N94-21340

AN IN-DEPTH ANALYSIS AND MODELLING OF THE SHUTTLE TO MILA S-BAND TELEMETRY LINK

Armen Caroglanian
Fernando A. Pellerano
NASA Goddard Space Flight Center
Telecommunication Systems Branch
Greenbelt, MD 20771

Dale D. Shama
Loral Aerosys
Beltsville, MD 20705

Summary- The S-Band radio frequency (RF) link between the Merritt Island (MILA) Tracking Station and the Space Shuttle launch pads is a critical communication path for pre-launch and launch operations. The proposed siting of the Center for Space Education (CSE) at the Visitor Center required a study to avoid RF line-of-sight blockage and reflection paths. The study revealed the trees near MILA's 9-meter (9-M) antennas are obstructing the optical line-of-sight. The studies found diffraction is the main propagation mechanism. This paper describes a link model based on the Geometric Theory of Diffraction.

1.0 Introduction

The S-Band radio frequency (RF) link between the Merritt Island (MILA) Tracking Station at the Kennedy Space Center (KSC) and the Space Shuttle launch pads is a critical communication path for pre-launch and launch operations. The Visitor's Information Center (VIC) is located near the lines-of-sight. As new buildings are added to the VIC, care has been taken to avoid RF line-of-sight blockage and reflection paths. The proposed siting of the Center for Space Education (CSE) at the VIC required extensive theoretical and experimental studies [1], [2], [3].

The work, performed by NASA, Bendix, Lincom and ECAC, identified scattering from buildings, vegetation, and the launch pad as probable causes of link degradation. In addition, weather was found to be a factor in altering the RF propagation. Field probes in front of the MILA 9-M antennas determined the trees in the near-field were placing a severe illumination taper on the antenna aperture. The modeling of the RF perturbation caused by the trees is the focus of this report.

2.0 RF measurements

Currently, an optical line-of-sight does not exist between the 9-M antennas and the launch pads. Maximum signal strength at MILA is achieved when the 9-M antennas are pointed at the top edge of the forest. The maximum signal pointing angle is above the line-of-sight angle, meaning the top edge of the trees appears to be a diffraction source. Previous studies [4] have modelled this effect as knife-edge diffraction. Multipath, however, has also been detected. Improved test procedures to measure the influence of diffraction and multipath individually were conducted during a test trip to MILA in May 1992. Data analysis showed that, although multipath was detected, diffraction was a stronger mechanism [5]. A theoretical forest attenuation model developed George Washington University was also employed [6]. The model determined the forest was "hard". That is, the average attenuation is high, therefore multipath effects will be minimal. Using the measurements and the model, it was determined that link maintenance analysis would be based on diffraction models.

3.0 Diffraction Theory and Modelling

The MILA diffraction model is based on the Geometric Theory of Diffraction [7]. The model has two modes of operation. One mode calculates RF energy incident at a given point on an antenna's surface in the presence of blockage. The second mode calculates the total received RF power of a reflector antenna due to either direct (free-space), diffracted, or the combined RF energy.

The RF energy originates from an omnidirectional power source at the launch pad and may be partially blocked by a perfectly-conducting knife-edge obstacle (see Figure 1). This set-up closly parallels the actual conditions at MILA. In the MILA link, the polarization of the transmitted signal is circular. The MILA diffraction model, however, utilizes linear polarization. Circular polarization can be modeled by properly phasing and summing the two orthogonal linear received electric fields.

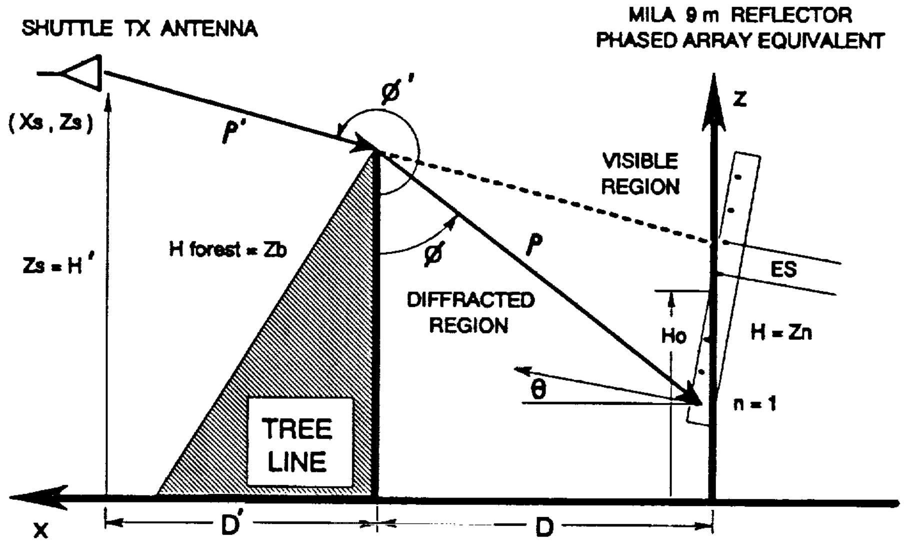

Figure 1 MILA diffraction model geometry.

The received electric field at the output of the 9-M antenna may be calculated on the basis of the following development. The incident (i.e. non integrated) direct E field is found as,

$$E_o(h) = Z(h) \frac{\lambda}{4\pi R} e^{-jkR} \qquad (1)$$

where h = vertical height on the 9-M antenna aperture

R = distance from the transmit antenna to the 9-M antenna

k = the wavenumber = $2\pi/\lambda$

Z(h) = 0, blocked

= 1, unblocked

Function Z(h) determines, by the given geometry, whether the transmitted energy is blocked by the tree-line or not. The incident diffracted E field at the 9-M antenna is found as,

$$E_d(h) = \frac{\lambda}{4\pi\rho'} * e^{-jk\rho'} * CDCH * A\, e^{-jk\rho} \qquad (2)$$

where ρ' = distance from the transmit antenna to diffraction edge

ρ = distance from diffraction edge to the 9-M antenna aperture

CDCH = diffraction coefficient for vertical polarization

(or CDCS = diffraction coefficient for horizontal polarization)

A = spatial attenuation function for diffracted power.

The diffraction coefficient CDCH, a complex quantity, is generated from an expression dependant upon the incidence angle ϕ', the reflected angle of diffraction ϕ, the distance from the diffracting edge to the source, D', the distance from the diffracting edge to the receive antenna, D, and the assumption that the diffracting edge is a perfectly-conducting half-plane. The function A, represents the spatial attenuation for the diffracted field, and is given by,

$$A = \sqrt{\frac{\rho'}{\rho\,(\rho'+\rho)}} \qquad (3)$$

The received E field is found as a function of the incident signal integrated over the gain function of the receive antenna aperture. The model assumes no E field variation in the horizontal direction of the aperture. This is a valid assumption because the direct and diffracted fields incident on the antenna are planar and cylindrical fields, respectively. The gain function of the receive antenna is generated by a separate reflector antenna model [8]. The model breaks up the aperture into horizontal segments of width ES λ and calculates the complex values for the electric field (far field) on the aperture. An equivalent field for the segment is generated, thus the 9-M antenna gain model becomes a phased array with vertical dependance only. This simplification greatly reduces the computation time for the model. For the present study, an optimal value of ES=1 was used. The antenna may also be pointed at an angle θ with respect to the horizontal plane. The received (integrated) field, E_r can be found as,

$$E_r(H_{forest}, D) = \sum_k G_k(h)\,[E_{o_k} + E_{d_k}] \qquad (4)$$

where H_{forest} = height of the forest edge

D = distance of the forest edge to the 9-M antenna

G(h) = gain function of the 9-M antenna

E_{Ok} = incident direct field (equation 1)

E_{dk} = incident diffracted field (equation 2)

It is mathematically possible to analyze the contributions of the direct and diffracted fields independently. All cases can be analyzed as a function of blockage height and distance from the antenna, signal frequency, or antenna pointing angle. Both the magnitude and phase relationships are calculated for each case and can be plotted in terms of electric field or power.

4.0 Simulation Results and Analysis

The first check of the GTD software was the calculation of the 9-M antenna receive elevation pattern. Figure 2 shows the comparison of the experimental and theoretical results. The peak receive signal, as expected, occurs when the 9-M antenna is pointed to an elevation angle corresponding to the closest tree-line. The experimental and calculated patterns show good agreement out to the first sidelobe. The slightly higher than expected receive energy at low elevation angles may be due to forest multipath and/or ground reflections.

Figure 3 shows the MILA 9-M received energy for a simulated forest being trimmed in height. The 9-M received energy contributions for direct, diffracted, and total signal are shown. For the current blockage case, the trees near the 9-M are at a height of 45 ft. The trees would have to be reduced in height to 30 feet, all the way out to the VIC, to recover the direct signal. Figure 4 shows the results of trimming the forest back and leaving the closest trees at a height of 45 feet. The trees would have to be trimmed back nearly 5,000 feet for

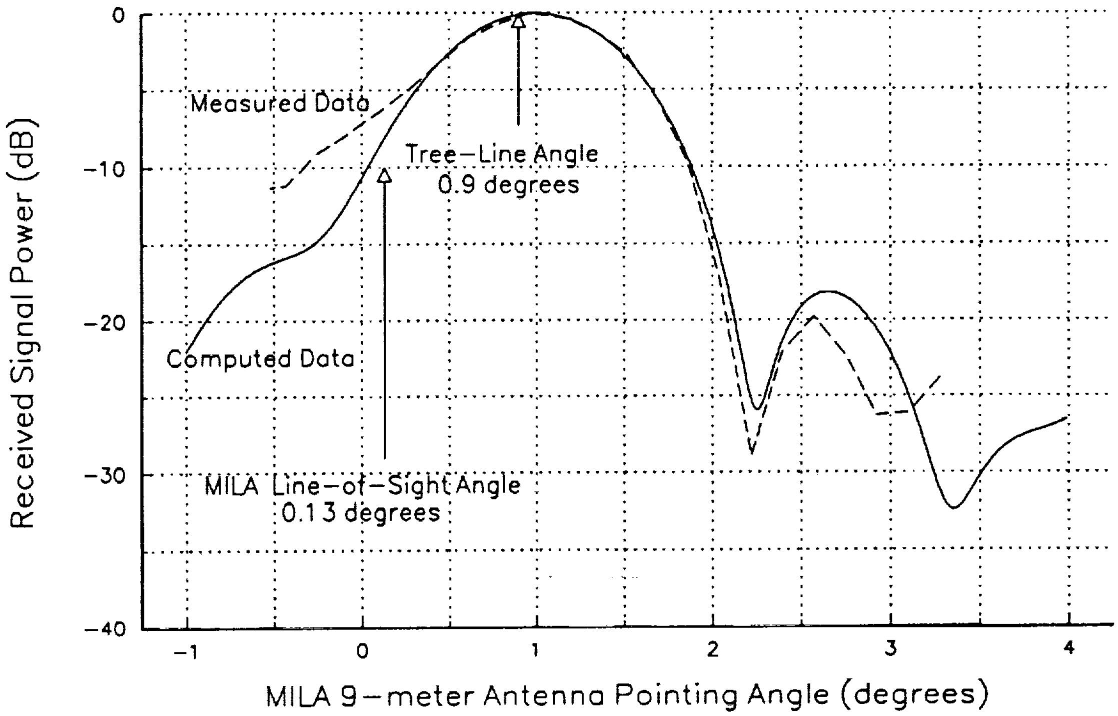

Figure 2 MILA 9-M antenna pattern.

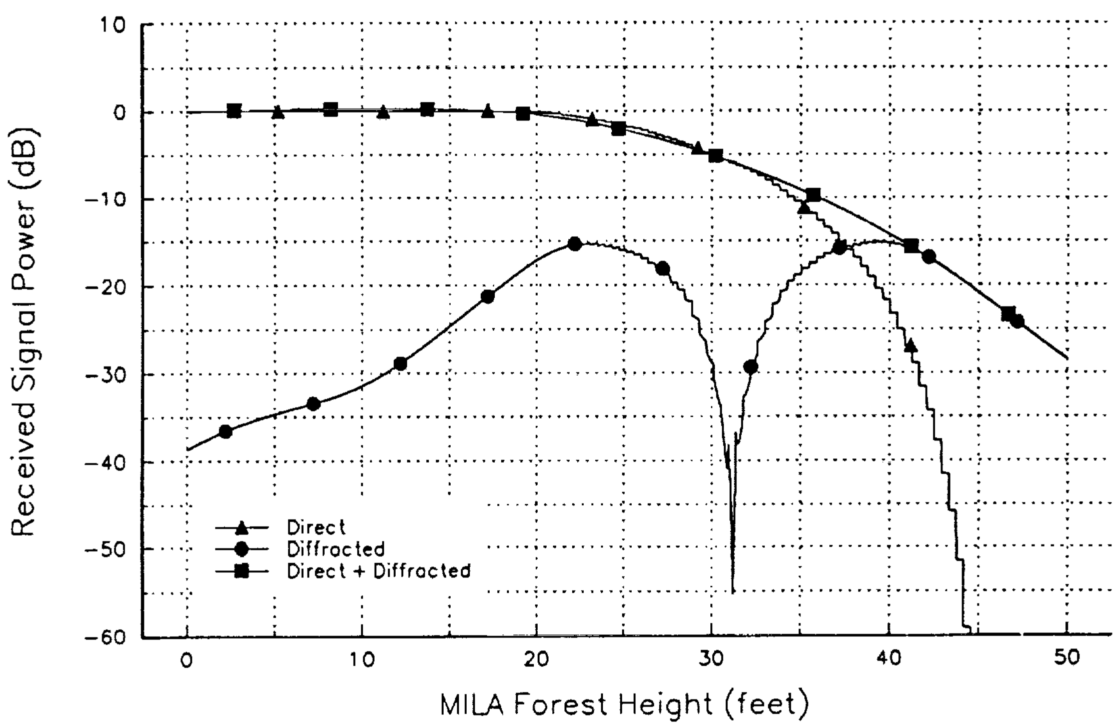

Figure 3 MILA 9-M received power vs. forest height

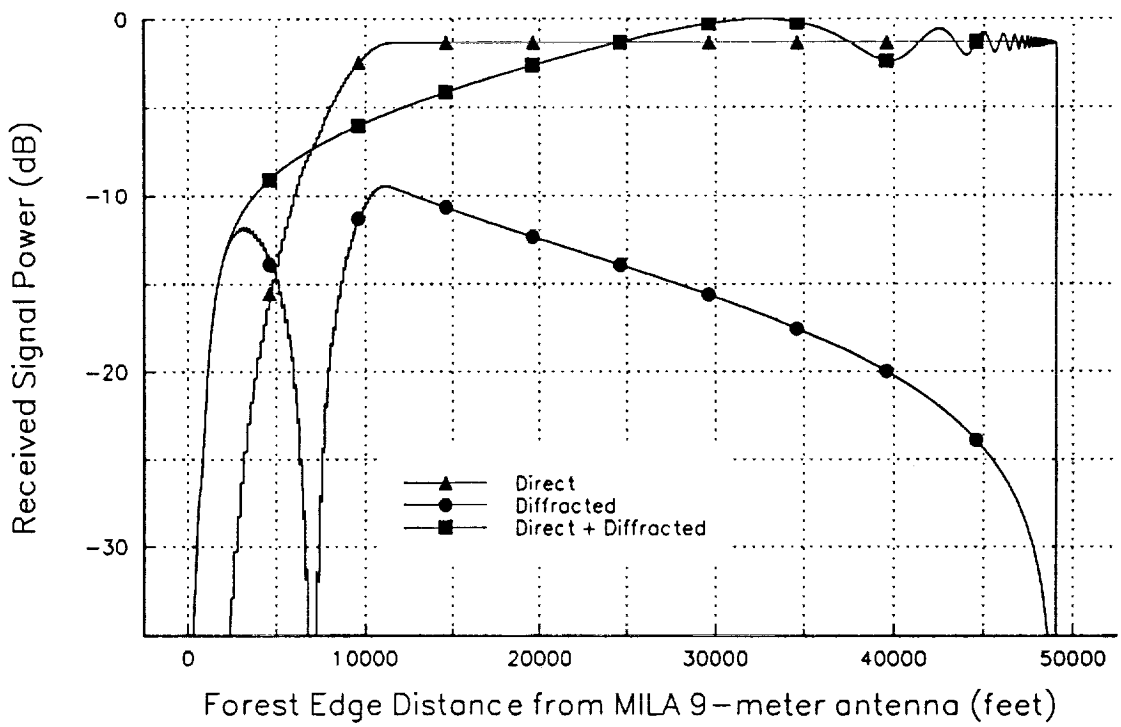

Figure 4 MILA 9-M received power vs. forest edge distance.

the direct signal to match the diffracted signal level. This approach would result in a mile long deforested path.

5.0 Forest Characterization

To apply the model to the MILA forest, the forest height and tree locations are needed. The bulk of the trees are located along the swampy mile-long path between MILA and the VIC. During the MILA link studies, surveyors targeted selected tree-lines and obtained a few height/position measurements.

A technique known as stereoscopic photography is being used to map out the heights and positions of the trees. Photos are taken of the trees from the vantage point of a cherry picker located at MILA. Two pictures, separated 50 to 100 feet, are taken at precisely known locations. The photos are then scanned into a computer. The location of the Vehicle Assembly Building and rockets at the VIC are used as reference objects for the analysis. The tree image position and image shift between the right and left photos is used by a spreadsheet program to calculate the tree's height and position on map.

6.0 Conclusions

The GTD Diffraction Model is a valuable tool for modelling the MILA/Shuttle S-Band RF Link. Tree cutting at MILA is extremely difficult due to strict environmental regulations. The diffraction model is currently being used to evaluate various tree cutting scenarios at MILA. The preferred approach is selective cutting. With the help of the GTD Diffraction Model, the benefits of a potential tree cutting can be evaluated and justified.

7.0 References

[1] W.C. Peng, "CLASS MILA Interference Analysis", NASA/GSFC Technical Report TR-8707-03, 1991.

[2] A. Caroglanian, editor, "MILA/Pad 39 S-Band Shuttle Support Link RF Testing and Launch Monitoring Study Report", NASA/GSFC Technical Memorandum, 1991.

[3] D.Kenney, et al, "Analysis of MILA 9M Antenna to Orbiter S-Band PM Subsystem", ECAC Engineering Memorandum, EM-91-DN-001.

[4] R.F.White, et al, "Engineering Considerations for Microwave Communications Systems", GTE Lenkurt, 1970, p.35.

[5] F.A.Pellerano, "A Study of the Effects of Vegetation on the Performance of S-Band Radio Frequency Links", NASA/GSFC Professional Intern Program Report, May 1991.

[6] S.S. Seker, "Determination of an Electromagnetic Model for Vegetation in Support of the MILA/Shuttle RF Link Study", GWU Technical Report, 1991.

[7] C.A.Balanis, "Advanced Engineering Electromagnetics", Wiley & Sons Publishers, New York, 1989.

[8] D.D.Shama, "MILA Diffraction Model", NASA/GSFC Internal Memorandum, March 1993