Goldstone STDN 9-Meter Radiation Test

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The GSTDN 9-meter tests were conducted from February through July 1981 to characterize the near-field radiation patterns of the S-band and fourth harmonic frequency emissions. The test configurations and results are presented, with graphs of the antenna patterns. The tests indicated that X-band leakage may be suppressed to levels of approximately -190 dBm/cm² at 200 meters.

I. Introduction

The Mark IVA configuration of the Deep Space Network (DSN) will require that the antennas of each Deep Space Communications Complex (DSCC) be colocated close to the 64-meter antenna, except for Deep Space Station (DSS) 12 at Goldstone. This colocation of antennas within line-of-sight of each other and some as close as 200 meters from each other greatly increases the requirements for electromagnetic compatibility within the DSCC to insure continued mission support. Each of the antennas to be colocated represents a potential source of electromagnetic interference.

The DSN 34- and 64-meter antennas are presently colocated in Australia and Spain and have been engineered to suppress electromagnetic interference. However, the Mark IVA configuration also requires the colocation of a Spaceflight Tracking and Data Network (STDN) 9-meter antenna with transmit and receive capability for supporting near-earth missions. The 9-meter antenna has a diverse S-band operating frequency range, with a fourth harmonic that falls within the DSN X-band receiver operational frequency range. Further, the 9-meter antenna tracks earth satellites at relatively fast tracking speeds, which substantially increases the opportunity for a transmitting antenna to radiate into the front of a receiving antenna. This made the 9-meter antenna the most likely antenna to cause electromagnetic interference (EMI). Existing data on the 9-meter antenna did not provide adequate information on its near-field radiation characteristics at fundamental and harmonic frequencies. The RF signature of this antenna was required to develop an antenna interference model. Therefore, actual near-field measurements of the STDN 9-meter's fundamental frequency and fourth harmonic radiations were required.

The STDN 9-meter facility normally operates in one of two modes: exciter bypass or power amplifier mode. In the exciter bypass mode, the output of the exciter bypasses the power amplifier (klystron) and is connected to the antenna through most of the same waveguide as the output of the power amplifier. Our initial concerns for these tests related only to the power amplifier mode; however later we had to include the exciter bypass mode in our test plan.

II. Test Criteria

Test criteria were as follows:

(1) Measure the maximum continuous wave (CW), radio frequency (RF) radiation from the 9-meter antenna, with the transmitter set for the frequency of 2105 MHz and the antenna radiating 10 kW, from a distance of less than 500 meters. Measurements were to be made at 2105 and 8420 MHz with the receiving antenna on boresight of the 9-meter antenna.

(2) Measure the CW RF radiation levels of frequencies 2105 and 8420 MHz, as received from the 9-meter antenna, as a function of the antenna elevation in degrees relative to the boresight of the receive antenna. Transmit frequency 2105 MHz.

(3) Measure the CW RF radiation levels of frequencies 2105 and 8420 MHz, as received from the 9-meter antenna, as a function of antenna azimuth in degrees relative to the boresight of the receive antenna. Transmit frequency 2105 MHz.

III. Test Configurations

A. 500-Meter Test Configuration

(1) Test site 476 meters from the 9-meter antenna.

(2) Equipment configuration 1 (see Appendix).

(3) Test system's signal measurable threshold.[1]

(a) -134.5 dBm/cm^2 at frequency 2105 MHz.

(b) -176.8 dBm/cm^2 at frequency 8420 MHz.

(4) Path loss.[2]

(a) S-band estimated to be 92.45 dB.

(b) X-band estimated to be 104.49 dB.

B. 200-Meter Test Configuration

(1) Test site 200 meters from 9-meter antenna.

(2) Equipment configuration 2 (see Appendix).

(3) Test system's signal measurable threshold.

(a) -172.0 dBm/cm^2 at frequency 8420 MHz.

(b) S-band measurements were not required.

(4) Path loss at X-band estimated to be 96.67 dB.

C. 70-Meter Test Configuration

(1) Test site 70 meters from 9-meter antenna.

(2) Equipment configuration 3 (see Appendix).

(3) Test system's signal measurable threshold was -172 dBm/cm^2 at frequency 8420 MHz.

(4) Path loss at X-band estimated to be 87.72 dB.

D. Equipment Leakage Test Configuration

(1) Test site inside 9-meter transmitter equipment room.

(2) Test system's signal measurable threshold

(a) -135 dBm at frequency 2105 MHz.

(b) -133 dBm at frequency 8420 MHz.

IV. Test Results

A. 500-Meter Test Results

The S-band tests were performed and adequate information was obtained to predict the RF radiation pattern of the 9-meter antenna. See Figs. 1 and 2 for the radiation patterns. No further S-band testing was performed due to time restrictions.

The X-band tests were not completed due to time restrictions. However, the highest fourth harmonic power flux density levels were -122 dBm/cm^2 at 476 meters from the 9-meter antenna. Confirmation testing was conducted at the STDN 9-meter antenna facility in Spain with similar results. Investigations there concluded that the high level of radiation from the STDN antennas was due to a zero delay device[3] (ZDD) that was bolted onto the side of the STDN antenna. When the device was removed, in Spain, from the 9-meter STDN antenna, the fourth harmonic signal level dropped below the detecting equipment threshold. The Goldstone fourth harmonic preliminary test results are depicted in Figs. 3 and 4.

B. 200-Meter Test Results

The primary test location was 200 meters from the Goldstone 9-meter STDN antenna. Fourth harmonic measurements

[1] A preamplifier was locally fabricated to increase the sensitivity of the Hewlett-Packard, HP-8566A, that was used as the receiver.

[2] All test locations are considered to be in the near field of the antenna radiation pattern. Therefore, the distance loss applies to signals in directions out of the main antenna beam.

[3] The zero delay device is a small parabolic antenna, with a crystal detector, that is pointed at the subreflector of the 9-meter antenna. It is used for calibrating transmit and receive delay times to zero distance.

were conducted with the zero delay device (ZDD) installed and with the device removed. The difference in fourth harmonic signal level was dramatic; the maximum X-band signal level received with the ZDD installed was -110.5 dBm/cm^2 and maximum without ZDD was -152.2 dBm/cm^2 (see Fig. 6). A total of four azimuth and four elevation tests were conducted with good repeatability. The test results are depicted in Figs. 5 and 6. The results of these tests indicated that, when the ZDD was removed, there was no discernible antenna pattern for fourth harmonic radiation.

After the last elevation test, the transmitter was terminated into a dummy load and a level of -159.5 dBm/cm^2 was received at the test site. Therefore we concluded that the fourth harmonic radiation signature measured when the ZDD was not installed was distorted by X-band leakage from within the 9-meter facility and/or reradiation. These distortions had to be reduced to measure the fourth harmonic antenna radiation signature. Therefore, additional tests were scheduled and the test site was moved to a location 70 meters from the 9-meter antenna. We wanted to find out whether the leakage could be eliminated by temporary fixes.

C. 70-Meter Test Results

A location approximately 70 meters from the 9-meter antenna was selected to enable continued illumination of the receive antenna by the entire 9-meter antenna facility, while minimizing adjacent reradiating surfaces. In conjunction with this test the spectrum analyzer was also used in the 9-meter transmitter facility to measure the exciter's output. Additional tests were made with the spectrum analyzer and a small X-band horn for detection of X-band radiation leaks in the transmitter system. See Table 1 for test data.

(1) These tests validated the distance related model as the fourth harmonic signal levels initially measured at the 70-meter location were consistent with the previous measurements.

(2) Almost equal levels of fourth harmonic signals were received at the 70-meter site, with transmitter terminated into the antenna or a dummy load. This verified that X-band leakage was distorting our ability to measure the X-band signature of the 9-meter antenna. Therefore, we conducted tests in the transmitter facility to isolate the leakage.

(3) In the transmitter room, the main source of fourth harmonic generation was the exciter. The exciter had X-band components in its output and the exciter was radiating X-band RF signals from its power output stage.

(a) The X-band components in the exciter's output varied 40 dB, while the S-band output remained within established parameters. Measured X-band levels varied from -98 to -58 dBm over the test period.

(b) The X-band radiation from the exciter cabinet was -77 dBm/cm^2. The main radiator was the output stage which radiated -57 dBm/cm^2, with exciter drawer open and output assembly exposed. Therefore, the exciter cabinet assembly only provided approximately 20 dB shielding.

(c) A notch filter (2100-2150 MHz, 50-dB attenuation) was used to determine the effect the exciter X-band output had on the X-band output of the klystron. These tests indicated that X-band input levels below -100 dBm had little effect on the klystron X-band output, while input levels of -100 to -70 dBm seemed to pass through the klystron increasing the X-band output by close to a one to one ratio.

(4) The following was determined by leak detection testing.

(a) The transmission waveguide was leaking X-band signals at most flanges, and at the waveguide switch.

(b) The klystron was generating X-band signals.

(c) The highest detectable level of X-band radiation on the surface of the dish was -144.3 dBm/cm^2, with 10 kW, S-band power output.

V. Temporary Fixes and the Differential Effects (see Table 1)

Trial fix	Differential effect	Test configuration
(1) Sealed a waveguide flange	Reduced X-band leakage 13 dB from −163.3 to 176.9 dBm/cm^2	6-26-81 70-m site, antenna at zenith, 10 kW output
(2) Sealed exciter cabinet	Reduced X-band leakage by 15 dB from −142.4 to −157.1 dBm/cm^2	7-2-81 70-m site, antenna at zenith, 10 kW output
(3) Sealed exciter cabinet and filtered exciter X-band components	Reduced X-band leakage by 25 dB from −146.6 to −174 dBm/cm^2	7-2-81 70-m site, TX antenna pointed at RX antenna, exciter bypass mode

VI. Conclusions

The tests characterized the S-band and fourth harmonic radiations of the 9-m antenna in its current operational configuration. The temporary fixes indicated that the X-band radiation levels may be suppressed to a satisfactory level.

A. Exciter Bypass Mode

By the use of temporary fixes we were able to reduce the level of fourth harmonic emission from the 9-meter antenna to a level below -172 dBm/cm^2 at 70 meters from the antenna. Also the X-band leakage was reduced to a level below -177 dBm/cm^2.

The X-band output of the exciter varied more than 40 dB during these tests, while the S-band output was within tolerance.

B. 10-kW Power Amplifier Mode

The changes in the X-band components of the exciter's output caused variances in the level of fourth harmonic signals received at the test locations. The best case test results indicated a level of -168.5 dBm/cm^2 at antenna boresight and -176.9 dBm/cm^2 with antenna at zenith. Therefore, if the exciter X-band outputs can be controlled, the fourth harmonic power flux density will be below -170 dBm/cm^2 at 200 meters.

Acknowledgment

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Table 1. 70-meter site test results data

Exciter bypass mode TX antenna pointed at RX antenna		
Date, 1981	X-band *PFD*, dBm/cm^2	Test conditions
6-26	−163.4	WG flange "sealed"
6-30	−150.4	WG flange "sealed"
7-2	−174.0	WG flange and the exciter cabinet "sealed", exciter output filtered
Exciter bypass mode TX antenna pointed at zenith		
6-26	−168	WG flange "sealed"
6-30	−150.8	WG flange "sealed"
7-2	−146.6	WG flange "sealed"
7-2	−175.8	WG flange and the exciter cabinet "sealed"
7-2	>−177	WG flange and the exciter cabinet "sealed," exciter output filtered
10-kW power amplifier mode TX antenna pointed at RX antenna		
6-26	−168.5	WG flange "sealed"
6-30	−150.4	WG flange "sealed"
7-2	−154.5	WG flange and the exciter cabinet "sealed"
10-kW power amplifier mode TX antenna pointed at zenith		
6-26	−163.3	Inital check
6-26	−176.9	WG flange "sealed"
6-30	−150.8	WG flange "sealed"
7-2	−142.4	WG flange "sealed"
7-2	−157.1	WG flange and the exciter cabinet "sealed"

Exciter RF power outputs

Exciter 1			
Date, 1981	S-band, dBm	X-band, dBm	Remarks
6-17			Equipment inoperative
6-19	43	−74	Equipment repaired
6-30	43	−61	Equipment tuned
7-2	42	−58.1	No maintenance
Exciter 2			
Date, 1981	S-band	X-band	Remarks
6-17	43	−71	Operating
6-19	43	−98.4	Equipment tuned
6-30	42	−83	Equipment tuned
7-2	42	−79	No maintenance

NOTES: 1. Exciter output power was measured directly with spectrum analyzer using a band-pass filter.

2. The remarks reflect actions taken by GSTDN personnel for their normal operation. No maintenance was performed during tests.

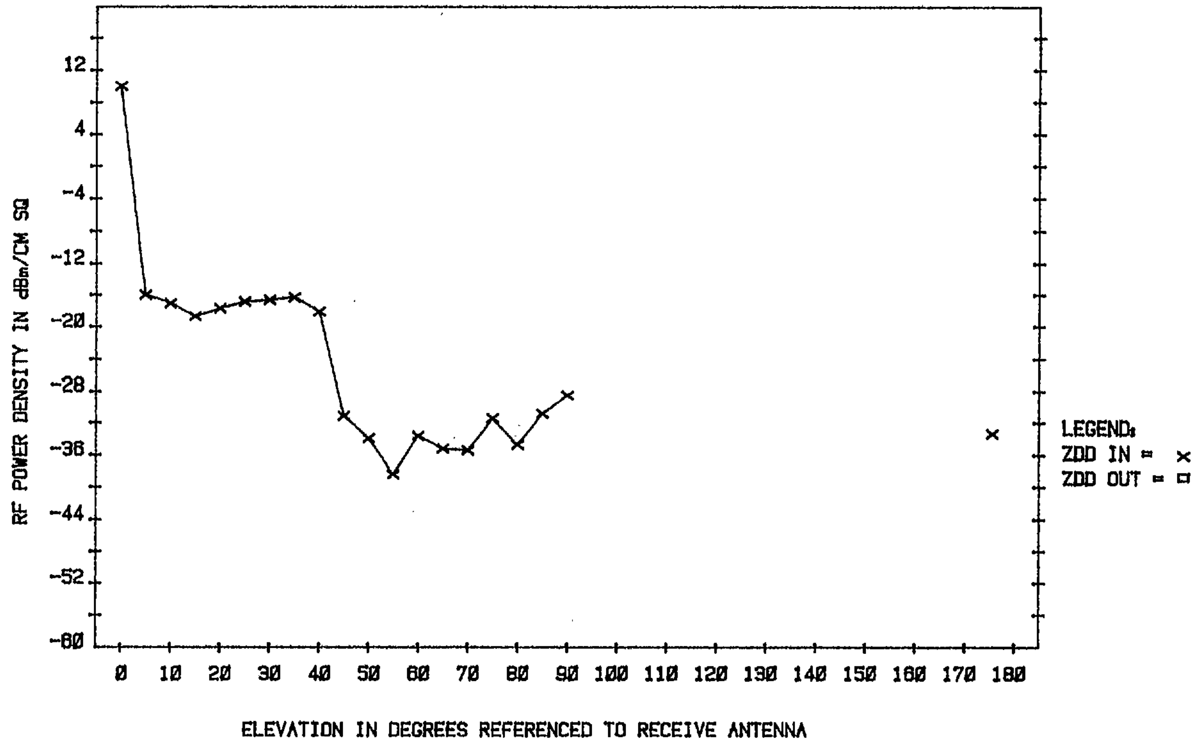

Fig. 1. Power flux density of S-band signal (2105 MHz) at 476 meters, elevation

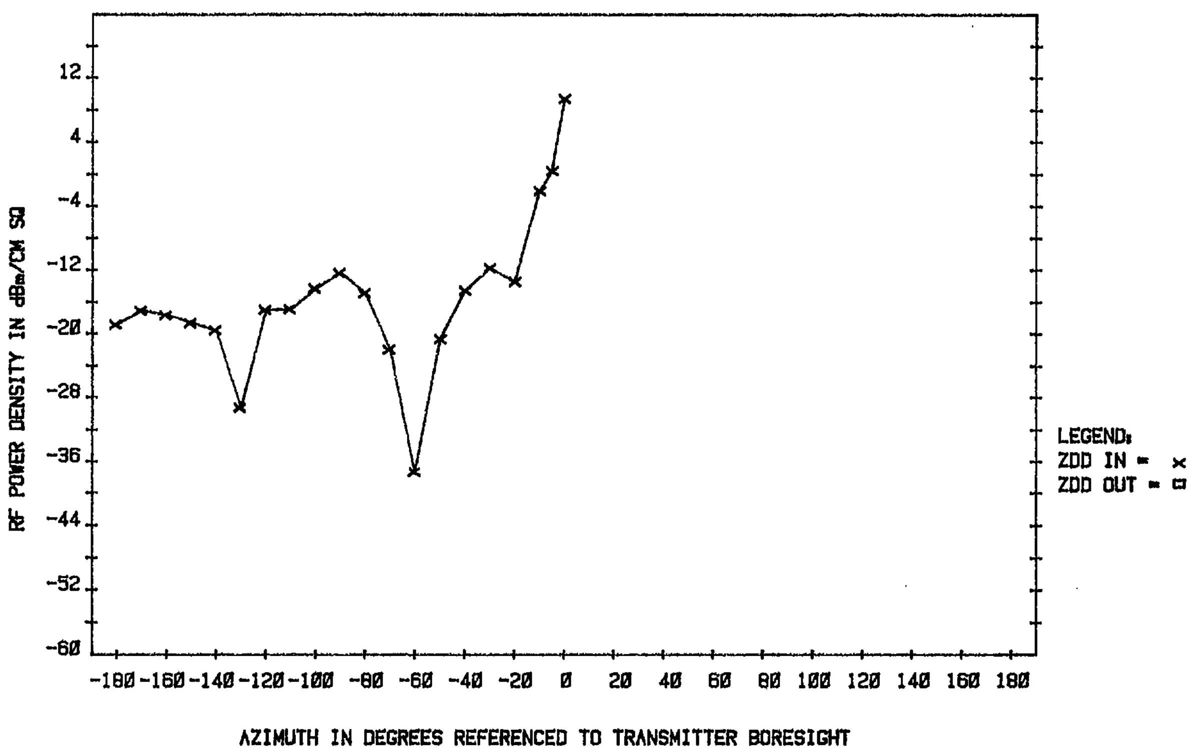

Fig. 2. Power flux density of S-band signal (2105 MHz) at 476 meters, azimuth

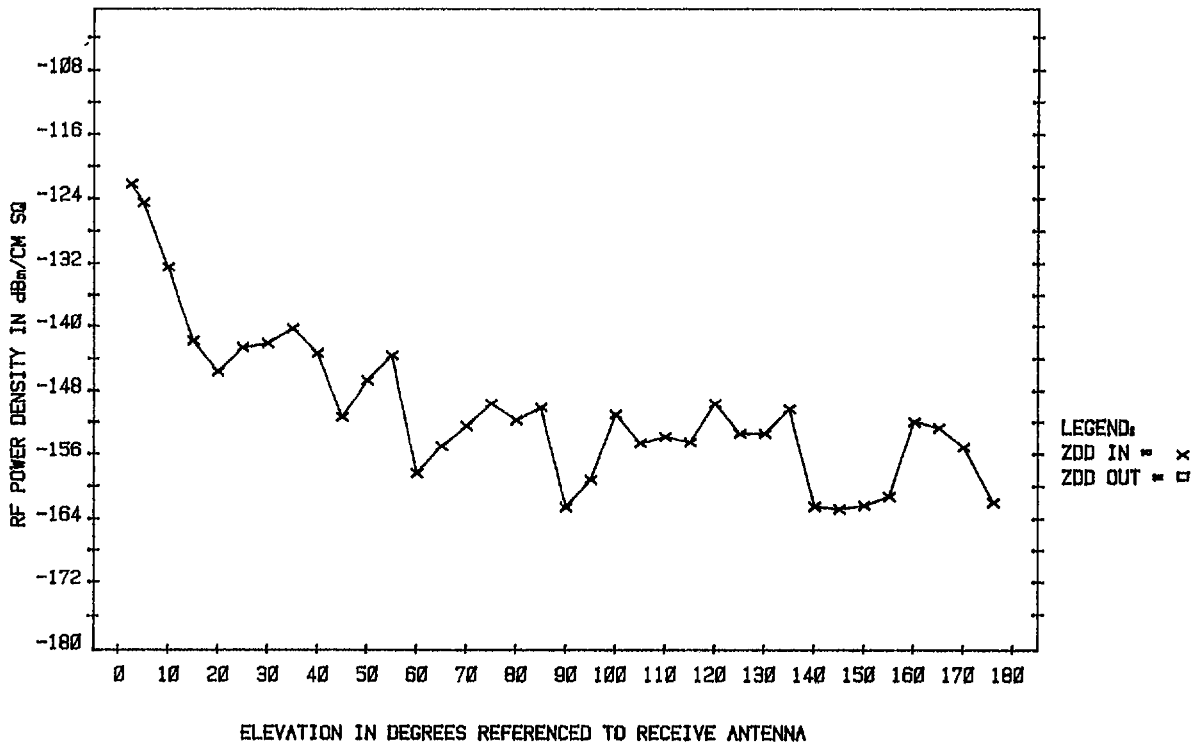

Fig. 3. Power flux density of fourth harmonic (8420 MHz) at 476 meters, elevation

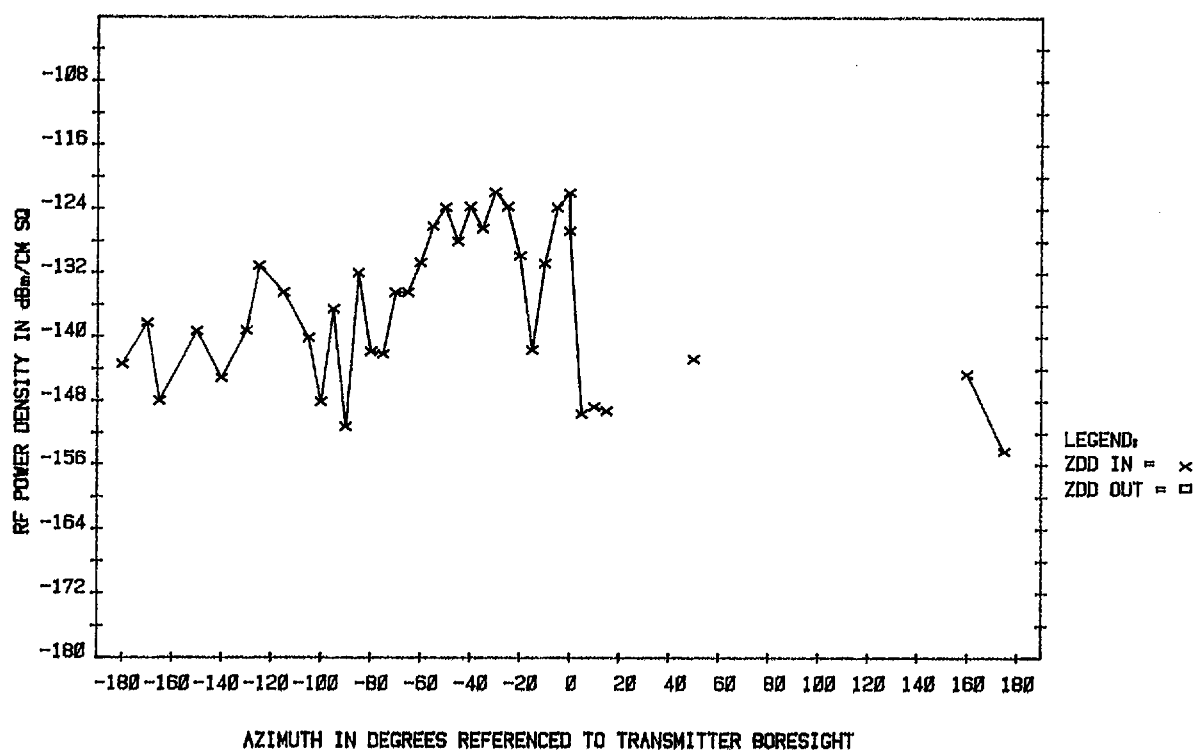

Fig. 4. Power flux density of fourth harmonic (8420 MHz) at 476 meters, azimuth

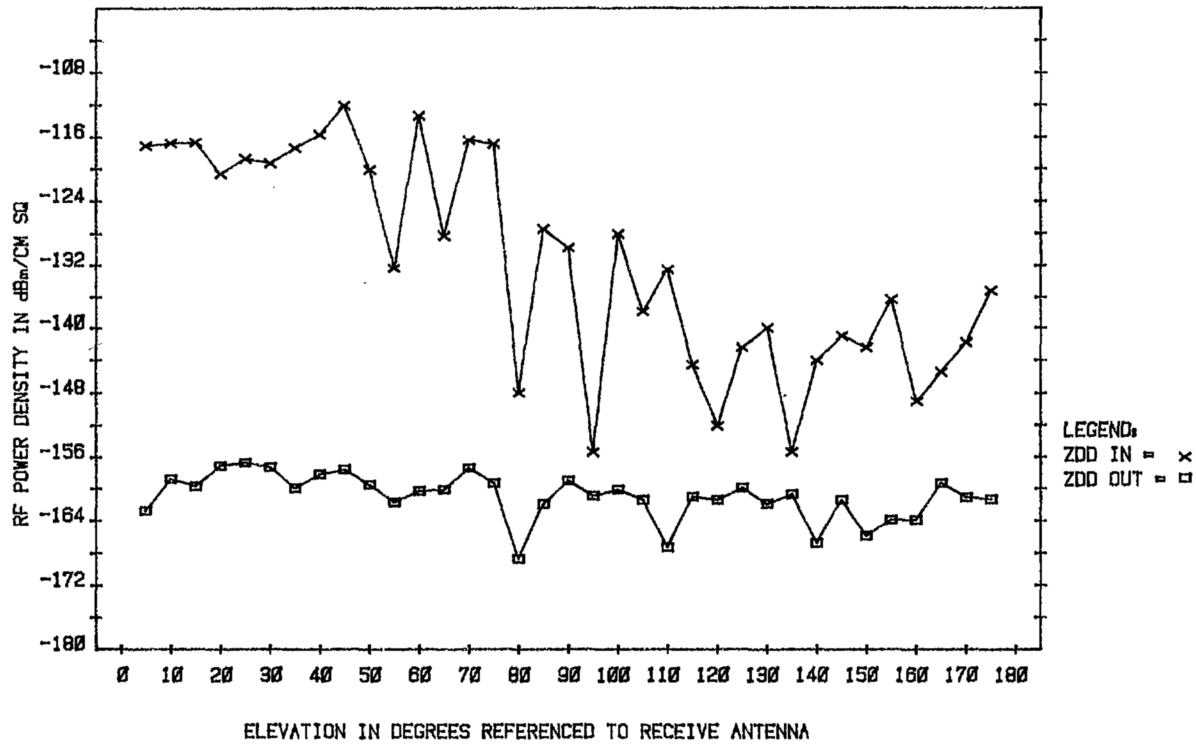

Fig. 5. Power flux density of fourth harmonic (8420 MHz) at 200 meters, elevation

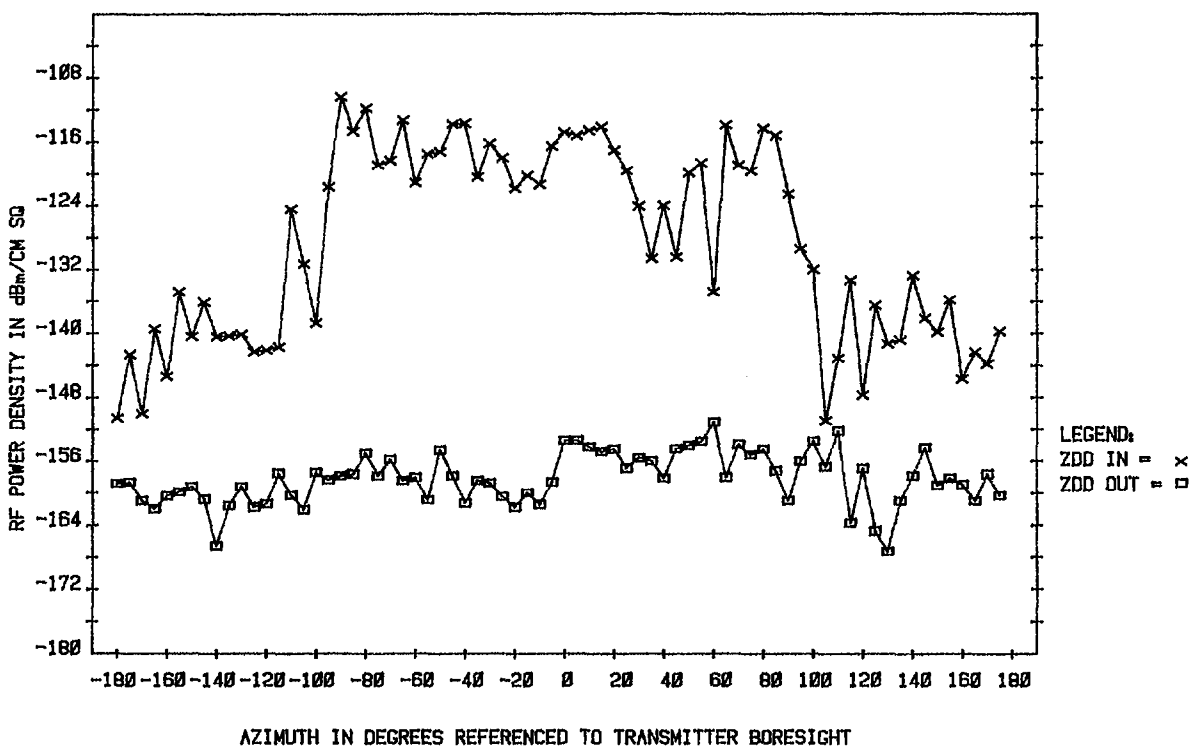

Fig. 6. Power flux density of fourth harmonic (8420 MHz) at 200 meters, azimuth

Appendix

The S-band radiation detection equipment configuration is depicted in Fig. A-1. The S-band minimum measurable signal, with 5 dB signal-to-noise ratio was -134.5 dBm/cm^2. The X-band radiation detection equipment configuration is depicted in Fig. A-2.

To determine the minimum measurable signal of the X-band RF detection system employed for this project, we must first determine the temperature of the system. This RF detection system consists of:

(1) Antenna: X-band, DSN standard gain, horn.

(2) Low noise front end: Locally engineered X-band preamplifier.

(3) Receiver: Hewlett-Packard, HP-8566A, spectrum analyzer.

System parameters are depicted in Fig. A-2. The loss L-3 was a variable due to different cable lengths required for specific measurement setups. The theoretical system temperature calculations are:

System temperature:

$$T_S = T_i + T_r$$

where

T_i = input temperature

T_r = receive system temperature

$$T_i = \frac{290}{L_1} \cdot 290 \left(1 - \frac{1}{L_1}\right) = 290 \text{ kelvin}$$

$$T_S = 290 + (F - 1)\, 290 + \frac{(F_2 - 1)_{290}}{G_1 \cdot L_2} + \frac{(F_3 - 1)_{290}}{G_1, G_2, L_2, L_3}$$

The cable length between the preamplifier and the spectrum analyzer resulted in the following values for L_3:

Test Configuration 1: $L_3 = -5.6$ dB

Test Configuration 2: $L_3 = -30$ dB

Using the above formula and the parameters from Fig. A-2, we can derive the system temperature in kelvin. Once T_S is derived we can determine the receive threshold by:

$$\text{Noise threshold} = N_0 = KT$$

$$= -198.6 \text{ dB M/Hz} \cdot \text{K} + 10 \log (T_S)$$

and

$$\text{Receiver threshold} = N_0 \; BW = N_0 + \log \text{(RX bandwidth)}$$

Therefore

Test Configuration	System Temperature	Receiver Threshold
1	473.8 K	-161.8 dBm
2	1,387.4 K	-157.2 dBm

To determine the minimum measurable input signal level, the RF detection system was set up in a certified screen room at the JPL Compatibility Test Area (CTA-21). An external, calibrated, X-band RF signal source (DSN X-band translator) was routed through precision attenuators and input to the screen room. By experimentation it was determined that, by employing 20 video averages, a signal-to-noise ratio of 5 dB could accurately measure the signal level.

As the RF detection system was to be used in the field, we assumed that minor antenna pointing errors may occur. Therefore we adjusted our antenna gain figure to 21 dB.

In view of the above, we concluded that, conservatively speaking, our thresholds including antenna gain were:

Test Setup	Measurable Signal Threshold	Observable Signal Threshold
1	-176.8 dBm/cm^2	-181.8 dBm/cm^2
2	-172.0 dBm/cm^2	-177.0 dBm/cm^2

Thresholds in terms of field strength and power flux density are as follows:

The field strength values may be determined by:

$$E = V_r + K$$

where

E = dBm = dB referenced to 1 μv

V_r = received signal in dBm = *PFD*

K = antenna factor in dB/m = 20 log (F) - G - 29.8 dB

Thus $K = 27.70624183$; F = 8420 MHz

(Note: For 50 ohm input 0 dBm = 107 dBμV.)

The power flux density $= PFD = P_R - A_E$

where

$$A_E = G\,dB_i + \frac{\lambda^2}{4\pi}(\mathrm{dB}) = G\,dB_i - 39.95\ \mathrm{dB/m^2}$$

or

A_E = 21 – 40 = –19 dB/m^2

PFD = threshold in dBm –(– 19).

Therefore:

(1) PFD at thresholds are:

Test Setup	Measurable Signal Threshold	Observable Signal Threshold
1	–137.8 dBm/m^2	–141.8 dBm/m^2
2	–132.0 dBm/m^2	–137.0 dBm/m^2

(2) Field strengths at thresholds are:

Test Setup	Measurable Signal Threshold	Observable Signal Threshold
1	–42.09 dBμV	–47.09 dBμV
2	–37.29 dBμV	–42.29 dBμV

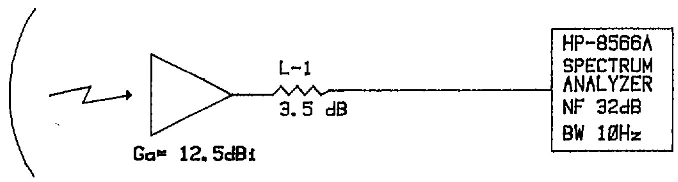

Fig. A-1. S-band equipment configuration

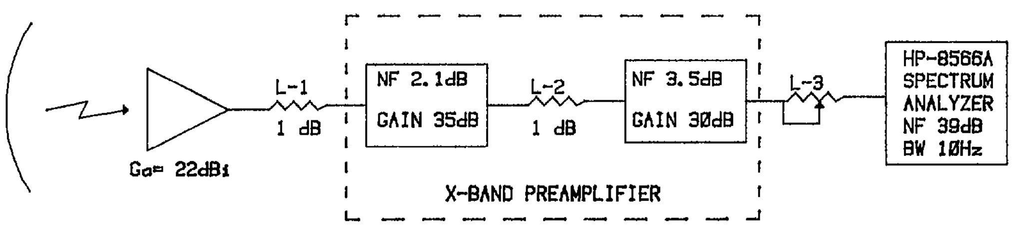

Fig. A-2. X-band equipment configuration