# RADIATION PATTERN MEASUREMENTS OF THE NASA MARS SCIENCE LABORATORY UHF ENTRY ANTENNA USING A SPHERICAL NEAR-FIELD RANGE

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**ABSTRACT**

Measurements of a conical micro-strip Wraparound™ antenna array mounted on a portion of the entry vehicle for NASA's Mars Science Laboratory mission were completed at Nearfield Systems, Inc.'s new spherical near-field range facility. The Wraparound™ antenna, designed and manufactured by Haigh-Farr, Inc., provides nearly full spherical coverage and operates in the UHF frequency band for telecommunications to orbiting assets at Mars. A summary of the measurements techniques and results are presented, along with a comparison of the measured and calculated patterns.

**Keywords**: Chamber, Measurement, Modeling, Pattern, Spherical, VHF/UHF

## 1.0 Introduction

The Mars Science Laboratory (MSL) mission will launch and land a rover on the surface of Mars as part of NASA's Mars Exploration Program. The main objective of the mission is to determine whether the Martian environment is, or ever was, capable of supporting life. The rover will carry a suite of scientific instruments that will sample and analyze Martian rocks and soil, looking for the chemical building blocks of life and studying the historical carbon and water cycles.

During the Entry, Descent, and Landing (EDL) phase of the mission, the primary telecommunications path will be via a UHF uplink from the MSL spacecraft to the Mars Reconnaissance Orbiter (MRO) spacecraft. An X-band direct-to-Earth (DTE) link will also be provided during the EDL phase. The UHF link to the orbiter enables higher data rates than the X-band DTE link, and does not requires a direct line of sight to Earth.

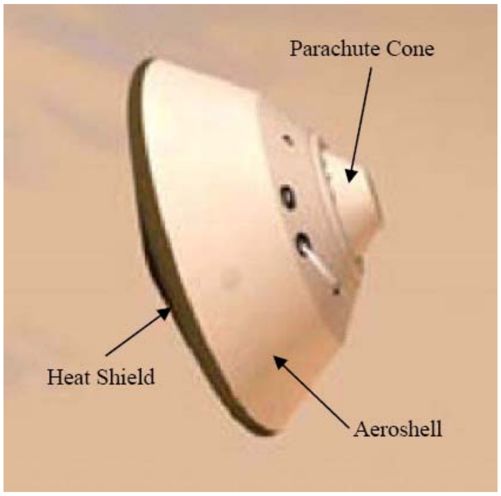


**Figure 1 – MSL Entry Configuration**

About 10 minutes before entry, the cruise stage will separate from the entry vehicle. The entry vehicle consists of an aeroshell, heat shield, and parachute cone, as shown in Figure 1. A short time before cruise stage separation, the UHF telecommunications system will be turned on. The Parachute Cone UHF (PUHF) antenna will be the first of three UHF antennas used in the EDL sequence, operating from cruise separation until the beginning of the powered descent. The PUHF antenna is mounted on the parachute cone and has a close to omni-directional pattern. An omni-directional antenna pattern is needed to link to MRO over a variety of potential landing sites and landing dates.

## 2. Antenna Design and Verification Plan

When MSL was in the early design stage, NASA's Phoenix spacecraft was in the final stages of installing and testing a Haigh-Farr Wraparound™ micro-strip patch array on the parachute cone of its entry vehicle. MSL developed the PUHF antenna's development, installation, and verification strategy based on the Phoenix mission's experiences.

The PUHF Wraparound™ antenna comprises four individual segments shaped to mount on the conical parachute cone. Each segment contains two circularly polarized patch antennas and together the four segments are fed through a four-way power divider and phase-matched cables. The eight patch antennas are equally distributed around the parachute cone to provide optimal spherical coverage.

Two thermal protective layers are employed to protect the PUHF Wraparound™ antenna from the heat of entry. The first is integral to the antenna and provides a uniform known interface over the high field areas of the patches. The second layer is the parachute cone assembly's Thermal Protection System (TPS) material, which is applied over the entire parachute cone surface including over the top of the antenna. Inasmuch as the second TPS layer is fairly thick, and is applied at the very end of the parachute cone assembly process, steps had to be taken during the antenna design to compensate for the change in resonant frequency caused by its installation. Computer modeling was utilized to characterize this effect.

Simulation results of the return loss both with and without the second TPS layer are given in Figures 2 and 3. Further, to verify the second TPS effects, the return loss versus frequency was measured on a single patch antenna both with and without the TPS material in place. These results are given in Figures 4 and 5. The simulated results agreed very closely with the measured single element results and a pre-TPS tuning delta frequency was established. The PUHF Wraparound™ antenna was then tuned during manufacture to be slightly higher in frequency by the determined delta frequency to compensate for the pulling or loading of the radiating elements once the secondary TPS was installed.

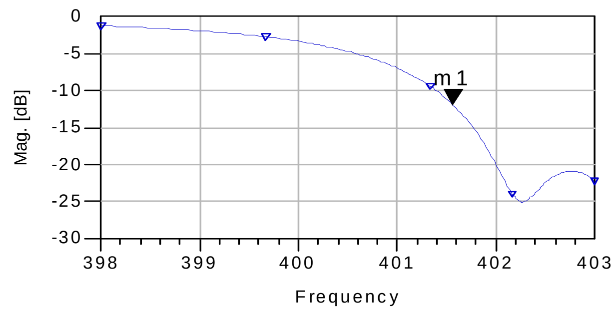


**Figure 2 - Simulated Return Loss of Single Patch without Secondary TPS (*Frequency in MHz*)**

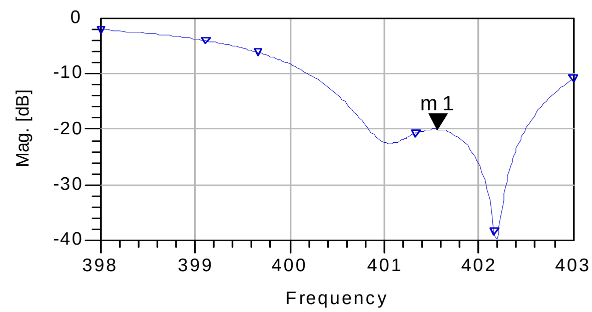


**Figure 3 - Simulated Return Loss of Single Patch with Secondary TPS (*Frequency in MHz*)**

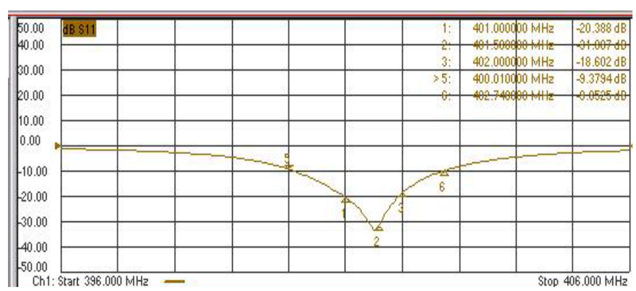


**Figure 4 - Measured Return Loss of Simple Patch without Secondary TPS**

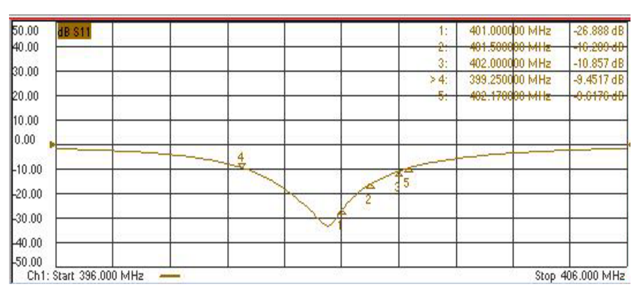


**Figure 5 - Measured Return Loss of Simple Patch with Secondary TPS**

Measuring the PUHF antenna patterns on the actual MSL entry vehicle was not viable due to the large vehicle size and programmatic constraints, but establishing the pattern characteristics was key to determining link performance during the descent to Mars. In the spacecraft build, the parachute cone and aeroshell were fabricated as separate assemblies, and integrated after the PUHF assembly was integrated onto the parachute cone. This proved to be advantageous for generating a practical verification plan consisting of the following steps, and depicted in Figure 6.

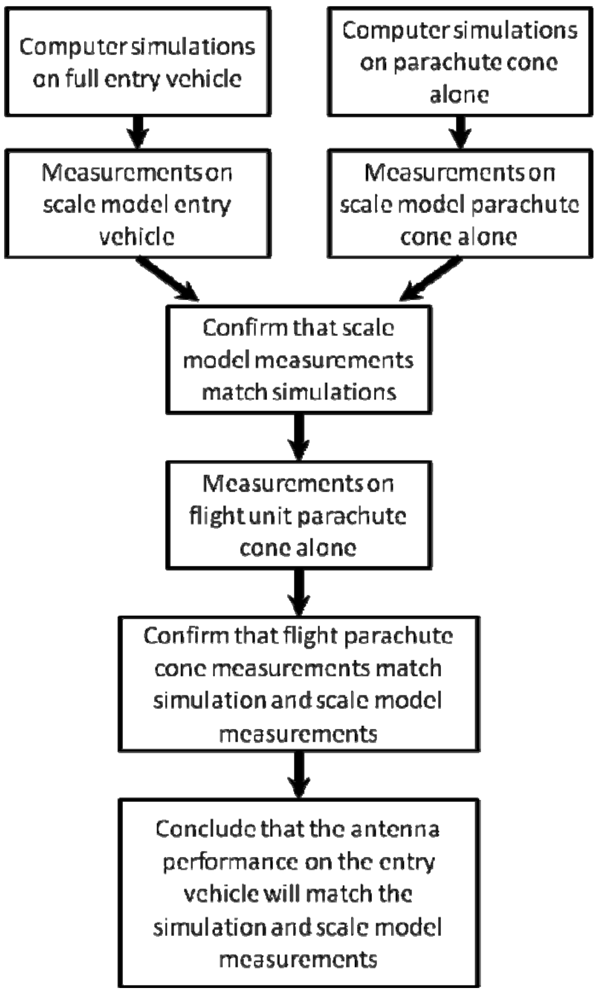


**Figure 6 – Radiation Pattern Verification Strategy**

1. In the design phase of the antenna, radiation patterns of the PUHF antenna installed on the entire entry vehicle and on just the parachute cone alone were simulated by computer modeling. The Finite Difference Time Domain (FDTD) technique was used to calculate the pattern characteristics on the parachute cone only and on the full aeroshell. FDTD was selected because, unlike Method of Moments (MOM) and most other numerical methods, it handles very large objects easily and accurately.

2. Fifth-scale models of the PUHF antenna and the entry vehicle were built, with the parachute cone portion separable from the rest of the entry vehicle. Radiation pattern measurements were made with the fifth scale antenna on the parachute cone model alone and with the entire entry vehicle model. This step verified the modeling accuracy of the antenna response on the spacecraft.

3. The flight antenna unit was mounted onto the flight parachute cone. Radiation pattern measurements were conducted to verify the antenna performance before TPS application.

4. The TPS was applied to the parachute cone. A final round of radiation patterns measurements was conducted to verify the antenna performance in its final configuration.

5. The final measurements were compared to the predicted measurements of the antenna on the parachute cone, as well as the fifth-scale measurements on the parachute cone-only configuration. Good agreement between the patterns indicated that the fifth scale model measurements and the calculated patterns on the entire entry vehicle were valid.

## 3. The Measurement Facility

Antenna pattern characterization and gain measurements were done at Nearfield Systems Inc.'s (NSI) new spherical test range. The spherical near-field technique was selected since it provides nearly full pattern coverage over a full sphere, can be conducted in a controlled indoor environment, and the raw measurement data can be reprocessed to yield far-field pattern results in different coordinate systems, different angular resolutions, and at various polarizations if needed.

NSI's new spherical near-field test facility is located at their Torrance, CA facility. It has an NSI-700S-75 spherical near-field scanner system that consists of a high capacity Phi/Theta AUT positioner and motorized probe rotation stage. The system is capable of measuring antennas as large as 3m in diameter. The system is located in a 6m x 6m x 6.3m test chamber that is fully lined with 1m pyramidal anechoic absorber. Floor absorber is mounted on wheeled pallets to facilitate mounting and alignment of the test antenna. Prior to the load-in of the flight unit parachute cone, NSI conducted extensive tests to determine the performance level of the anechoic material. It was determined that the reflection level was approximately 35dB at 400 MHz.

The flight unit was mounted to a fixture that was designed to place the antenna near the intersection of the theta and phi axes; thereby minimizing the measurement sphere and reducing test time. In this mounting configuration the antenna occupied a 76cm measurement sphere. The flight unit measurements were performed both before and after the TPS application. For the measurement after the TPS application, the unit was enclosed in a protective germanium-coated polymide-film cover to protect the TPS material from contamination and damage. A turn-over fixture was employed to roll the antenna from a horizontal to vertical orientation, and a lifting fixture was then attached. The flight unit was moved into the range and lifted into position using a forklift. Figure 7 shows one step in the set-up of the flight unit before TPS application. Figure 8 shows the flight unit with TPS and the protective cover. Mechanical alignment of the scanner was accomplished using a Faro laser tracker. Additional laser tracker measurements to fixed reference points in the chamber were also made to ensure the same alignment when remounting the antenna.

**Figure 7 – Mounting of the Flight Unit on the Phi Stage (Flight Unit Shown Before TPS Application)**

The measurement was set up to scan in phi and step in theta over a full sphere with a 2X oversample at two closely spaced frequencies around 400 MHz. Figure 9 shows the coordinate system referenced to the parachute cone. The RF system was an Agilent PNA. The probe was an NSI model NSI-SP-835 Dual Polarized Broad-Band Horn Antenna that is capable of covering 0.4-10 GHz. Absolute gain was established by the substitution method using a 10.8 dBi standard gain horn supplied by the Jet Propulsion Laboratory (JPL) with an estimated accuracy of ± 0.5 dB.

## 4. Results and Conclusions

The flight unit measurement data showed excellent agreement with both the scale model measurement data and the simulated data. The results are plotted in Figures 10 through 16. A return loss measurement was also performed while the TPS-covered flight unit was installed in the NSI anechoic chamber. The results are shown in Figure 17.

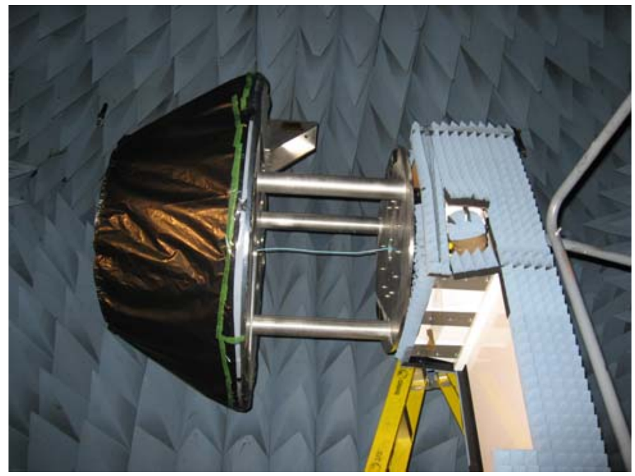

**Figure 8 – Flight Unit Parachute Cone Mounted on NSI Positioner**

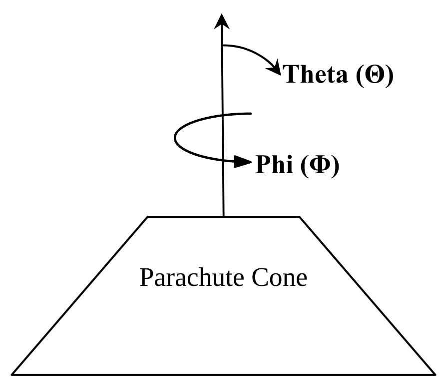


**Figure 9 – Reference Coordinate System**

The largest areas of deviation in the patterns are in the backlobe and in the region around ±50° in theta. The backlobe area is not unexpected due to the blockage from the mounting hardware and positioner. In the region around ±50 in theta, earlier simulation had showed that the gain dip in this area was very sensitive to the transition geometry between the parachute cone and the aeroshell. We suspect that the difference is due to slight geometry differences in the bottom edge of the parachute cone between the flight unit with the mounting plate and the RF model. The discrepancy is small and was not a cause for concern.

The verification of the MSL PUHF antenna was successfully completed. We concluded that the fifth-scale model and the simulated data of the antenna performance on the entire entry vehicle were valid and could be used for the MSL telecommunications link analysis.

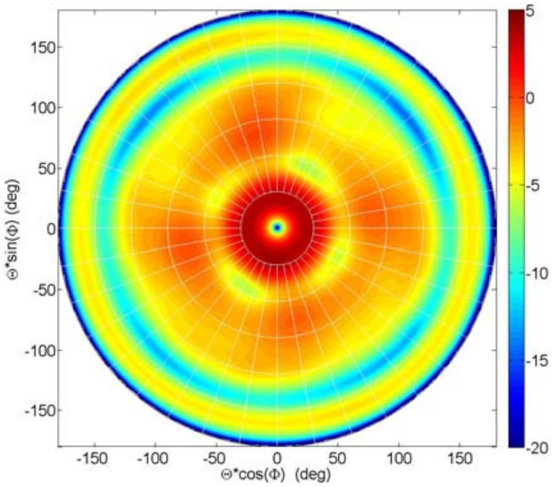


**Figure 10 – Parachute Cone Only Simulated Co-pol Gain (dBi)**

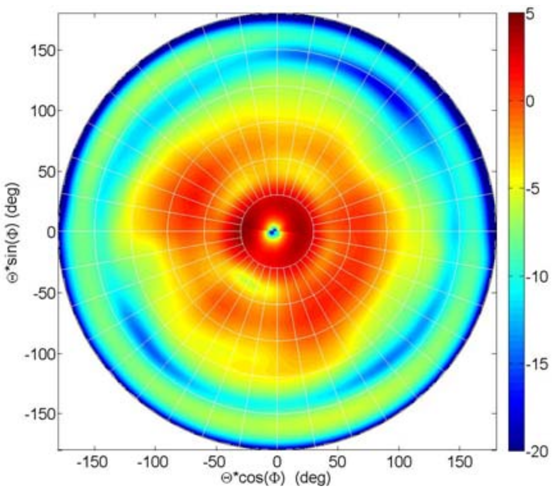


**Figure 11 – Scale Model Parachute Cone Only Measured Co-pol Gain (dBi)**

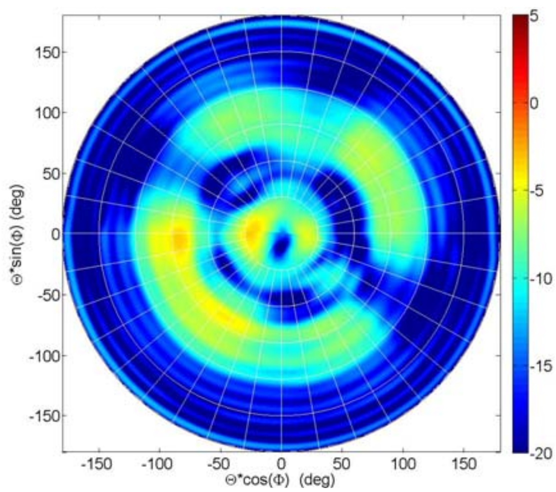


**Figure 13 – Scale Model Parachute Cone Only Measured Cross-pol Gain (dBi)**

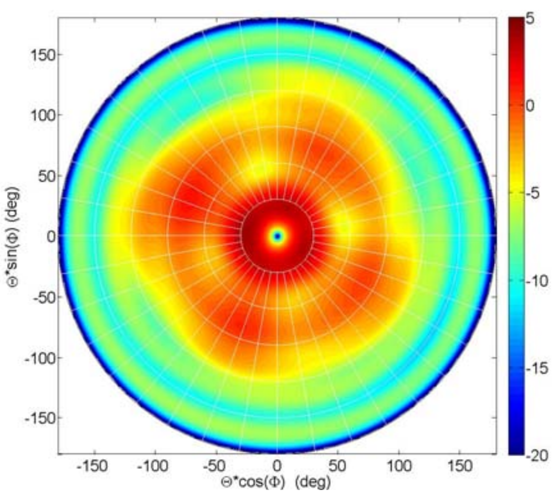


**Figure 12 – Flight Unit Parachute Cone Only Measured Co-pol Gain (dBi)**

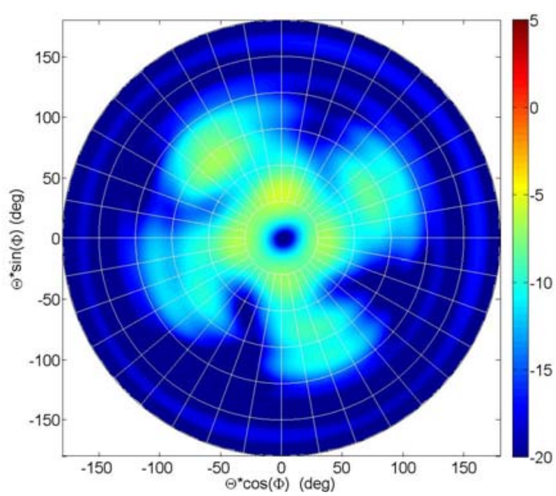


**Figure 14 – Flight Unit Parachute Cone Only Measured Cross-pol Gain (dBi)**

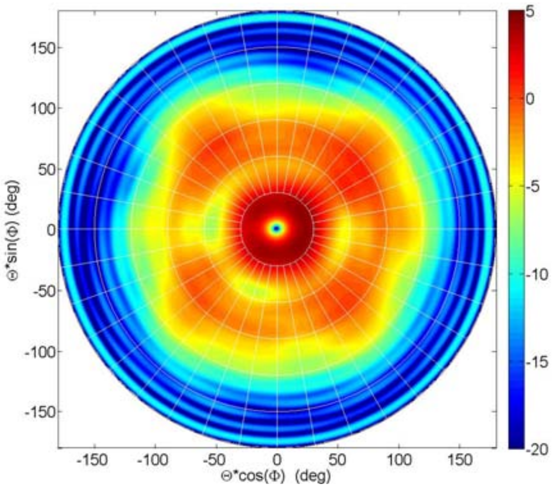


**Figure 15 - Full Aeroshell Predicted Co-pol Gain (dBi)**

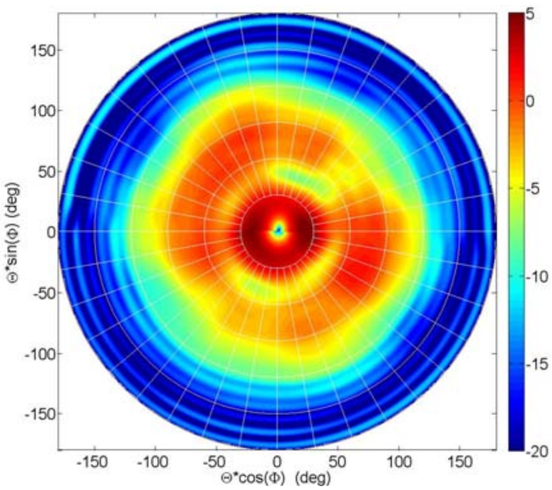


**Figure 16 – Scale Model Full Aeroshell Measured Co-pol Gain (dBi)**


**Figure 17 – Measured Return Loss of Flight Unit (Operational Frequency is Middle Marker)**

## 5. ACKNOWLEDGMENTS


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- Tim Newby and Kim Sun who led the JPL/NSI team who installed the flight unit on the NSI range.
- Karl Haner and Allen Newell from NSI for conducting the flight unit measurements, and Jeff Harrell from JPL, who provided the test engineering interface.
- The Phoenix team who originally developed and implemented the verification method for the Phoenix mission.