AMT-12435
12000-18000	“	AMT-18038

1.2 System sensitivity

The system sensitivity is:

$$S_{sys} = kTB + NF - G_{sys} + SN$$

Where: S_{sys} = System sensitivity in dBm
kTB = Thermal noise floor of receiver in dBm
NF = System noise figure in dB
G_{sys} = Composite gain/loss term for system
SN = signal to noise ratio required for detection (in dB)

Worst Case Values of S_{sys}

Frequency Range (MHz)	S_{sys} (dBm)	RBW (Hz)
10-60	-135	10^3
60-200	-156	10^3
200-300	-162	10^3
300-1000	-156	10^3
1000-2000	-145	10^4
2000-2900	-139	10^4
2900-6500	-138	10^4
6500-8000	-140	10^4
8000-12000	-137	10^4
12000-13200	-141	10^4
13200-18000	-127	10^4

The resolution bandwidth of the receiver figures into the system sensitivity as follows:

kTB = $\mathbf{N_{av} + 10\ log(RBW)}$

The complete calculation, as well as Gain/loss data for the antennas, cables, amplifiers, and bias T's are included in Appendix A.

2. Procedure

2.1 Preparation

To minimize local sources of RFI, most of the NRAO and ESO monitoring instruments and computers were shut down. It should be noted, however, some equipment was not turned off, including the 225 GHz tipper, the sub-mm tipper, the 183 GHz radiometer, a tone operated power switch, the seismometer and its GPS, the power inverters, fluorescent lights, and probably some other sources we failed to identify. In addition, equipment at the Cal Tech Cosmic Background Imager, about 1 km West, and the ASTE, about 8 km NE, were all still operating during our measurements, and a surveying team was operating their measurement and communications equipment less than 1 km away. Figures 5 and 6 were taken before and immediately following the equipment shutdown:

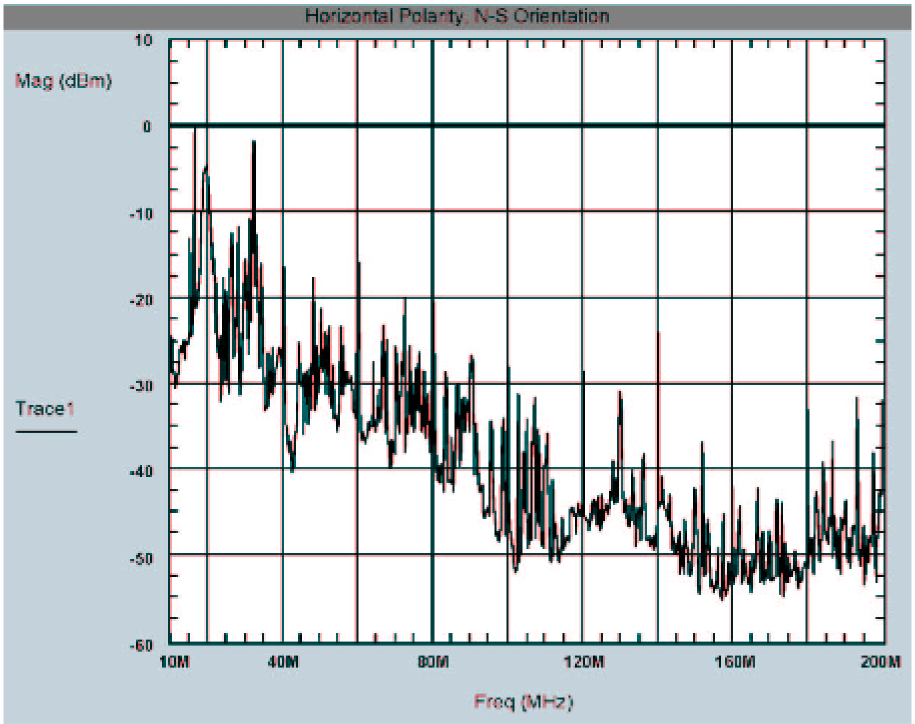


Figure 5: 10 - 200 MHz, all NRAO and ESO monitoring equipment operating.

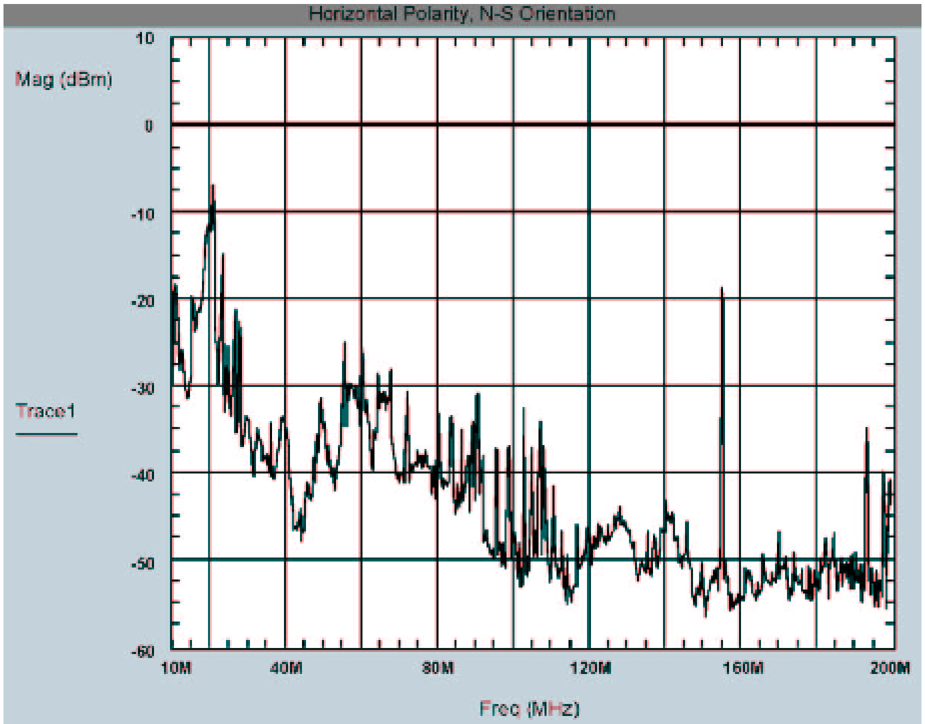


Figure 6: 10 - 200 MHz, most NRAO and ESO monitoring equipment shut down.

In these preliminary plots, it is obvious that a lot of noise in this range is generated by the electronic equipment already present on site, and strong intermittent signals, e.g., at 155 MHz (Figure 6), can occur.

2.2 Observation procedure

The initial observation spans were determined by the cutoff frequencies of the equipment. Since the data gathering program does not impose a limit to the number of signals measured, and since peak excursion, not absolute threshold, was used to gather data, there is no penalty inherent in looking at the largest span possible in the initial run. The basic procedure, aided by the software, runs as follows:
1) The span and various measurement parameters are adjusted manually on the spectrum analyzer, and the max hold function is executed for (roughly) a couple of minutes.
2) The data collection software records amplitude and frequency data and then, using the peak search function, steps through and identifies all peaks that meet the peak excursion criterion.
3) The software then causes the spectrum analyzer to center on the highest peak, and sets the span to 10% of the center frequency. Then it waits for the operator to make any manual adjustments to the display, to maximize the signal, and to take notes on the time-varying and modulation characteristics of the signal. The trace and its relevant parameters are recorded and the spectrum analyzer moves on to the next peak until the list is exhausted.

The antenna pattern determined how many times a range was observed; this is examined in some detail in Appendix B. All ranges were observed in both horizontal and vertical polarizations. Measurements with the biconical Antenna were observed in the North-South and East-West orientations for horizontal polarity and just one position for vertical polarity (due to the radial symmetry of the antenna pattern). The log periodic antenna was oriented North, South, East, and West for both polarities. The horn antenna was used this way up to 2 GHz, above which very few signals were found. Above 2 GHz, the max hold function was used while the horn antenna was swept 360°.

3. Data

3.1 Large spans

The plots on the following pages are the “big picture” view of the survey. We have opted to display only vertical, North-facing, or omnidirectional data for the sake of brevity, but note that data was taken for both polarities, and in N, S, E, and W positions where applicable. The complete data set is available from the authors. The table that follows each graph is a composite tabulation of discrete signals found in all orientations and azimuth positions combined for that span. In cases where a signal was detected in more than one orientation, the strongest amplitude is reported. Also included in the tables is a conversion of our measurements from dBm to dB(W/m^2) which accounts for all system gains and losses as well as the effective collecting area of the antenna as follows:

$$P(dB(W/m^2)) = P(dBm) - (G_{amp} + L_{tot}) - 30 - 10\log(\lambda^2/4\pi) - G_{ant}(dBi)$$

Where:

P(dBm) = measured power in dBm
G_{amp} = preamplifier gain in dB
L_{tot} = sum of cable and bias T losses (negative)
-30 converts from dBm to dBW
$-10\log(\lambda^2/4\pi) - G_{ant}(dBi)$ divides by the effective antenna collecting area

Additionally, a column is provided that shows the margin (in dB) to the proposed SUBTEL QZ limit of -57 dB(W/m^2).

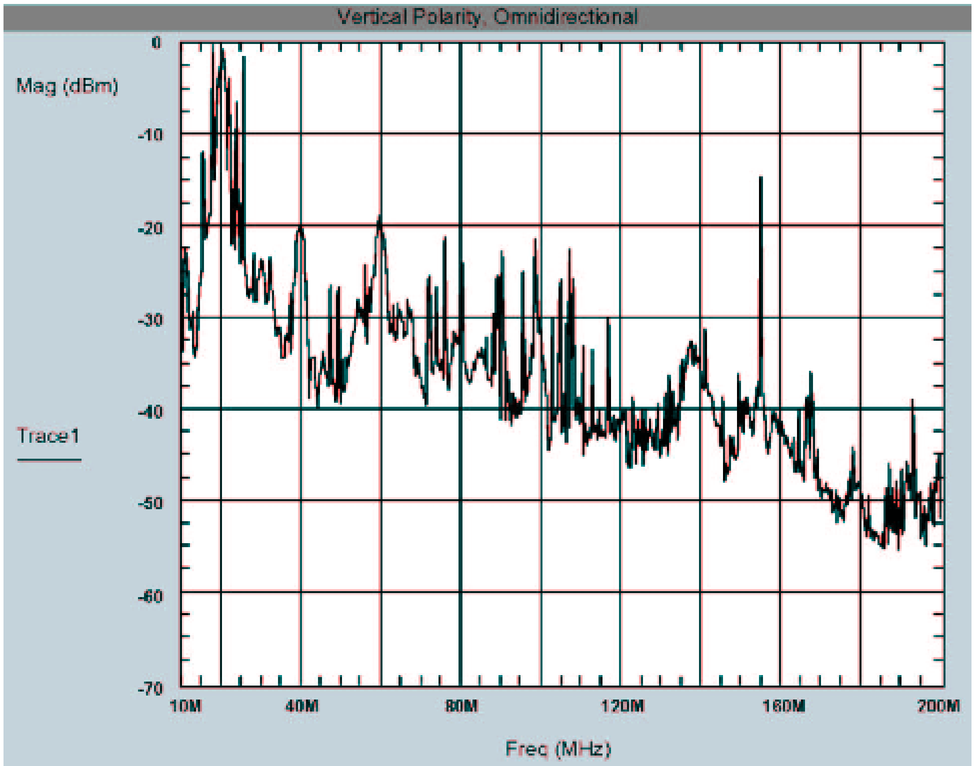


Figure 7: 10 MHz - 200 MHz, Vertical Polarity, Omnidirectional.

(Frequency/amplitude table on following page)

Frequency (Hz)	Amplitude (dBm)	Amplitude (dB(W/m2))	Proposed SUBTEL limit margin (dB)	Frequency (Hz)	Amplitude (dBm)	Amplitude (dB(W/m2))	Proposed SUBTEL limit margin (dB)
2.536e+07	-4.2	-70.1	-13.1	9.849e+07	-33.8	-119.3	-62.3
2.569e+07	-5.2	-71.2	-14.2	9.976e+07	-33.7	-119.0	-62.0
2.670e+07	-36.3	-103.0	-46.0	1.025e+08	-31.0	-116.1	-59.1
3.687e+07	-34.0	-106.4	-49.4	1.025e+08	-38.5	-123.6	-66.6
3.820e+07	-25.8	-99.0	-42.0	1.025e+08	-31.8	-116.9	-59.9
3.915e+07	-30.2	-103.9	-46.9	1.047e+08	-41.2	-126.1	-69.1
3.916e+07	-38.3	-112.1	-55.1	1.047e+08	-33.0	-117.9	-60.9
4.711e+07	-26.8	-105.2	-48.2	1.047e+08	-27.0	-111.9	-54.9
4.800e+07	-28.8	-107.7	-50.7	1.071e+08	-24.0	-108.7	-51.7
4.916e+07	-27.0	-106.5	-49.5	1.079e+08	-27.7	-112.3	-55.3
5.000e+07	-24.8	-104.8	-47.8	1.079e+08	-35.0	-119.6	-62.6
5.500e+07	-22.5	-105.4	-48.4	1.106e+08	-34.3	-118.7	-61.7
5.571e+07	-32.7	-116.0	-59.0	1.127e+08	-36.3	-120.5	-63.5
5.600e+07	-14.3	-97.8	-40.8	1.167e+08	-32.7	-116.4	-59.4
5.700e+07	-18.5	-102.6	-45.6	1.167e+08	-41.2	-124.9	-67.9
5.944e+07	-18.7	-104.2	-47.2	1.229e+08	-41.2	-124.7	-67.7
6.000e+07	-22.7	-108.5	-51.5	1.270e+08	-45.8	-129.4	-72.4
6.002e+07	-18.5	-104.3	-47.3	1.312e+08	-37.8	-121.4	-64.4
6.400e+07	-23.3	-111.5	-54.5	1.321e+08	-38.5	-122.1	-65.1
6.760e+07	-32.2	-120.6	-63.6	1.401e+08	-41.5	-125.2	-68.2
7.169e+07	-28.2	-116.2	-59.2	1.413e+08	-35.5	-119.2	-62.2
7.174e+07	-34.2	-122.2	-65.2	1.454e+08	-39.7	-123.4	-66.4
7.373e+07	-26.8	-114.7	-57.7	1.495e+08	-37.7	-121.5	-64.5
7.578e+07	-20.7	-108.3	-51.3	1.536e+08	-39.8	-123.7	-66.7
7.988e+07	-25.7	-112.9	-55.9	1.547e+08	-46.0	-129.9	-72.9
8.325e+07	-28.2	-115.1	-58.1	1.549e+08	-9.7	-93.6	-36.6
8.602e+07	-27.2	-113.8	-56.8	1.675e+08	-43.8	-127.9	-70.9
8.809e+07	-29.5	-116.0	-59.0	1.676e+08	-36.8	-120.9	-63.9
8.810e+07	-39.0	-125.5	-68.5	1.681e+08	-42.2	-126.2	-69.2
8.907e+07	-24.7	-111.0	-54.0	1.700e+08	-44.7	-128.8	-71.8
8.910e+07	-33.2	-119.5	-62.5	1.782e+08	-42.3	-126.6	-69.6
9.030e+07	-23.0	-109.3	-52.3	1.827e+08	-47.8	-132.1	-75.1
9.151e+07	-39.0	-125.1	-68.1	1.843e+08	-45.5	-129.8	-72.8
9.529e+07	-33.8	-119.6	-62.6	1.873e+08	-47.8	-132.2	-75.2
9.530e+07	-25.5	-111.3	-54.3	1.917e+08	-47.0	-131.4	-74.4
9.531e+07	-34.3	-120.1	-63.1	1.933e+08	-40.3	-124.8	-67.8
9.626e+07	-39.5	-125.2	-68.2	1.933e+08	-45.7	-130.1	-73.1
9.845e+07	-21.2	-106.7	-49.7	1.978e+08	-37.8	-122.3	-65.3
9.848e+07	-34.5	-120.0	-63.0	1.994e+08	-36.8	-121.4	-64.4

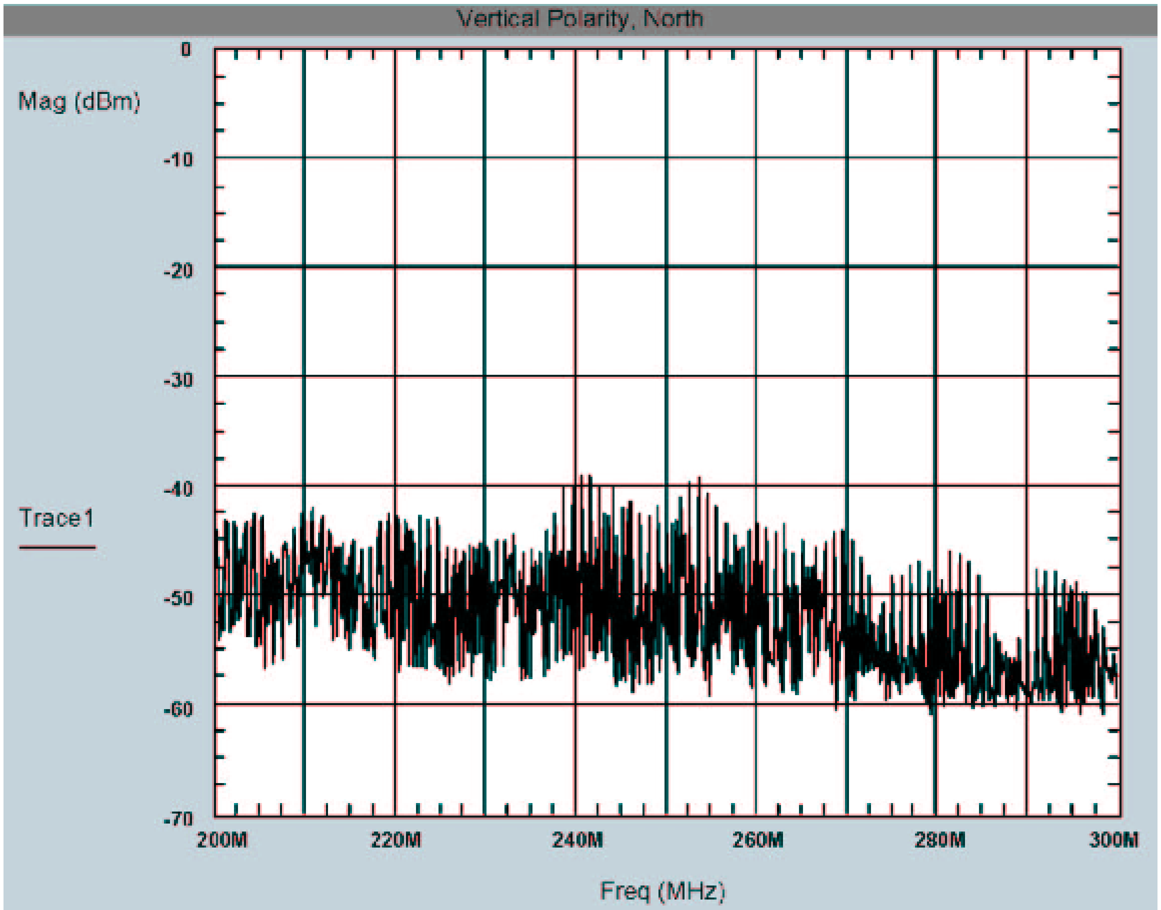


Figure 8: 200 MHz - 300 MHz, Vertical Polarity, North Orientation.

(Frequency/amplitude table on following pages)

Frequency (Hz)	Amplitude (dBm)	Amplitude (dB(W/m^2))	Proposed SUBTEL limit margin (dB)	Frequency (Hz)	Amplitude (dBm)	Amplitude (dB(W/m^2))	Proposed SUBTEL limit margin (dB)
2.03e+08	-42.5	-131.6	-74.6	2.26e+08	-46.8	-136.0	-79.0
2.05e+08	-30.0	-119.1	-62.1	2.27e+08	-46.8	-136.0	-79.0
2.06e+08	-40.8	-130.0	-73.0	2.27e+08	-46.3	-135.5	-78.5
2.07e+08	-45.2	-134.3	-77.3	2.27e+08	-48.3	-137.5	-80.5
2.07e+08	-45.7	-134.8	-77.8	2.27e+08	-48.2	-137.3	-80.3
2.08e+08	-44.7	-133.8	-76.8	2.27e+08	-43.5	-132.6	-75.6
2.09e+08	-41.0	-130.1	-73.1	2.28e+08	-46.0	-135.1	-78.1
2.09e+08	-47.5	-136.6	-79.6	2.28e+08	-45.0	-134.1	-77.1
2.10e+08	-44.2	-133.3	-76.3	2.29e+08	-45.8	-135.0	-78.0
2.10e+08	-38.5	-127.6	-70.6	2.30e+08	-46.8	-136.0	-79.0
2.11e+08	-45.3	-134.5	-77.5	2.30e+08	-53.3	-142.5	-85.5
2.11e+08	-47.7	-136.8	-79.8	2.31e+08	-46.5	-135.6	-78.6
2.12e+08	-47.2	-136.3	-79.3	2.31e+08	-45.7	-134.8	-77.8
2.12e+08	-46.2	-135.3	-78.3	2.31e+08	-54.3	-143.5	-86.5
2.13e+08	-47.7	-136.8	-79.8	2.32e+08	-47.8	-137.0	-80.0
2.13e+08	-49.3	-138.5	-81.5	2.32e+08	-47.3	-136.5	-79.5
2.15e+08	-47.7	-136.8	-79.8	2.33e+08	-43.8	-133.0	-76.0
2.16e+08	-49.0	-138.1	-81.1	2.33e+08	-46.3	-135.5	-78.5
2.17e+08	-47.7	-136.8	-79.8	2.33e+08	-42.8	-132.0	-75.0
2.18e+08	-46.8	-136.0	-79.0	2.34e+08	-37.5	-126.6	-69.6
2.19e+08	-48.0	-137.1	-80.1	2.34e+08	-45.2	-134.3	-77.3
2.20e+08	-46.3	-135.5	-78.5	2.36e+08	-53.2	-142.3	-85.3
2.21e+08	-39.3	-128.5	-71.5	2.36e+08	-49.8	-139.0	-82.0
2.21e+08	-42.7	-131.8	-74.8	2.36e+08	-35.8	-125.0	-68.0
2.21e+08	-46.0	-135.1	-78.1	2.36e+08	-43.7	-132.8	-75.8
2.22e+08	-46.7	-135.8	-78.8	2.38e+08	-50.3	-139.5	-82.5
2.22e+08	-44.3	-133.5	-76.5	2.38e+08	-50.2	-139.3	-82.3
2.23e+08	-68.7	-157.8	-100.8	2.39e+08	-60.7	-149.8	-92.8
2.23e+08	-43.7	-132.8	-75.8	2.39e+08	-46.7	-135.8	-78.8
2.23e+08	-42.5	-131.6	-74.6	2.40e+08	-53.5	-142.6	-85.6
2.23e+08	-43.5	-132.6	-75.6	2.40e+08	-52.8	-142.0	-85.0
2.23e+08	-42.2	-131.3	-74.3	2.40e+08	-50.5	-139.6	-82.6
2.24e+08	-43.8	-133.0	-76.0	2.40e+08	-49.5	-138.6	-81.6
2.24e+08	-43.7	-132.8	-75.8	2.41e+08	-51.7	-140.8	-83.8
2.25e+08	-46.5	-135.6	-78.6	2.41e+08	-51.7	-140.8	-83.8
2.25e+08	-45.7	-134.8	-77.8	2.41e+08	-48.5	-137.6	-80.6
2.25e+08	-43.8	-133.0	-76.0	2.41e+08	-67.2	-156.3	-99.3
2.25e+08	-41.3	-130.5	-73.5	2.42e+08	-55.0	-144.1	-87.1
2.26e+08	-46.0	-135.1	-78.1	2.42e+08	-51.8	-141.0	-84.0
2.26e+08	-44.0	-133.1	-76.1	2.43e+08	-45.8	-135.0	-78.0

Frequency (Hz)	Amplitude (dBm)	Amplitude (dB(W/m^2))	Proposed SUBTEL limit margin (dB)	Frequency (Hz)	Amplitude (dBm)	Amplitude (dB(W/m^2))	Proposed SUBTEL limit margin (dB)
2.26e+08	-45.8	-135.0	-78.0	2.43e+08	-44.3	-133.5	-76.5
2.26e+08	-47.2	-136.3	-79.3	2.43e+08	-53.7	-142.8	-85.8
2.43e+08	-47.5	-136.6	-79.6	2.58e+08	-46.7	-135.8	-78.8
2.44e+08	-51.7	-140.8	-83.8	2.58e+08	-42.7	-131.8	-74.8
2.44e+08	-50.2	-139.3	-82.3	2.58e+08	-45.8	-135.0	-78.0
2.45e+08	-51.3	-140.5	-83.5	2.60e+08	-50.2	-139.3	-82.3
2.46e+08	-42.2	-131.3	-74.3	2.60e+08	-52.5	-141.6	-84.6
2.46e+08	-42.3	-131.5	-74.5	2.63e+08	-43.8	-133.0	-76.0
2.46e+08	-42.2	-131.3	-74.3	2.63e+08	-47.0	-136.1	-79.1
2.46e+08	-45.3	-134.5	-77.5	2.63e+08	-48.2	-137.3	-80.3
2.47e+08	-49.0	-138.1	-81.1	2.64e+08	-47.7	-136.8	-79.8
2.48e+08	-47.0	-136.1	-79.1	2.64e+08	-61.0	-150.2	-93.2
2.48e+08	-48.7	-137.8	-80.8	2.65e+08	-38.0	-127.2	-70.2
2.49e+08	-1.5	-90.6	-33.6	2.67e+08	-50.2	-139.3	-82.3
2.50e+08	-49.0	-138.1	-81.1	2.68e+08	-44.5	-133.7	-76.7
2.50e+08	-44.5	-133.6	-76.6	2.69e+08	-48.8	-138.0	-81.0
2.50e+08	-43.8	-133.0	-76.0	2.71e+08	-50.7	-139.8	-82.8
2.51e+08	-56.2	-145.3	-88.3	2.72e+08	-50.3	-139.5	-82.5
2.51e+08	-40.7	-129.8	-72.8	2.72e+08	-51.8	-141.0	-84.0
2.52e+08	-49.0	-138.1	-81.1	2.73e+08	-44.5	-133.7	-76.7
2.52e+08	-46.0	-135.1	-78.1	2.73e+08	-51.5	-140.7	-83.7
2.53e+08	-48.5	-137.6	-80.6	2.77e+08	-53.2	-142.3	-85.3
2.54e+08	-48.5	-137.6	-80.6	2.80e+08	-43.3	-132.5	-75.5
2.56e+08	-49.5	-138.6	-81.6	2.95e+08	-57.5	-146.7	-89.7
2.56e+08	-44.5	-133.6	-76.6	2.95e+08	-45.5	-134.7	-77.7
2.57e+08	-48.5	-137.6	-80.6	2.95e+08	-48.0	-137.2	-80.2
2.57e+08	-63.2	-152.3	-95.3	2.95e+08	-52.5	-141.7	-84.7

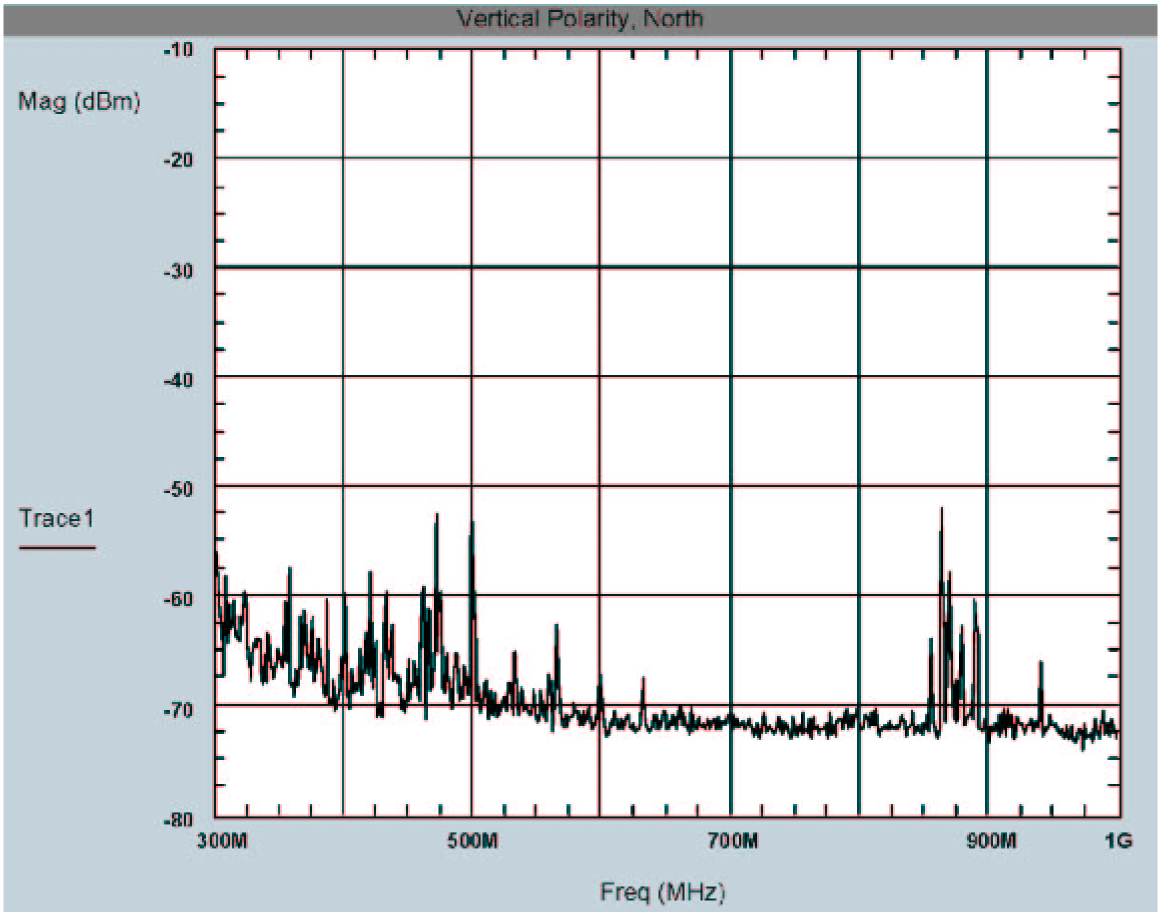


Figure 9: 300 MHz - 1 GHz, Vertical Polarity, North Orientation.

(Frequency/amplitude table on following page)

Frequency (Hz)	Amplitude (dBm)	Amplitude (dB(W/m²))	Proposed SUBTEL limit margin (dB)	Frequency (Hz)	Amplitude (dBm)	Amplitude (dB(W/m²))	Proposed SUBTEL limit margin (dB)
3.01e+08	-56.2	-139.9	-82.9	4.32e+08	-61.3	-146.9	-89.9
3.06e+08	-54.3	-138.1	-81.1	4.32e+08	-58.2	-143.7	-86.7
3.07e+08	-59.2	-143.0	-86.0	4.36e+08	-63.3	-148.9	-91.9
3.07e+08	-55.7	-139.5	-82.5	4.42e+08	-60.5	-146.0	-89.0
3.08e+08	-48.5	-132.3	-75.3	4.55e+08	-58.8	-144.3	-87.3
3.13e+08	-59.7	-143.6	-86.6	4.57e+08	-63.7	-149.2	-92.2
3.13e+08	-55.8	-139.8	-82.8	4.61e+08	-54.8	-140.3	-83.3
3.17e+08	-57.8	-141.8	-84.8	4.61e+08	-58.8	-144.3	-87.3
3.20e+08	-56.3	-140.4	-83.4	4.65e+08	-65.2	-150.7	-93.7
3.26e+08	-64.5	-148.7	-91.7	4.65e+08	-60.7	-146.2	-89.2
3.32e+08	-58.2	-142.5	-85.5	4.71e+08	-52.5	-138.0	-81.0
3.38e+08	-60.8	-145.2	-88.2	4.71e+08	-62.7	-148.1	-91.1
3.41e+08	-55.2	-139.6	-82.6	4.72e+08	-57.8	-143.3	-86.3
3.41e+08	-57.8	-142.3	-85.3	4.72e+08	-62.0	-147.5	-90.5
3.50e+08	-56.7	-141.3	-84.3	4.76e+08	-58.5	-144.0	-87.0
3.56e+08	-56.0	-140.8	-83.8	4.79e+08	-58.5	-144.0	-87.0
3.56e+08	-55.0	-139.8	-82.8	4.80e+08	-61.2	-146.6	-89.6
3.56e+08	-56.5	-141.3	-84.3	4.82e+08	-53.3	-138.8	-81.8
3.57e+08	-58.3	-143.1	-86.1	4.87e+08	-55.3	-140.8	-83.8
3.63e+08	-62.0	-146.9	-89.9	4.87e+08	-58.7	-144.1	-87.1
3.69e+08	-56.0	-141.0	-84.0	4.94e+08	-57.8	-143.3	-86.3
3.69e+08	-58.8	-143.9	-86.9	4.94e+08	-61.0	-146.4	-89.4
3.69e+08	-60.3	-145.4	-88.4	4.98e+08	-62.3	-147.7	-90.7
3.69e+08	-59.0	-144.0	-87.0	4.99e+08	-55.7	-141.1	-84.1
3.70e+08	-58.5	-143.5	-86.5	4.99e+08	-55.7	-141.1	-84.1
3.75e+08	-56.2	-141.3	-84.3	4.99e+08	-64.7	-150.1	-93.1
3.76e+08	-60.5	-145.7	-88.7	5.01e+08	-56.2	-141.6	-84.6
3.77e+08	-62.3	-147.5	-90.5	5.09e+08	-62.0	-147.4	-90.4
3.81e+08	-60.8	-146.1	-89.1	5.10e+08	-66.3	-151.7	-94.7
3.87e+08	-59.2	-144.6	-87.6	5.31e+08	-63.7	-149.0	-92.0
3.87e+08	-62.8	-148.2	-91.2	5.32e+08	-56.3	-141.7	-84.7
3.98e+08	-64.2	-149.8	-92.8	5.32e+08	-65.2	-150.5	-93.5
4.00e+08	-58.7	-144.3	-87.3	5.32e+08	-71.7	-157.0	-100.0
4.00e+08	-61.5	-147.1	-90.1	5.32e+08	-61.8	-147.2	-90.2
4.00e+08	-65.0	-150.6	-93.6	5.33e+08	-66.0	-151.3	-94.3
4.00e+08	-60.0	-145.6	-88.6	5.38e+08	-62.0	-147.3	-90.3
4.13e+08	-60.7	-146.3	-89.3	5.38e+08	-63.8	-149.2	-92.2
4.20e+08	-57.0	-142.6	-85.6	5.59e+08	-65.3	-150.6	-93.6
4.20e+08	-58.8	-144.4	-87.4	5.59e+08	-66.3	-151.6	-94.6
4.20e+08	-58.7	-144.3	-87.3	5.65e+08	-60.8	-146.1	-89.1
4.24e+08	-64.3	-149.9	-92.9	5.65e+08	-61.8	-147.1	-90.1

Frequency (Hz)	Amplitude (dBm)	Amplitude (dB(W/m^2))	Proposed SUBTEL limit margin (dB)	Frequency (Hz)	Amplitude (dBm)	Amplitude (dB(W/m^2))	Proposed SUBTEL limit margin (dB)
4.32e+08	-54.3	-139.9	-82.9	5.65e+08	-61.2	-146.4	-89.4
5.65e+08	-53.8	-139.1	-82.1	8.48e+08	-62.2	-146.8	-89.8
5.65e+08	-61.0	-146.3	-89.3	8.53e+08	-74.5	-159.1	-102.1
5.65e+08	-63.2	-148.4	-91.4	8.53e+08	-60.8	-145.5	-88.5
5.66e+08	-61.3	-146.6	-89.6	8.53e+08	-63.7	-148.3	-91.3
5.66e+08	-52.0	-137.3	-80.3	8.56e+08	-63.5	-148.1	-91.1
5.71e+08	-63.8	-149.1	-92.1	8.63e+08	-58.7	-143.2	-86.2
5.84e+08	-72.3	-157.6	-100.6	8.64e+08	-52.0	-136.6	-79.6
5.97e+08	-64.0	-149.2	-92.2	8.65e+08	-63.7	-148.2	-91.2
5.97e+08	-63.3	-148.5	-91.5	8.65e+08	-57.3	-141.9	-84.9
5.99e+08	-63.7	-148.9	-91.9	8.66e+08	-57.8	-142.4	-85.4
6.12e+08	-62.0	-147.2	-90.2	8.72e+08	-59.2	-143.7	-86.7
6.25e+08	-73.2	-158.3	-101.3	8.73e+08	-66.2	-150.7	-93.7
6.32e+08	-61.7	-146.8	-89.8	8.73e+08	-59.3	-143.8	-86.8
6.41e+08	-67.3	-152.5	-95.5	8.74e+08	-59.0	-143.5	-86.5
6.72e+08	-73.2	-158.3	-101.3	8.77e+08	-66.8	-151.3	-94.3
7.20e+08	-73.2	-158.2	-101.2	8.77e+08	-62.7	-147.2	-90.2
7.59e+08	-60.7	-145.7	-88.7	8.80e+08	-68.0	-152.5	-95.5
7.67e+08	-63.3	-148.3	-91.3	8.80e+08	-61.3	-145.8	-88.8
7.74e+08	-62.5	-147.5	-90.5	8.80e+08	-61.5	-146.0	-89.0
7.89e+08	-61.8	-146.8	-89.8	8.84e+08	-73.0	-157.4	-100.4
8.04e+08	-61.0	-145.9	-88.9	8.90e+08	-67.8	-152.2	-95.2
8.18e+08	-59.0	-143.8	-86.8	8.91e+08	-66.2	-150.6	-93.6
8.18e+08	-59.7	-144.5	-87.5	8.92e+08	-65.2	-149.6	-92.6
8.33e+08	-61.7	-146.4	-89.4	8.92e+08	-62.8	-147.2	-90.2
8.33e+08	-59.0	-143.7	-86.7	8.94e+08	-72.5	-156.9	-99.9

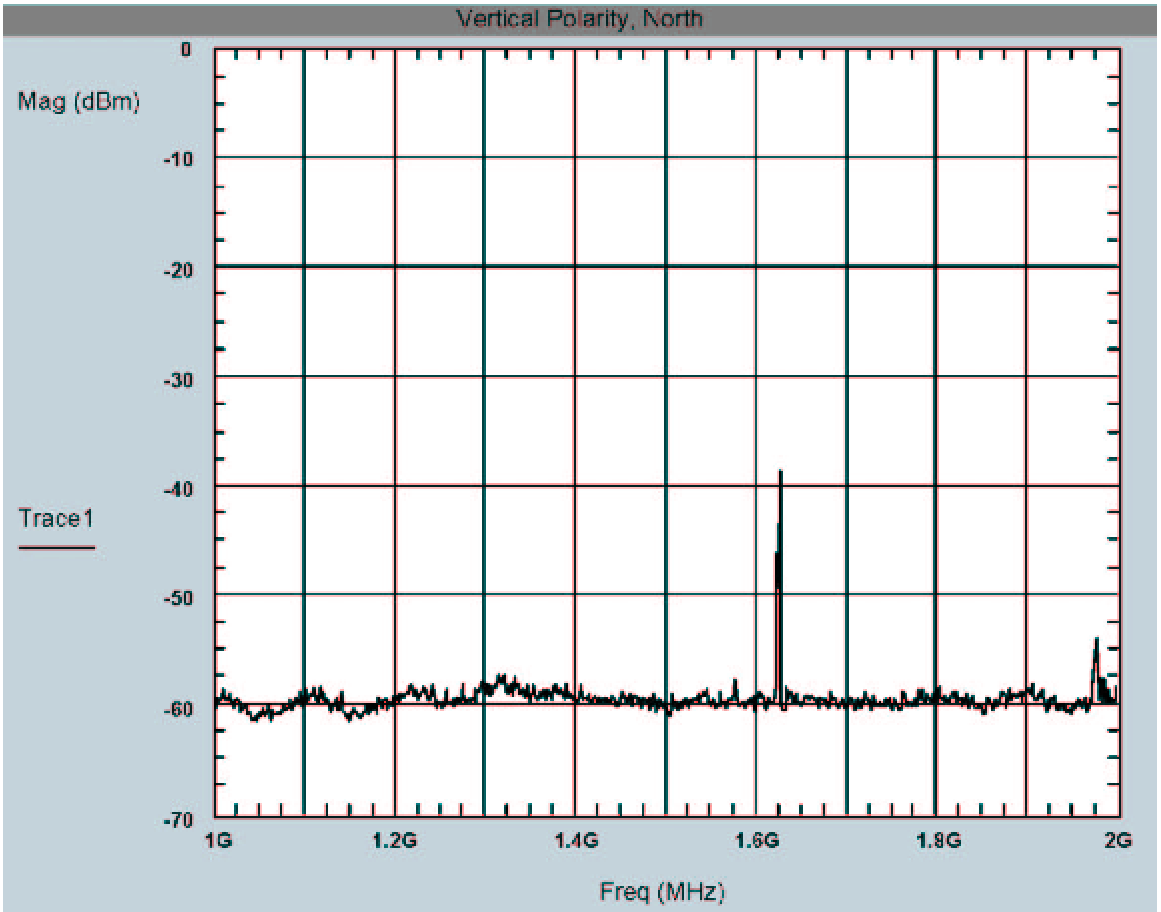


Figure 10: 1 GHz - 2 GHz, Vertical Polarity, North Orientation

Frequency (Hz)	Amplitude (dBm)	Amplitude (dB(W/m^2))	Proposed SUBTEL limit margin (dB)
1.104e+09	-54.0	-138.1	-81.1
1.201e+09	-55.2	-139.3	-82.3
1.254e+09	-59.2	-143.4	-86.4
1.390e+09	-52.3	-136.6	-79.6
1.424e+09	-58.2	-142.5	-85.5
1.532e+09	-52.7	-137.1	-80.1
1.626e+09	-34.5	-119.0	-62.0
1.627e+09	-37.5	-122.0	-65.0
1.977e+09	-53.7	-138.5	-81.5

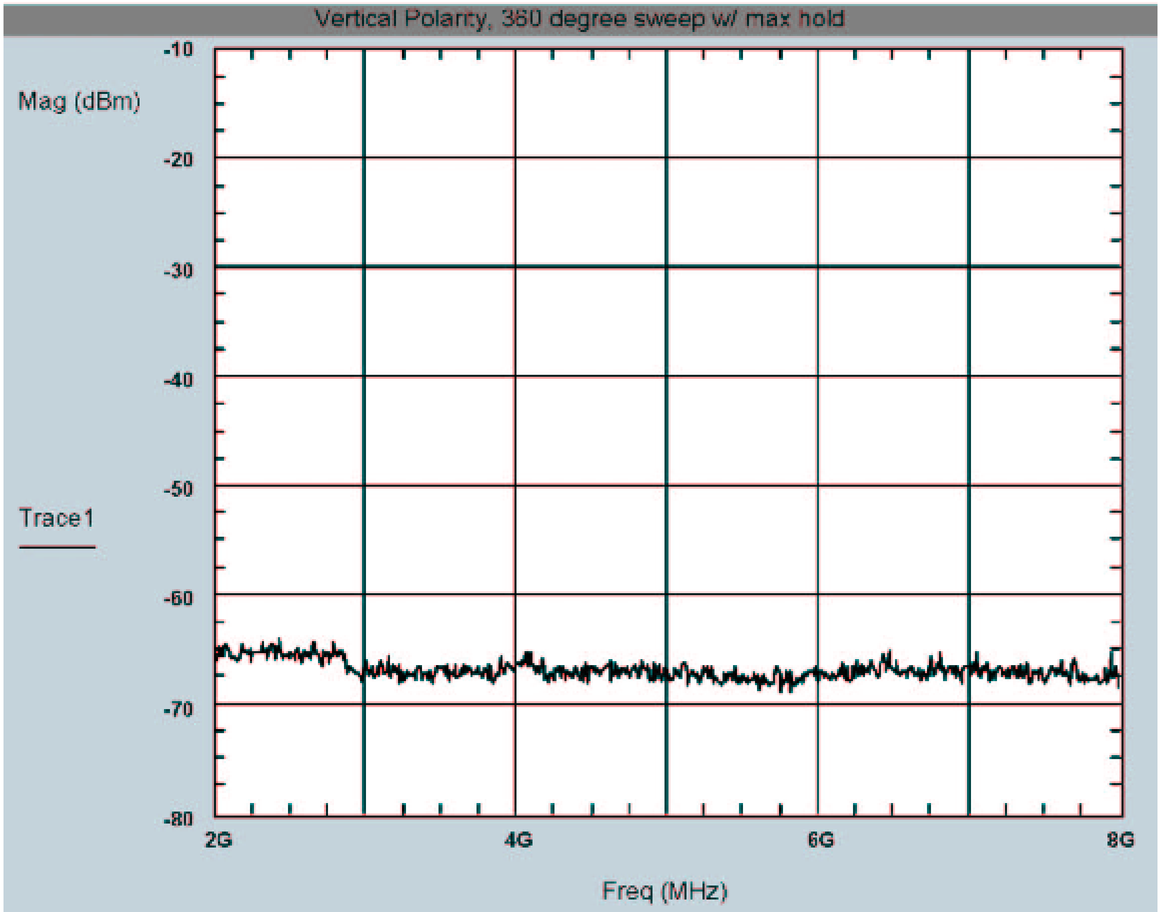


Figure 11: 2 GHz - 8 GHz, Vertical Polarity, 360° sweep with max. hold

Frequency (Hz)	Amplitude (dBm)	Amplitude (dB(W/m^2))	Proposed SUBTEL limit margin (dB)
2.49e+09	-65.5	-140.6	-83.6

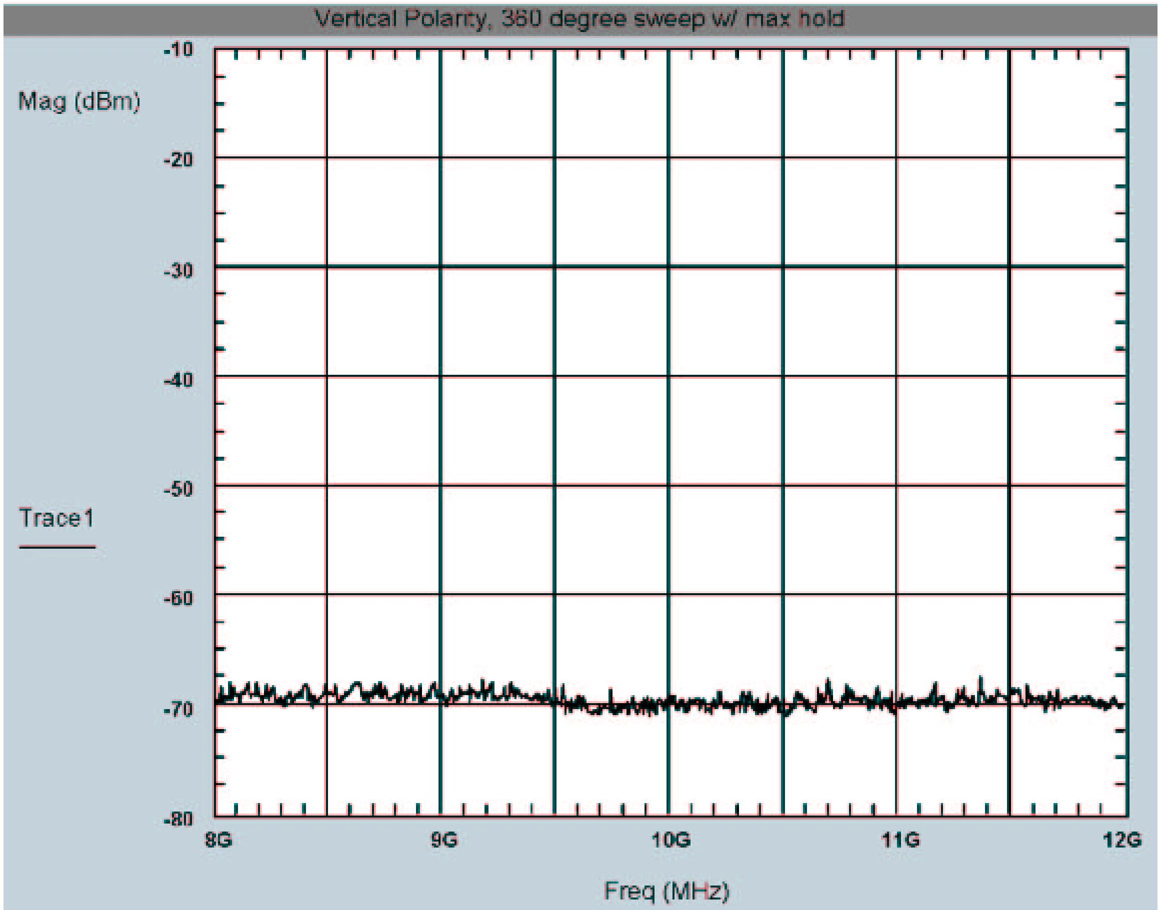


Figure 12: 8 GHz - 12 GHz, Vertical Polarity, 360° sweep with max. hold.

(No signals found)

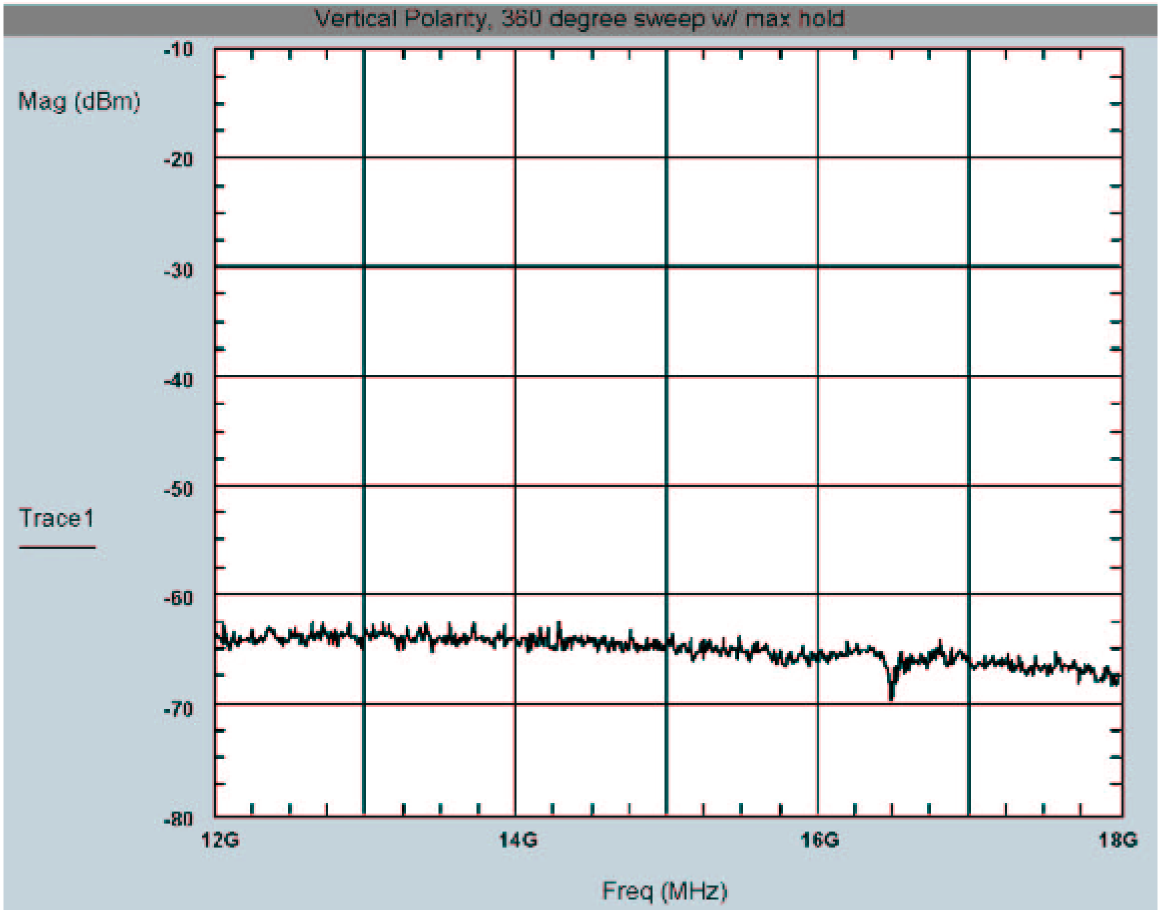


Figure 13: 12 GHz - 18 GHz, Vertical Polarity, 360° sweep with max. hold.
Note: The dip near 16.5 GHz is due to cable characteristics;
see appendix A, cable CH1.

(No signals found)

In the VEE data retrieval program, it is possible to expand the scales of the data represented, use markers, etc., so any questions about the data not addressed in this memo can be further investigated. Contact the authors for further details.

3.2 General categories of signals found and signals of particular interest

We collected 504 individual signal plots during our survey. A best guess based upon the nature of the signal and notes taken during the survey places the signals into the following categories:

3.2.1 Noise from nearby electronic equipment: (70%)

Not surprisingly, the vast majority of detected signals fell into the category of unintentional noise, some undoubtedly generated by nearby equipment. This was the case from 10 MHz up to roughly 850 MHz. (Noise was either broad band or narrow band, the narrower signals were often part of a harmonic series.) Harmonic series with a separation of 500 kHz accounted for quite a few of these signals; Figure 8 is a good illustration of this type of interference where these spikes paint the entire span from 200 to 300 MHz. In this case, the antenna was pointing North, right at the nearby ESO container. These spikes were found to be intermittent; they do not appear at all in some of the subsequent measurements.

3.2.2 Land-based fixed, and mobile services: (21%)

Admittedly, this is a very broad category, including land-based cellular telephones, amateur and citizen's band radio, and a host of other radio services. Of these signals, 27% were found between 850 and 890 MHz, in the cellular telephone bands, and were characterized by intermittent usage. The remaining signals that fell into this category were fairly evenly distributed below 850 MHz, characterized mostly by their intermittent nature, with or without modulated tones or voice, and represent a wide variety of services; it was not possible to determine exactly what most of them were.

3.2.3 Broadcast services: (5%)

Broadcast services have their own category because the signals are typically quite strong and consistently present. Every signal we looked at in this study was evaluated for AM or FM content, so broadcast became immediately evident. The highlight of the study was "Song Sung Blue" by Neil Diamond coming in strong on 104.7 FM.

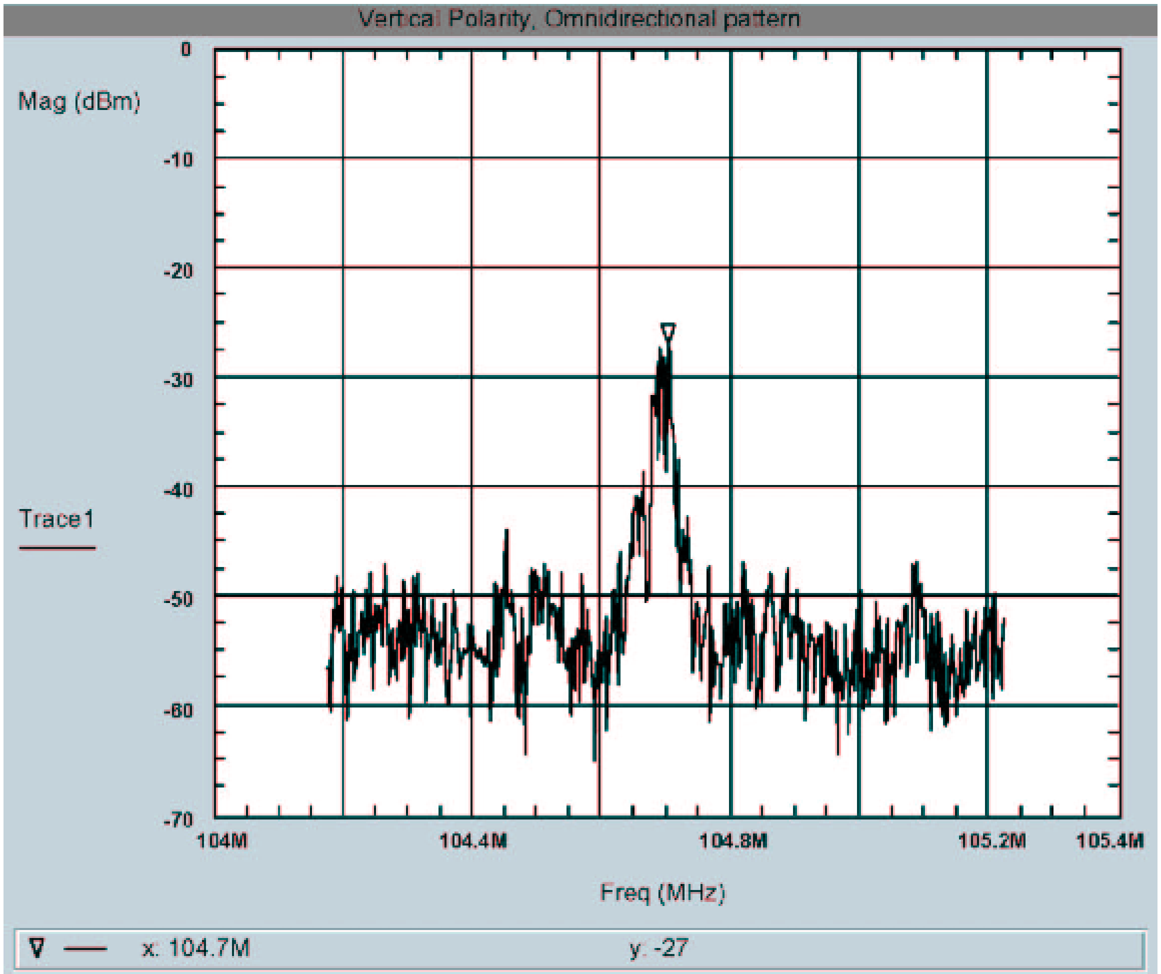


Figure 14: Example of a broadcast signal;
"Song Sung Blue" by Neil Diamond on 104.7 FM

3.2.4 Satellite services: (2%)

These get their own category as the location of the transmitters makes interference from satellites particularly troublesome for radio astronomy; you can't always point away from it. A signal was picked up at 1254 MHz; its intermittent nature and band allocation indicate it may have been a satellite-based signal. A one-time incidental signal was picked up at 1424 MHz which is in a radio astronomy band and may be worthy of further investigation. At 1532 MHz, a persistent, frequency-modulated signal was observed; space to earth communication, an mobile satellite services are licensed here. At all orientations and polarities, strong signals were found at 1626 and 1627 MHz; the first a band reserved for space to earth communications, the second in a band reserved for earth to space communications. Given the coincidence of the signals, however, we guess that the 1627 is a spurious signal associated with the 1626, probably mobile telecommunications. At 2490 MHz, an intermittent signal was found; it stayed off for about 10 min., and on for about 5 min. This could be radiolocation or mobile telecommunications. This was the highest frequency at which anything at all was found.

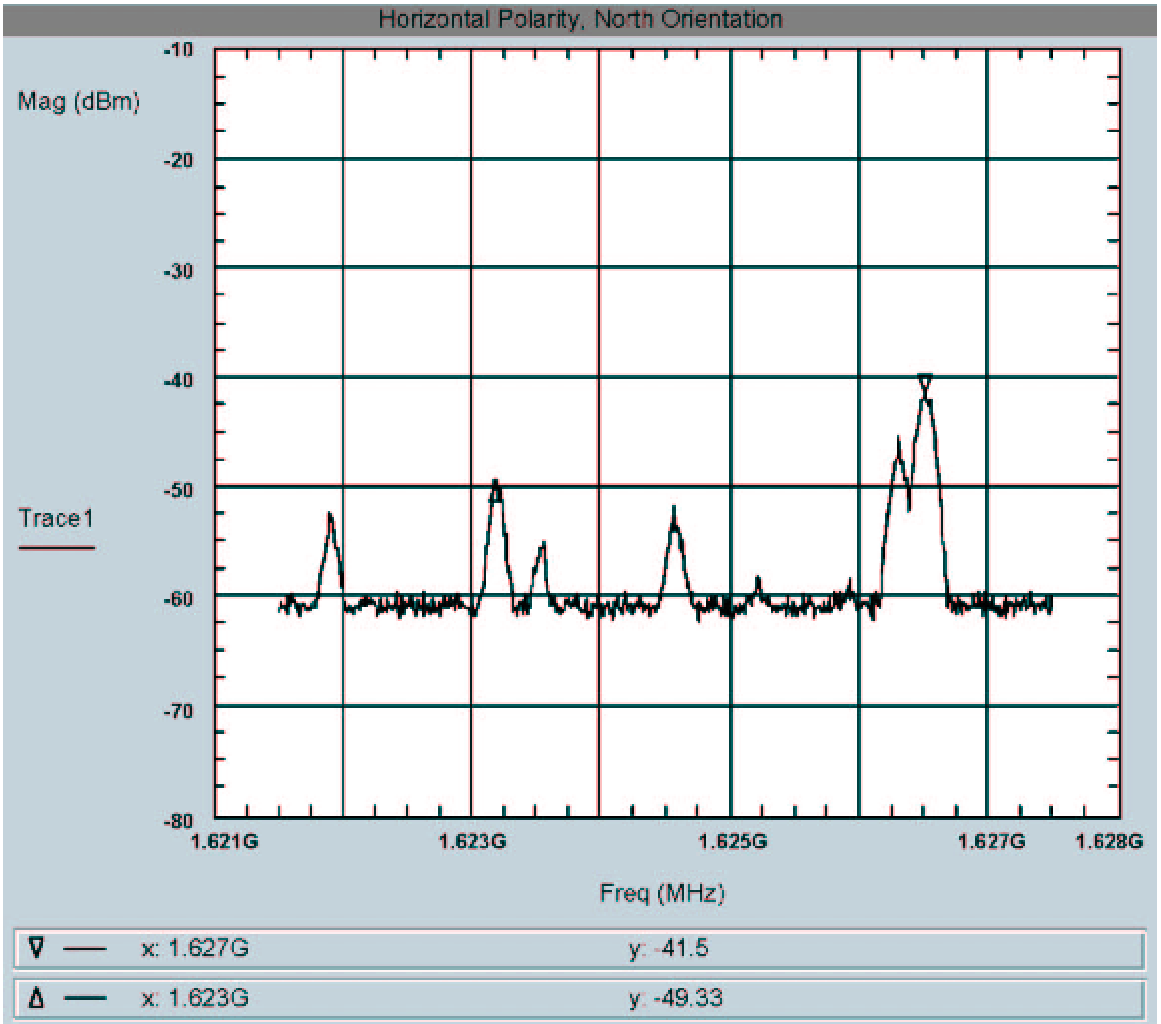


Figure 15: Example of a Satellite signal; adjacent signals appeared coincidentally and are probably spurious emissions from the same source.

3.2.5 aeronautical radionavigation and radar (2%)

A signal at 110.6 MHz with tone modulation falls into a aeronautical radionavigation band. The same is true of intermittent signals at 1104 and 1201 MHz. At 1390, an intermittent signal was observed, coinciding with the aeronautical radiolocation band.

4. Comparisons

4.1 Comparison with data taken at the Green Bank site

One general question was raised: How does this site compare with the Green Bank site in the National Radio Quiet Zone? To answer this, an abbreviated version (one azimuth position, one antenna orientation, large spans only) of the survey was conducted at Green Bank on March 27, 2003. All the same equipment, including cables, adapters, bias tees, etc. that was used in Chile was used in the Green Bank survey. Above 1 GHz, note that the RBW is different in the two surveys; we used 10 kHz RBW for the entire Green Bank survey, but switched to 100 kHz RBW in Chile. The reason for this was to decrease the IF sweep time of the spectrum analyzer thereby increasing probability of signal intercept during the 360 degree azimuth sweeps. For the Green Bank survey, our antenna was stationary and located on a platform roughly 550m West of the Jansky laboratory, and pointed due W, away from the Jansky laboratory. The following plots are displayed side by side with plots from the Chajnantor site:

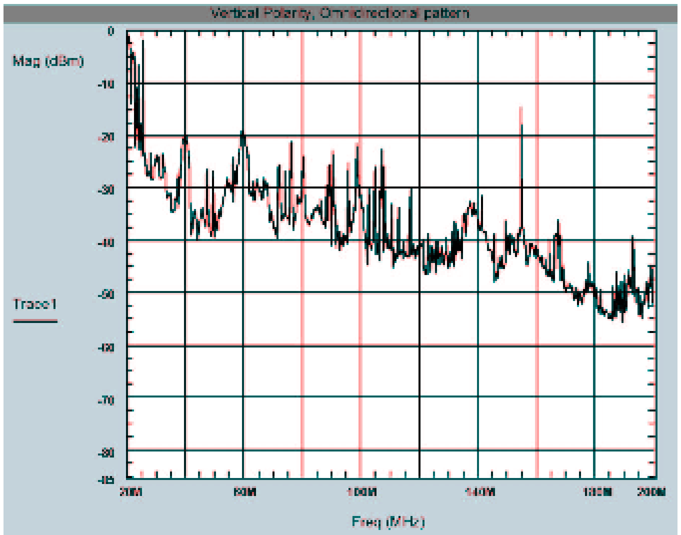


Figure 16
Chajnantor 20 MHz - 200 MHz

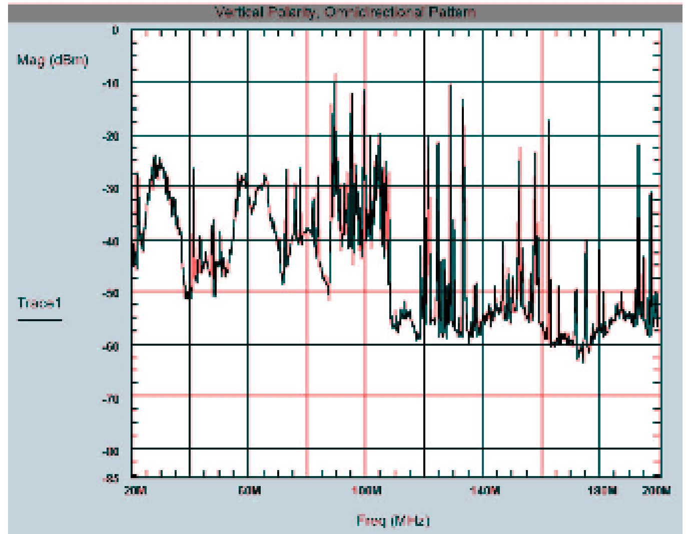


Figure 17
Green Bank 20 MHz - 200 MHz

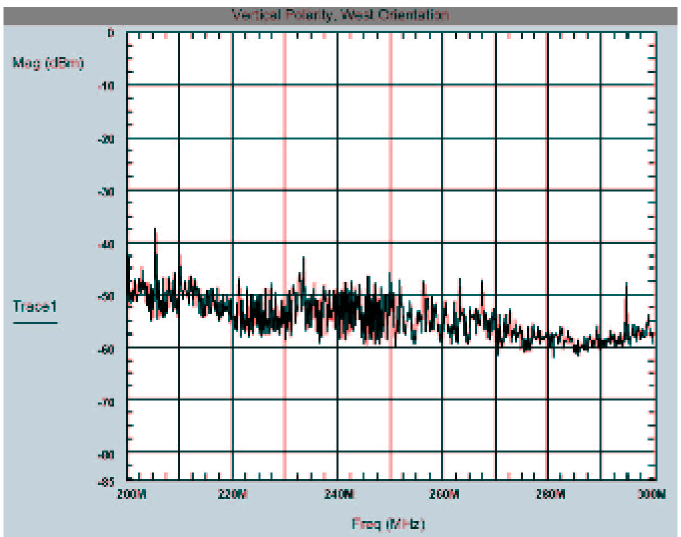


Figure 18
Chajnantor 200 MHz - 300 MHz

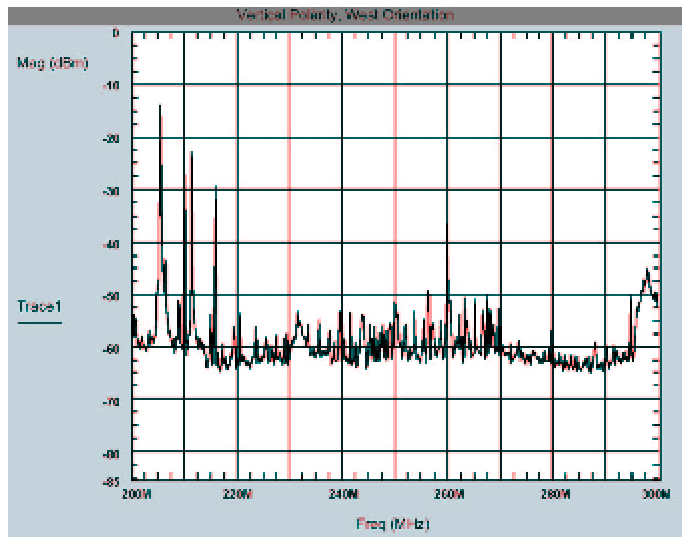


Figure 19
Green Bank 200 MHz - 300 MHz

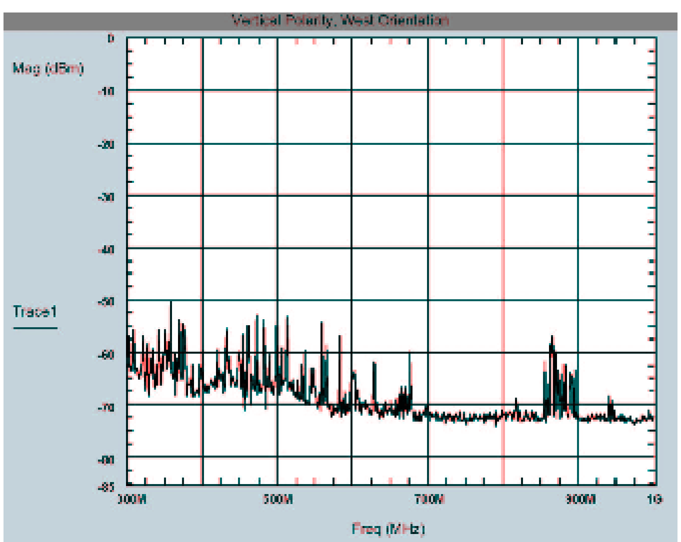


Figure 20
Chajnantor 300 MHz - 1 GHz

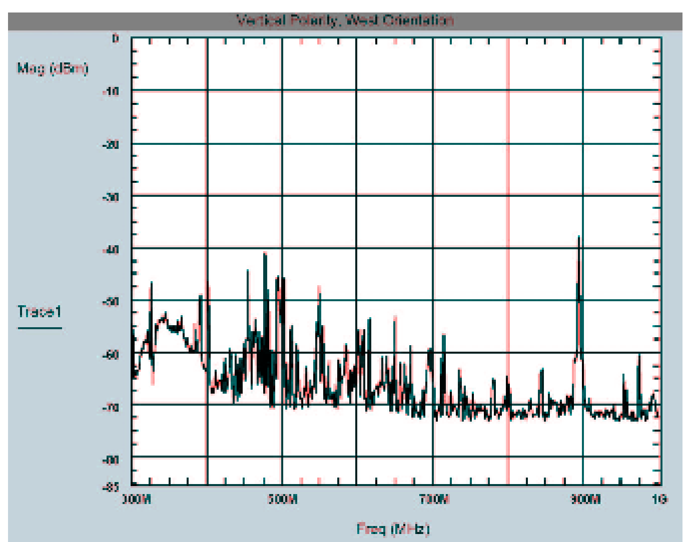


Figure 21
Green Bank 300 MHz - 1 GHz

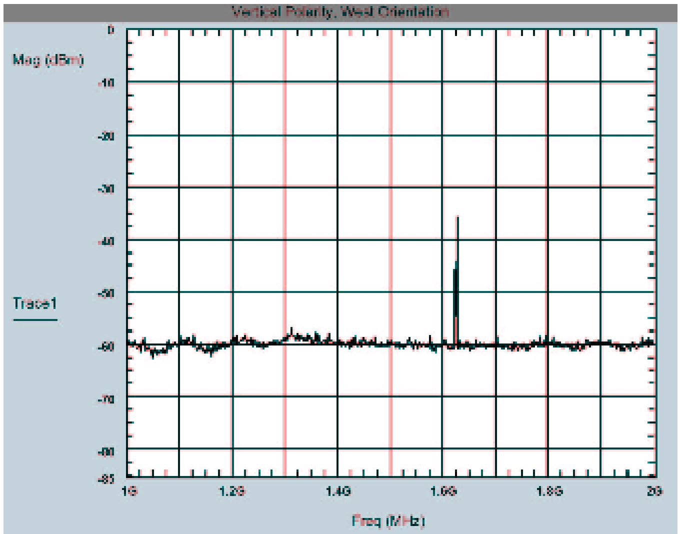


Figure 22
Chajnantor 1 GHz - 2 GHz RBW 100 kHz

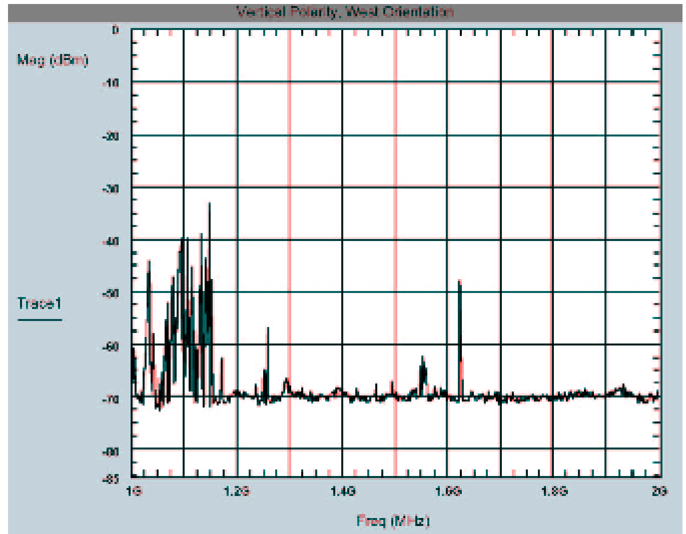


Figure 23
Green Bank 1 GHz - 2 GHz RBW 10 kHz

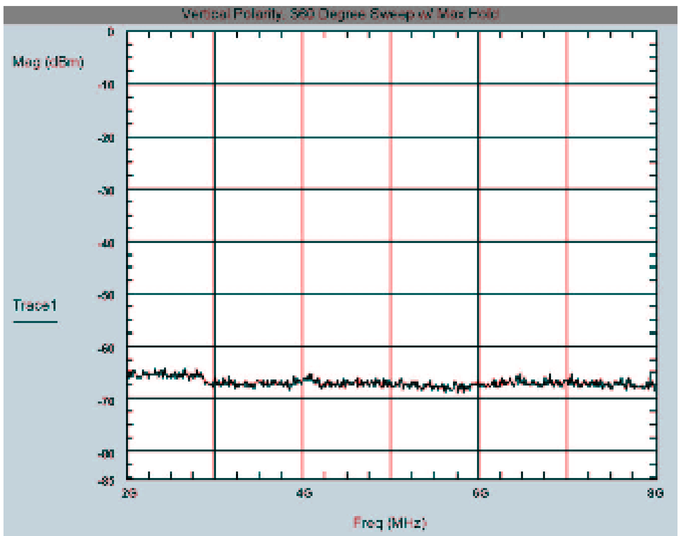


Figure 25
Chajnantor 2 GHz - 8 GHz RBW 100 kHz

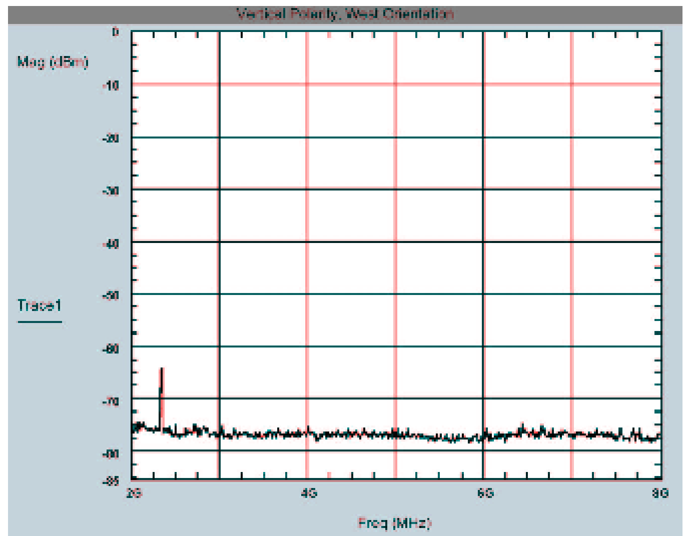


Figure 24
Green Bank 2 GHz - 8GHz RBW 10 kHz

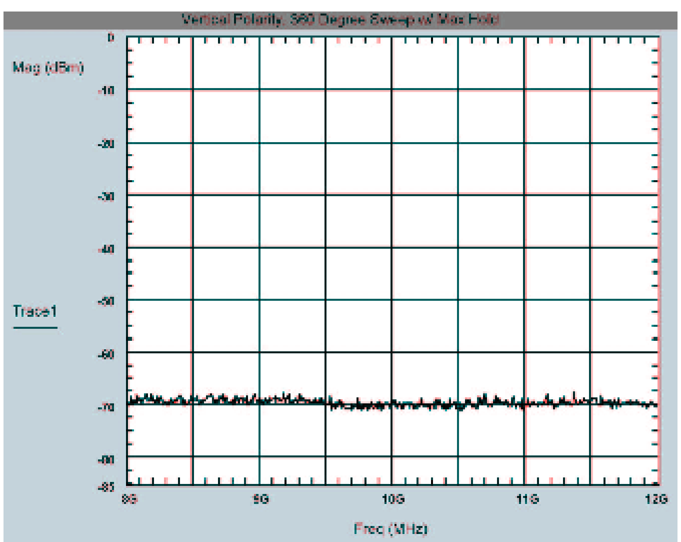


Figure 26
Chajnantor 8 GHz - 12 GHz RBW 100 kHz

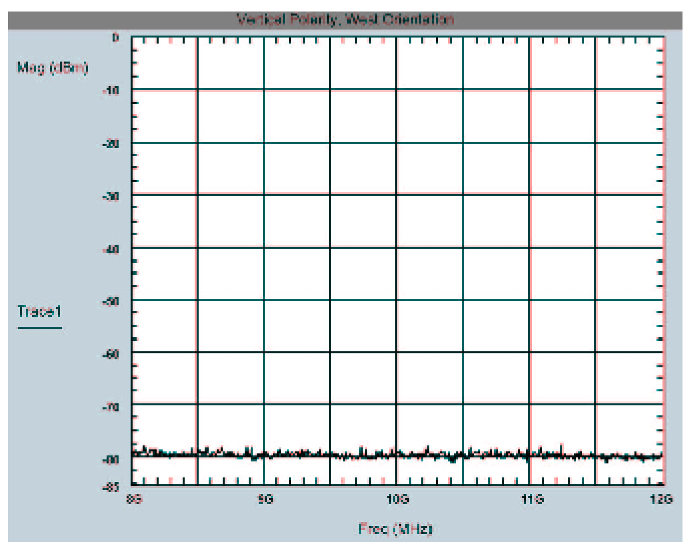


Figure 27
Green Bank 8 GHz - 12 GHz RBW 10 kHz

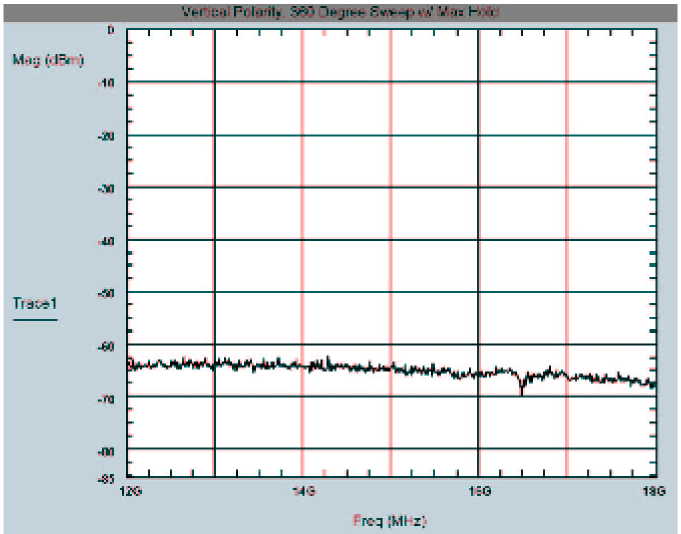


Figure 28
Chajnantor 12 GHz - 18 GHz RBW 100 kHz

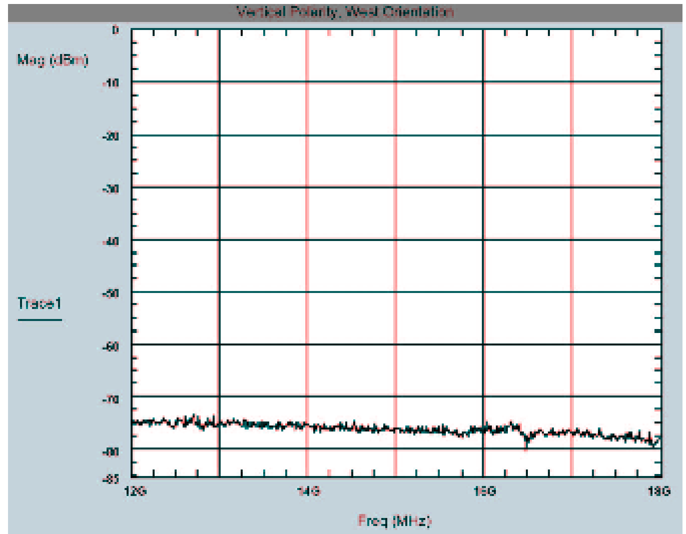


Figure 29
Green Bank 12 GHz - 18 GHz RBW 10 kHz

The National Radio Quiet Zone (NRQZ) affords some protection to the Green Bank site, but clearly by way of comparison, the site at Chajnantor is generally quieter. One can easily imagine that a lot of the noise seen in the first two spans (Figures 16 - 19) is local, unintentional radiation, which makes the two surveys hard to compare, but clearly in the FM broadcast band (88 MHz to 108 MHz) we see fewer and weaker signals at Chajnantor than we do at Green Bank (Recall that both Chile and Green Bank fall under ITU region 2 allocations). This is also the case in the aeronautical mobile bands from 118 MHz to 137 MHz, the fixed mobile bands from 150 MHz to 174 MHz, the television broadcasting band from 174 MHz to 216 MHz, and the aeronautical radionavigation band from 960 MHz to 1215 MHz. It is worth noting that both surveys found a strong signal centered at roughly 1622 MHz in the mobile-satellite band, and that the Green Bank survey picked up an additional strong signal at 2339 MHz, presumably broadcast satellite. The intermittent signal found at 2490 in the Chajnantor survey was not found at Green Bank.

5. Recommendations for Future Study

5.1 Some of the things one might want to learn from long-term, periodic monitoring of the spectrum are 1) Is the general background noise level rising? 2) Are there new services occupying spectrum that was previously quiet (especially at observation frequencies)? 3) Are there services operating in or near and spilling over into designated radio astronomy bands? At this writing, strategies for long-term monitoring are being developed for the Green Bank site, and the survey methodology and instrumentation are being tweaked to better support mission requirements. It is highly recommended that a long term RFI monitoring program be established for the ALMA project.

6. Conclusions

With the sensitivity of our system at the time of this survey, no interference was detected above 2.5 GHz.

70% of the noise detected in this study can be attributed to unintentional radiation from instruments operating near the survey antenna. Concerns have been expressed about interference at frequencies lower than observation frequencies contaminating the IF of the instrument. By far and away, the most likely source of such interference is ourselves, i.e., instrumentation located near enough, and unintentionally coupled into the LO IF chain. Observation frequencies are a different story, however, due to the high gain, highly sensitive nature of the front end of radio astronomy instruments. It might be a good idea to dedicate the operation of one such instrument to monitoring the spectrum full time. Today, RFI at 30 GHz is not an issue, but as technology progresses, this will likely change.

Due to the remoteness of the ALMA site, the terrestrial RFI situation appears to be even better than at Green Bank. Understanding the shielding provided by the natural terrain at Green Bank, not to mention the protection afforded by the NRQZ, this is saying quite a lot. Since the ALMA site is relatively free of existing harmful RFI, it should be a good candidate for a QZ. Furthermore, due to a minimum number of preexisting radio services, few would need to be grandfathered in should a QZ be formed. Cooperative agreements with satellite and airborne services would still be required to provide protection from non-terrestrial RFI.

Appendix A

System sensitivity was calculated as follows:

S_{sys} = kTB + NF - G_{sys} + SN

Where: S_{sys} = System sensitivity in dBm
kTB = Thermal noise floor of receiver in dBm
NF = System noise figure in dB
G_{sys} = Composite gain/loss term for system
SN = signal to noise ratio required for detection

kTB = Thermal noise floor of receiver in dBm:
The displayed average noise level N_{av}, of the HP 8563E is charted over frequency for a 1 Hz resolution bandwidth (RBW). Noise power is directly proportional to bandwidth and changes as 10 log RBW, so we adjust:
kTB = **N_{av}+ 10 log(RBW)**

NF = System noise figure in dB:
We used the **published, or measured (where applicable) NF of our preamplifier for this term**.

G_{sys} = Composite gain/loss term for system
For us, this means:
$G_{sys} = G_{an} - L_{c1} + G_{pa} - L_{c2} - L_{biasT}$

Where: G_{an} = Antenna gain (dBi)
L_{c1} = Loss from cable 1
G_{pa} = Preamplifier gain
L_{c2} = Loss from cable 2
L_{biasT} = Loss from bias T (where applicable)

SN = signal to noise ratio required for detection:
Using a display of 10 dB/ division, it is possible to visually resolve signals of roughly 2dB above the average noise level. Changing the display to 5 dB/ division, which we did when we were trying to detect signals in ranges where we weren't seeing anything, it is possible to resolve signals of roughly **1dB** above the average noise level. We'll use that value here, as it represents the limitations of our system. It must be noted, however, that in most cases we intentionally limited the signal detection threshold, using the peak excursion parameter of the HP8563E. This was to avoid spending too much time recording lots of relatively weak signals in crowded areas of the spectrum.

Gain/loss data for the antennas, cables, amplifiers, and bias T's is found on the following pages.

ELECTRO-METRICS
Gain and Antenna Factors
Model EM-6912

Serial Number: 721 **3 Meter Calibration**

FREQUENCY MHz	ANTENNA FACTOR dB/m	GAIN dBi	GAIN NUMERIC
20	19.25	-23.02	.0050
25	22.07	-23.90	.0041
30	18.91	-19.16	.0121
35	16.78	-15.69	.0270
40	14.41	-12.16	.0608
45	12.42	-9.15	.1217
50	10.43	-6.24	.2377
55	8.89	-3.88	.4096
60	6.97	-1.20	.7588
65	5.37	1.10	1.2880
70	5.64	1.47	1.4031
75	7.19	.52	1.1274
80	8.47	-.20	.9552
85	9.13	-.34	.9256
90	9.53	-.24	.9468
95	10.92	-1.15	.7669
100	12.19	-1.98	.6339
105	13.40	-2.77	.5287
110	13.15	-2.12	.6143
115	13.35	-1.92	.6422
120	14.13	-2.34	.5837
125	15.01	-2.86	.5175
130	15.03	-2.54	.5571
135	14.74	-1.93	.6417
140	14.80	-1.67	.6810
145	15.05	-1.62	.6892
150	15.85	-2.12	.6139
155	16.19	-2.18	.6058
160	15.18	-.89	.8149
165	15.41	-.86	.8213
170	16.14	-1.33	.7370

ELECTRO-METRICS
Gain and Antenna Factors
Model EM-6912

Serial Number: 721 | **3 Meter Calibration** |

FREQUENCY MHz	ANTENNA FACTOR dB/m	GAIN dBi	GAIN NUMERIC
175	17.37	-2.30	.5889
180	15.84	-.53	.8857
185	15.61	-.06	.9867
190	15.88	-.09	.9789
195	17.19	-1.18	.7621
200	17.10	-.87	.8185
205	16.01	.44	1.1060
210	15.81	.84	1.2140
215	15.91	.94	1.2429
220	17.36	-.31	.9320
225	17.41	-.16	.9642
230	15.86	1.59	1.4412
235	15.40	2.23	1.6714
240	16.39	1.42	1.3874
245	17.28	.71	1.1781
250	17.57	.60	1.1480
255	16.61	1.74	1.4912
260	17.04	1.47	1.4027
265	17.77	.90	1.2310
270	19.25	-.42	.9086
275	18.93	.06	1.0147
280	17.71	1.44	1.3937
285	18.79	.52	1.1268
290	19.76	-.31	.9320
295	21.19	-1.58	.6947
300	20.31	-.56	.8793

Specification compliance testing factor (3 meter spacing) to be added to receiver meter reading in dBuV to convert to field intensity in dBuV/m. Calibration per ARP-958 methodology.

ELECTRO-METRICS
Gain and Antenna Factors
Model LPA-30

Serial Number: 1952 **3 Meter Calibration**

FREQUENCY MHz	ANTENNA FACTOR dB/m	GAIN dBi	GAIN NUMERIC
200	12.50	3.73	2.3606
225	11.46	5.79	3.7947
250	12.97	5.20	3.3109
275	13.68	5.31	3.3989
300	15.66	4.09	2.5652
325	15.11	5.34	3.4189
350	15.68	5.41	3.4759
375	15.83	5.86	3.8551
400	15.96	6.29	4.2566
425	16.52	6.25	4.2207
450	17.42	5.85	3.8478
475	18.01	5.74	3.7471
500	18.43	5.76	3.7668
525	18.99	5.62	3.6489
550	19.04	5.97	3.9570
575	19.24	6.17	4.1368
600	19.57	6.20	4.1701
625	20.10	6.03	4.0076
650	20.27	6.20	4.1679
675	21.08	5.71	3.7265
700	21.24	5.87	3.8645
725	21.19	6.22	4.1912
750	21.29	6.42	4.3859
775	21.48	6.51	4.4802
800	22.07	6.20	4.1696
825	22.70	5.83	3.8323
850	22.63	6.16	4.1345
875	23.21	5.84	3.8371
900	23.23	6.06	4.0387
925	23.50	6.03	4.0100
950	23.87	5.90	3.8880

ELECTRO-METRICS
Gain and Antenna Factors
Model LPA-30

Serial Number: 1952 **3 Meter Calibration** **Page 2 of 2**

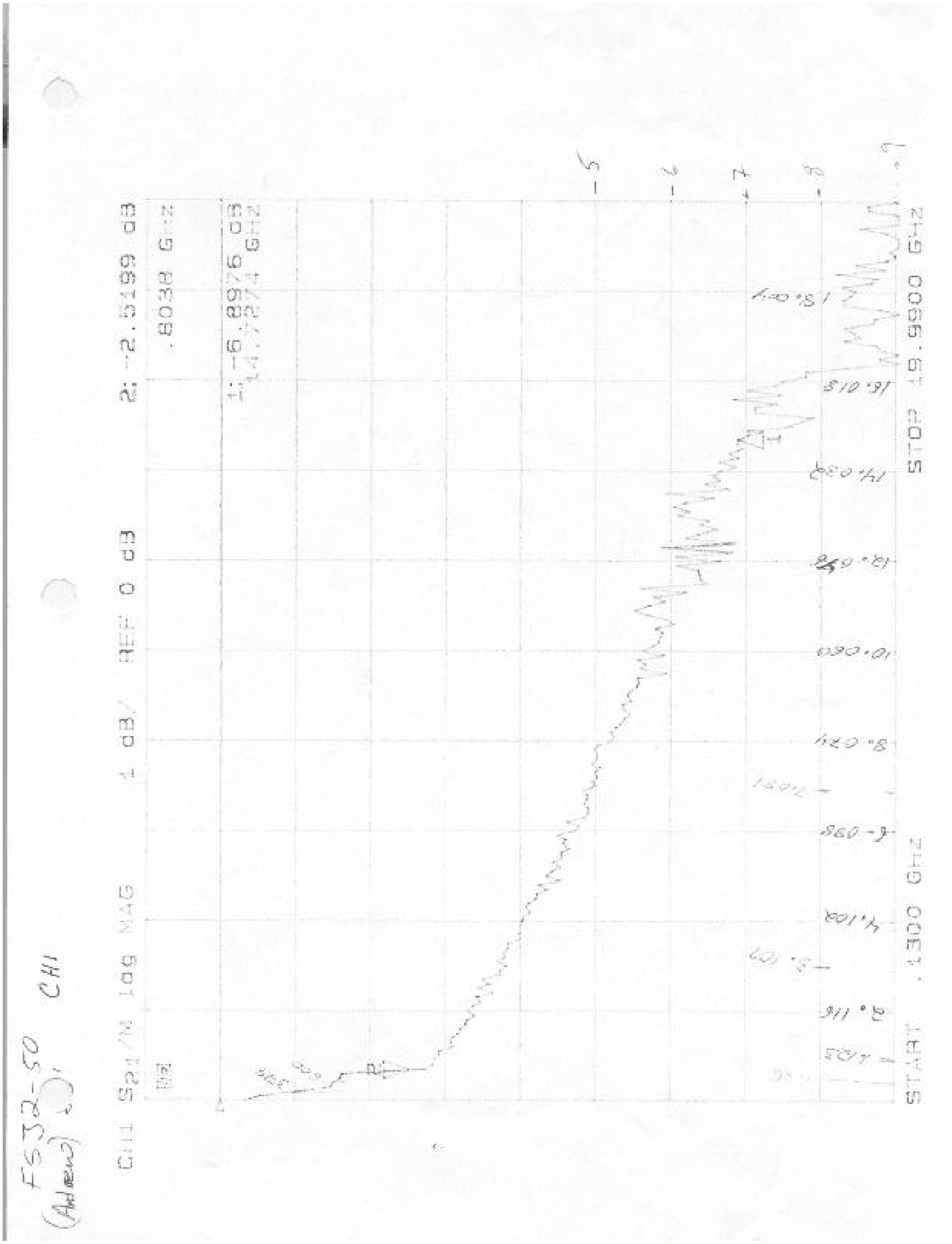
FREQUENCY MHz	ANTENNA FACTOR dB/m	GAIN dBi	GAIN NUMERIC
975	24.48	5.51	3.5564
1000	24.94	5.27	3.3651

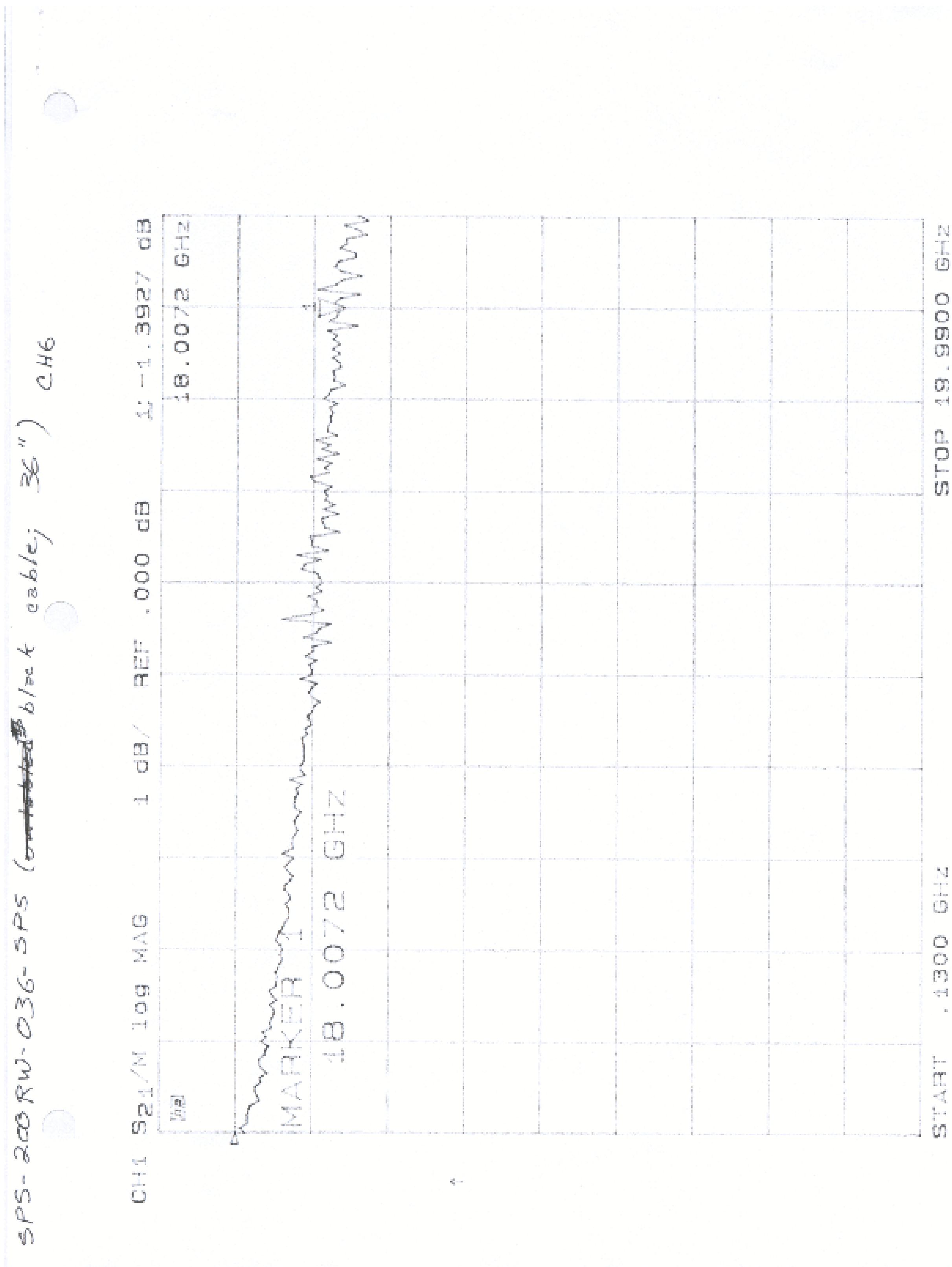
Specification compliance testing factor (3 meter spacing) to be added to receiver meter reading in dBuV to convert to field intensity in dBuV/m. Calibration per ANSI C63.5 methodology.

SERIAL NUMBER 6385	ELECTRO-METRICS GAIN AND ANTENNA FACTORS EM-6961	1.00 METER CALIBRATION

FREQUENCY MHZ	ANTENNA FACTOR dB/m	GAIN dBi	GAIN NUMERIC
1000	25.34	4.91	3.10
1500	26.62	7.15	5.19
2000	29.70	6.57	4.54
2500	30.44	7.77	5.98
3000	31.32	8.47	7.03
3500	32.70	8.43	6.97
4000	34.12	8.17	6.56
4500	33.15	10.16	10.38
5000	34.35	9.88	9.73
5500	34.71	10.34	10.81
6000	35.26	10.55	11.36
6500	35.76	10.74	11.86
7000	36.91	10.24	10.56
7500	38.67	9.06	8.08
8000	38.51	9.80	9.55
8500	38.03	10.80	12.02
9000	38.07	11.26	13.36
9500	38.21	11.59	14.43
10000	38.47	11.78	15.05
10500	38.83	11.84	15.29
11000	39.17	11.90	15.49
11500	39.43	12.03	15.97
12000	39.50	12.33	17.11
12500	40.52	11.66	14.67
13000	40.76	11.77	15.02
13500	41.42	11.43	13.91
14000	42.05	11.12	12.93
14500	41.54	11.93	15.59
15000	42.25	11.52	14.18
15500	43.75	10.30	10.73
16000	44.21	10.12	10.27
16500	42.91	11.69	14.76
17000	44.65	10.21	10.50
17500	47.57	7.54	5.67
18000	49.98	5.37	3.45

SPECIFICATION COMPLIANCE TESTING FACTOR (1 METER SPACING) TO BE ADDED TO RECEIVER METER READING IN dBuV TO CONVERT TO FIELD INTENSITY IN dBuV/METER. CALIBRATION PER ARP 958A METHODOLOGY.


CH1 S21/M log MAG 1 dB/ REF 0 dB
2: -2.5199 dB
.8038 GHz
1: -6.8976 dB
START .4300 GHz
STOP 19.9900 GHz
FS32-50
CH1


SPS-200RW-036-SPS (black cable; 36") CH6
CH1 S21/M log MAG 1 dB/ REF .000 dB △1: -1.3927 dB
18.0072 GHz
MARKER 1
18.0072 GHz
START .1300 GHz
STOP 19.9900 GHz

MITEQ Inc.
100 Davids Drive, Hauppauge, NY 11788
TEL: (631) 436-7400
FAX: (631) 436-7430
www.miteq.com

Bias Tee Test Data

Customer	NRAO
Model Number	AM-1523-9098
Purchase Order #	205897
MITEQ Project No.	P-119216
Date	September 9, 2002

Frequency (MHz)	Insertion Loss (dB)	VSWR ref 50Ω dB R.L. Input	VSWR ref 50Ω dB R.L. Output
1	-0.54± 0.5	>21	>21
10	↓	↓	↓
50	↓	↓	↓
100	↓	↓	↓
250	↓	↓	↓
500	↓	↓	↓
1000	↓	↓	↓
1500	↓	↓	↓
2000	↓	↓	↓
	883326 & 883327		

- Bias Tee Resistance: 5Ω
- Maximum Bias Current: 95mA

Bill Pope

W. Pope

Product Line Manager

MITEQ Inc.

100 Davids Drive, Hauppauge, NY 11788
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FAX: (631) 436-7430
www.miteq.com

AMPLIFIER TEST DATA

Customer	NRAO
Model Number	AU-1519-N-1306/E
Purchase Order #	205897
MITEQ Project No.	P-119216
Date	September 3, 2002

This Model will accept its DC operating power via the output RF center conductor as well as via the standard external solder pin. Any DC applied to this pin will also appear on the Output RF center conductor.

Maximum Safe RF Input Level is +13 dBm unless otherwise specified

Frequency (MHz)	Gain (dB)	VSWR ref 50Ω dB R.L. Input	dB R.L. Output	P.O. @ -1dB GC (+dBm)	Noise Figure (dB)	DC Current (mA) @+15V
1	58.8 ± 0.3	12	19	14	---	65
10	↓	13	20	14	0.98	
50	↓	15	20	14	0.89	
100	↓	21	20	14	0.88	
200	↓	24	22	13	0.89	
300	↓	22	22	13	0.97	Max +30V

S/N 883168

Bill Pope

Product Line Manager

MITEQ Inc.

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FAX: (631) 436-7430
www.miteq.com

AMPLIFIER TEST DATA

Customer	NRAO
Model Number	AM-4A-000110-N-1306/E
Purchase Order #	205897
MITEQ Project No.	P-119216
Date	September 3, 2002

This Model will accept its DC operating power via the output RF center conductor as well as via the standard external solder pin. Any DC applied to this pin will also appear on the Output RF center conductor.

Maximum Safe RF Input Level is +13 dBm unless otherwise specified

Frequency (MHz)	Gain (dB)	VSWR ref 50Ω dB R.L. Input	dB R.L. Output	P.O. @ -1dB GC (+dBm)	Noise Figure (dB)	DC Current (mA) @+15V
1	53.3 ± 0.5	26	13	11	---	84
10	↓	25	12	11	1.23	
50	↓	23	12	11	1.15	
100	↓	21	12	11	1.13	
250	↓	17	12	11	1.17	
500	↓	14	13	11	1.38	
750	↓	12	13	10	1.45	
1000	↓	14	12	9	1.56	Max +30V

S/N 836458

Bill Pope

Product Line Manager

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www.miteq.com

AMPLIFIER TEST DATA

Customer	NRAO
Model Number	AM-5A-1020-N-1306/E
Purchase Order #	205897
MITEQ Project No.	P-119216
Date	September 25, 2002

CAUTION! Any voltage applied to the +15V pin will also appear on the RF output center conductor. This amplifier is normally biased via the output coaxial cable

Maximum Safe RF Input Level is +13 dBm unless otherwise specified

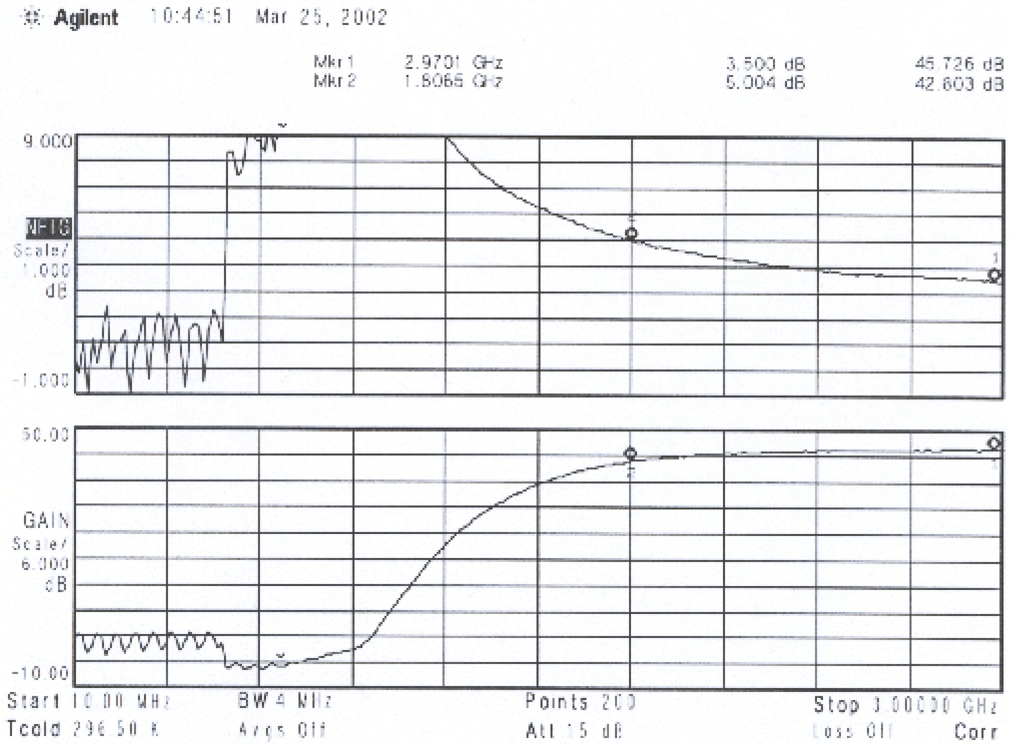
Frequency (MHz)	Gain (dB)	VSWR ref 50Ω dB R.L. Input	dB R.L. Output	P.O. @ -1dB GC (+dBm)	Noise Figure (dB)	DC Current (mA) @+15V
1000	53.9 ± 0.5	13	10	12	1.34	87
1200	↓	14	12	13	1.55	
1400	↓	15	13	14	1.69	
1600	↓	17	14	15	1.75	
1800	↓	15	16	15	1.85	
2000	↓	10	19	14	2.04	Max +30V

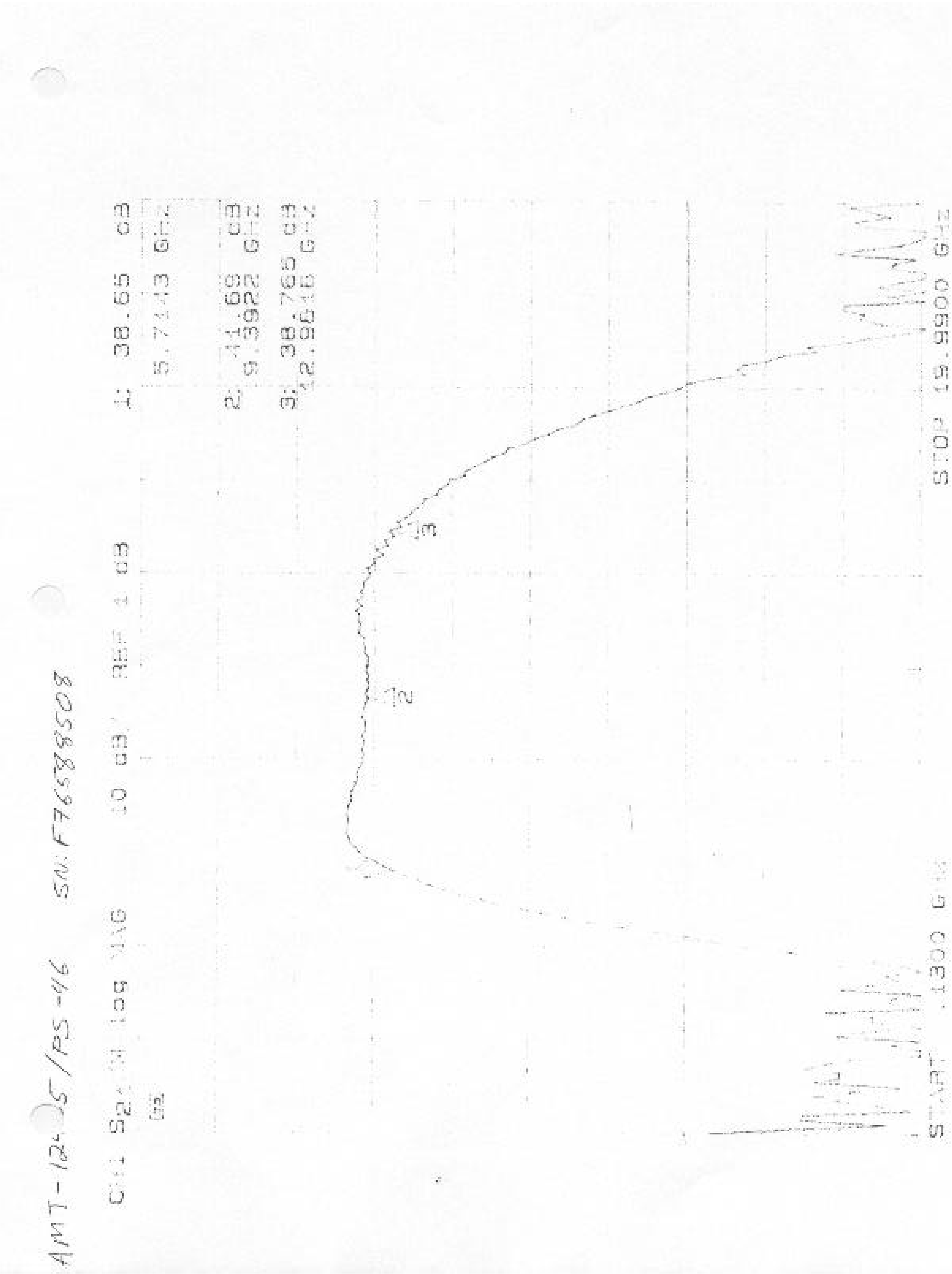
S/N 883404

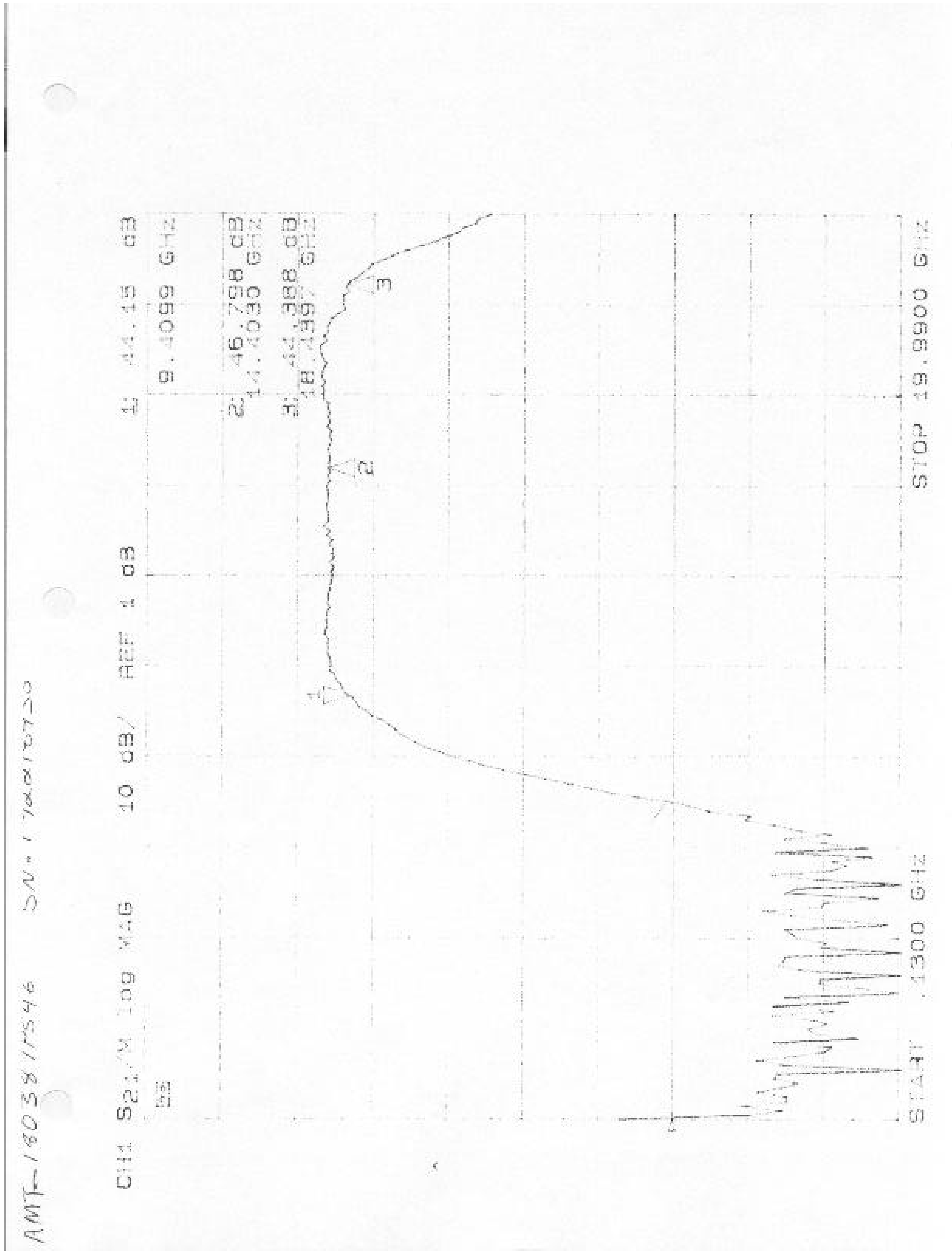
Bill Pope

Product Line Manager

Avantek AWT-8036 SN: 0115




AMT-12 5/PS-46 SN: F765885O8
CH1 S21 log MAG 10 dB/ REF 1 dB
1: 38.65 dB
5.7143 GHz
2: 41.69 dB
9.3922 GHz
3: 38.765 dB
12.9615 GHz
2
3
START .1300 GHz
STOP 19.9900 GHz


CH1 S21/M log MAG 10 dB/ REF 4 dB
1: 44.15 dB
9.4099 GHz
2: 46.798 dB
14.4030 GHz
3: 44.388 dB
18.4997 GHz
START .1300 GHz
STOP 19.9900 GHz

Appendix B

Post-Survey Analysis of Methodology

Any RFI survey of limited duration and scope will carry the risk that some spectral activity will be missed. This is an inherent problem in spectrum monitoring efforts and is one that may never be solved. The reasonable conclusion that is usually drawn is that an exhaustive survey that captures and totally characterizes every line of RF energy for all possible frequencies, polarizations, power levels, and angles of arrival does not exist in reality. Even if such a thing could be accomplished today, the situation may change by tomorrow. Thus, maintaining a total spectral picture, in real time, would require a herculean and perpetual effort. Jeff Acree, an RFI engineer at NRAO Green Bank has often noted that the Department of Defense has spent countless millions of dollars in pursuit of this elusive goal. He has also noted that as of December 2001, the date of his departure, the goal had not been met. So, in reality, the practical goal is to determine a level spectral characterization that is both useful and achievable. With this in mind, the scope of the ALMA RFI survey was narrowed to the point of being executable, via the following key drivers:

- RFI from non-terrestrial sources would not be impacted by regulatory protection mechanisms, so little effort to characterize such RFI was made
- It is unlikely that intentional, let alone unintentional sources of terrestrial RFI above 18 GHz will be problematic at the ALMA site. Since measurements above that would have required investment in new hardware and more time to execute, 18 GHz was adopted as the upper limit for the survey
- Consistent with the Director's original premise, the focus of the survey was to identify and catalog strong, persistent sources of RFI so that future sources could be properly identified as "new sources"
- Information on self-RFI would be useful and would be gathered to the extent practical.

Some of the more important technical tradeoffs which were considered are as follows:

- Sensitivity vs. probability of intercept (POI)
- POI vs. execution time
- Sensitivity vs. execution time
- Preparation time vs. product quality
- Cost vs. product quality
- Terrestrial vs. non-terrestrial sources.

The original plan was to do slow, 360° azimuth sweeps with directional antennas. Though this methodology would give rise to POI concerns, the higher antenna gain would result in substantial improvements in sensitivity over omni-directional antennas. It would also provide useful directional data. Unfortunately, fairly late in the game it was discovered that self-RFI from the antenna rotator had the potential to contribute to the RFI profile below 2 GHz so a compromise was made. For measurements below 2 GHz, the receive antenna was not swept in azimuth, but was sequentially positioned as required to provide 360° of approximately uniform coverage. The impact of this, as shown in Table 1, varied depending on the antenna used and the antenna orientation.

Frequency Range (MHz)	Antenna	Approximate Worst Case Reduction In System Sensitivity For Sources Beyond Azimuth Boresight at the Stated Antenna Orientation (dB)		See Note
		Vertical	Horizontal	
10 - 60	Biconical	0	3	[1]
60 - 200		0	3	
200 - 300	LP	1	4	[2]
300 - 1000		1.5	4	
1 - 2	Horn	6	7	
2000 - 18,000		N/A	N/A	[3]

Table 1. Impact of survey methodology on system sensitivity vs. terrestrial sources

For terrestrial sources, it can be reasonably concluded from Table 1 that the survey methodology was sound for frequencies below 1 GHz. The reduction in antenna gain for signals in the 1-2 GHz frequency range at 45° off azimuth boresight would be 6-7 dB down from the maximum. Thus, the system sensitivity for sources 45° off azimuth boresight would be degraded by an equal amount. This is a significant degradation, so in the future the procedure should be tweaked to improve this.

Since the survey was not intended to cover satellite and airborne RFI, no extra effort was directed at detecting sources high above the horizon. Still, the vertical beamwidth of some of the antennas was large enough to provide fairly high POI for non-terrestrial sources. The antenna parameters in Table 2 are provided to support the evaluation of the surveys effectiveness for non-terrestrial sources.

Per Table 2, sources at 22.5° or less elevation would be no more than 3 dB down from sources on the horizon at the same azimuth for frequencies below 13,200 MHz. At higher elevations and frequencies, the impact is greater. For sources at or near the zenith, very considerable degradation occurs in some cases. In retrospect the “hole” at the zenith could have been filled in

[1] Radiation patterns for the biconical antenna used in the survey are not currently available. Since the E and H plane patterns of a biconical antenna are quite similar to a half-wave dipole, the biconical antenna is assumed to be omni-directional when mounted vertically. The half-power beamwidth of a dipole occurs at about ±45° off boresight in the E-plane, so the combination of the two orthogonal orientations of the biconical antenna for the horizontal polarized measurements should have resulted in no more than 3 dB of sensitivity degradation for any value of azimuth. These assumptions are consistent with mfr data on a similar antenna.

[2] Since the antennas for 200 - 2000 MHz were sequentially moved between four quadrants, the worst case reduction in antenna gain would occur for a source at approximately ± 45° off azimuth boresight. The worst case reduction in sensitivity is therefore based on the relevant antenna gain in that direction. The data provided is based on generic radiation patterns for a LP antenna of the same frequency range as the antenna used in the survey.

[3] The horn antenna was swept in azimuth in this range.

nicely by doing a sweep with the antenna pointed at the zenith. Other voids could have been filled in by positioning the antenna at different elevations to compensate for elevation beamwidth, but it would be a fairly significant undertaking.

Frequency (MHz)	Antenna Type	Antenna Mounted Vertically			Antenna Mounted Horizontally		
		Gain Reduction @ 45° off Azimuth Boresight (dB)	Gain Reduction @ Zenith (dB)	Elevation 3dB Beamwidth (degrees)	Gain Reduction @ 45° off Azimuth Boresight (dB)	Gain Reduction @ Zenith (dB)	Elevation 3dB Beamwidth (degrees)
10-60	Biconical	0	>20?	90	3	0	0
60-200		0	>20?	90	3	0	0
200-300	LP	1	25	60	4	4	75
300-1000		1.5	11	50	6	6	60
1000-2000	Horn	5 - 6	8 - 15	70	2.5 - 7	11 - 20	76 - 67
2000-2900		N/A	> 20	70 - 45	N/A	> 20	≈67
2900-6500		N/A	"	≈45	N/A	"	67- 60
6500-8000		N/A	"	≈45	N/A	"	≈60
8000-12,000		N/A	"	≈45	N/A	"	≈60
12,000-13,200		N/A	"	≈45	N/A	"	≈60
13,200-18,000		N/A	"	45 - 5	N/A	"	60 - 10

Table 2. Approximate parameters for the antennas used in the ALMA RFI survey

Note that the data in Table 4 was obtained from manufacturers data sheets on the specific antenna used where available. In cases where such data was not available, data was obtained as follows:

- MFR data on a functionally similar antenna
- Generic data
- In-house measurements
- Best estimates.

As mentioned previously, the receive antenna was sequentially moved between four quadrants for the frequency range of 200 MHz - 2 GHz to cover 360° of azimuth and it was swept in azimuth for frequencies above 2 GHz. Due to lessons learned while analyzing the collected data, the following is a proposed methodology for the next general RFI survey of terrestrial RFI:

- For 10 MHz - 1 GHz monitoring - No change

- For vertical antenna orientation in the range of 1- 4 GHz, use a horn, such as Electro-Metrics EM-6961 but use eight quadrants instead of four
- For vertical antenna orientation in the range of 4 - 18 GHz use an omnidirectional antenna, such as the Electro-Metrics OWB-60
- For horizontal antenna orientation in the range of 1 - 12 GHz, use the EM-6961 in eight quadrants
- For horizontal antenna orientation in the range of 12 - 18 GHz, an improved methodology is TBD.