Strut Shaping of 34m BeamWaveguide Antenna for Reductions in Near-Field RF and Noise Temperature

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***Abstract*—Struts shaping of the NASA's Deep Space Network (DSN) 34m Beam Waveguide (BWG) antenna has been implemented to reduce near-field RF exposure while improving the antenna noise temperature. Strut shaping was achieved by introducing an RF shield that does not compromise the structural integrity of the existing structure. Reduction in the RF near-field exposure will compensate for the planned transmit power increase of the antenna from 20 kW to 80 kW while satisfying safety requirements for RF exposure. Antenna noise temperature was also improved by as much as 1.5 K for the low elevation angles and 0.5 K in other areas. Both reductions of RF near-field exposure and antenna noise temperature were verified through measurements and agree very well with calculated results.**

Keywords - reflector; struts; shaping; noise temperature; near field; RF exposure

I. INTRODUCTION

The highest power uplink capability in the Deep Space Network (DSN) is the 20kW on the 70 m antennas. In order to backup this capability, an equivalent uplink capability on the 34m BWG antenna is proposed, [1]. As a result, the transmit power must be increased to 80 kW to compensate for the lost antenna directivity of the 34-m aperture relative to 70-m. In order to eliminate the possibility of requiring a larger personnel exclusion zone on the ground near the antennas which will add additional cost and personnel constraints for all DSN 34 m antennas a solution is sought to minimize spurious scattering of the antenna structure in the near zone. In this study, the near field area of interest is on a plane in the vicinity of the antenna ranging from 20 to 300 m away from the antenna aperture.

During the course of this design, we have made sure that all other important antenna performance parameters are unchanged or improved. As an added benefit to minimizing the RF ground illumination levels on transmit, the antenna noise temperature, which is a strong function of ground illumination, is simultaneously reduced if near-field ground exposure is minimized.

In [2], an analysis of the near-field of 34m antenna was presented. Furthermore, a comparison between the calculated and measured near-field intensity of the antenna was made over a survey plan similar to the one shown in Figure 1. Even though near-field signature of the 34 m antenna is computed in [2], different features of the near-field were not associated with various scattering mechanism of the antenna structure.

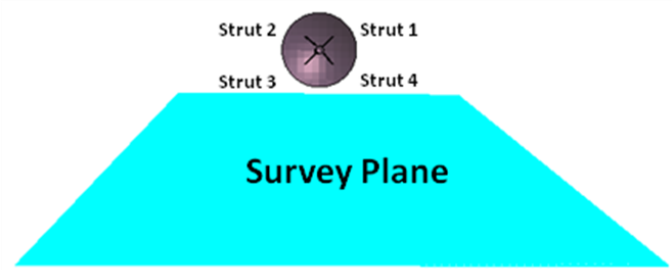

Figure 1: 34 m BWG antenna with respect to the survey plane.

In the first in this study, we explore the important scattering mechanisms and associate them with the ground signature. As a result, we will focus on the structural elements that need to be re-designed, a process which requires reviewing a number of candidates to solve the near-field intensity reduction. Furthermore, the associated antenna noise temperature will also be evaluated to make sure that the proposed design can also improve this important performance parameter.

II. EXISTING STRUT STRUCTURE AND PROPOSED MODIFICATIONS

Figure 2 shows the 34-m BWG subreflector and its structural support including its struts configuration. The strut structures are composed of a pair of beams supported by cross members connecting two beams. Our goal is to leave the structural integrity of the supporting struts intact by introducing RF shields which place the struts completely in their shadow region. Furthermore, the size of RF shield should not reduce the effective radiating area of the antenna aperture due to shadowing.

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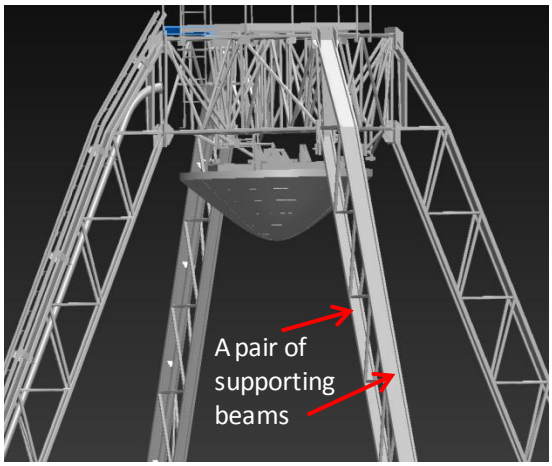

Figure 2: Mechanical drawing of the 34-m BWG subreflector and its associated supporting struts.

III. Scattering Mechanism and Structural Elements

Figure 3 shows the most significant ray contributions in the near field pattern, and Figure 4 shows the corresponding RF ground signature which is calculated using PO/PTD using GRASP [3]. It should be noted that the calculation in Figure 4 is at about 1.5 m above the ground level and reflection from ground is ignored in this calculation. In Figure 3, contribution R1 is from the plane wave from the main reflector which is reflected/diffracted by the struts. The cone shown in Figure 3 is due to contribution of the diffracted rays from the strut edges. Contribution R2 is due to subreflector illumination of the struts and subsequent re-radiation by the main reflector, and contribution R3 is the direct feed spillover contribution. A preliminary analysis shows that when the antenna is at its minimum elevation angle of 10 degrees 1%, 3.2% and 0.002% of the total feed radiation strikes the ground due to R1, R2 and R3, respectively. It can be shown that it is only the top two struts (struts 1 and 2 shown in Figure 1) that are contributing significantly to the ground illumination. In fact, above statement was verified through removing struts 3 and 4 from the calculations. Therefore, the bottom two struts (struts 3 and 4) require no modification, and will remain unchanged in both at the experimental verification of the strut scattering modifications and the final implementation.

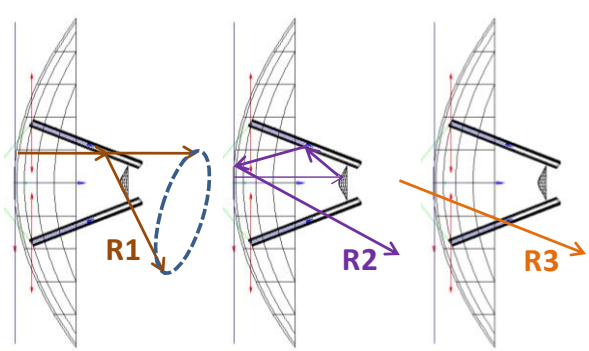

Figure 3: Major contributing rays to near-field ground signature

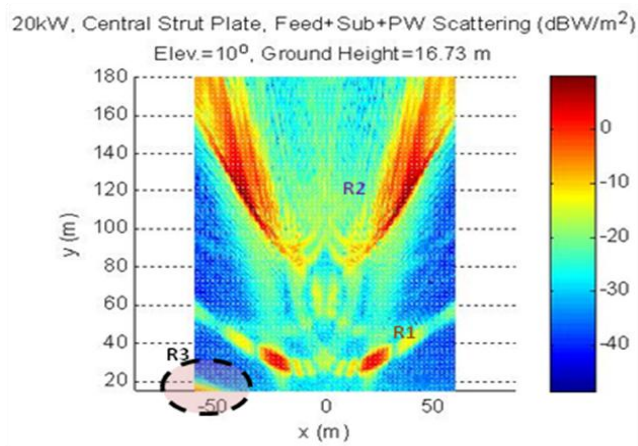

Figure 4: Near-field ground illumination and the associated scattering mechanism defined by R1, R2 and R3.

IV. Analytical and Preliminary Design Considerations

In order to reduce computational effort described in [2], a simplified strut model was employed here, where the two-beam strut was reduced to an equivalent single beam located half way in middle of two beams as shown in Figure 5. It was shown that a single beam reduces the computational complexity involving multiple interactions between beams but still results in a similar near-field behavior as was reported in [2]. In fact, Figure 4 is computed using a simplified RF model and compares well to what is reported in [2].

In Figure 4, the R2 lobes are result from the reflected rays from the subreflector mapping on a narrow strip along the main reflector. Therefore, to smear and diffuse those lobes on the ground, we seek to sweep the strut reflected field over a wider angular range or re-direct them above the horizon if possible. This can be achieved by introducing an RF shield using a 90° wedge or a half cylinder as shown in Figure 6. Either one of these configurations would spread the reflected energy from the struts over a wide angle which lowers the overall intensity on the ground. According to our calculations, a 90° wedge or a half cylinder will reduce the maximum field intensity by nearly 10 dB. This reduction is more than adequate to compensate for the power increase in the DSN operation from 20 kW to 80 kW (~6 dB).

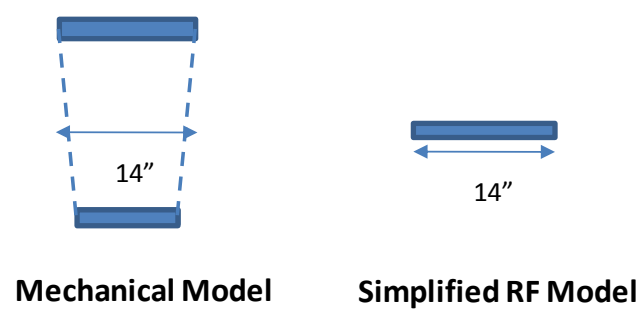

Figure 5: Mechanical strut model vs. a simplified RF model

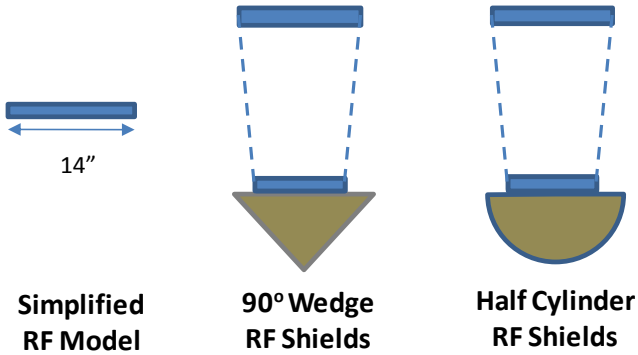

Figure 6: A pictorial representation of RF shields and their placement with respect to the supporting beams

On the other hand, realizing that each side of the 90° wedge in Figure 6 directs the reflected fields into different portion of the reflector, one can decompose the wedge into two edges as seen in Figure 7. Furthermore, the edge angle α can be varied to optimize the overall antenna performance. This was implemented in the final shield design, which is described next.

V. Final Desgin and Performance Verification

The implemented design of the RF shield is shown in Figure 8. A 30° RF shield is used to place the two-beam strut structure in its shadow region. Note that the 30° wedge angle is pointing toward the top of the main reflector. Had the edges been placed the opposite way (that is pointing to the side of the reflector), undesirable high intensity lobes would reappear on the ground due to the particular illumination of the main reflector. Further note that only the upper two struts are covered in this design for the reasons discussed earlier in the paper. The calculated near-field ground signature using a 30° edged RF shield is shown in Figure 9. Comparing to Figure 4, we note that all significant far-out lobes have disappeared. As a result, ground illumination in the region far from the aperture is reduced by more than 15 dB. Furthermore, the total ground scattered power with and without the RF shield is reduced by nearly a factor of 6 promising lowered overall antenna noise temperature.

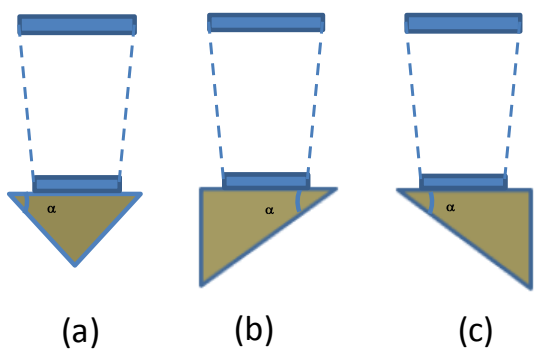

Figure 7: A wedge shaped RF shield (a) covering the two beams of the strut structure and its decomposition into two individual edges of or similar edge angles (b) and (c).

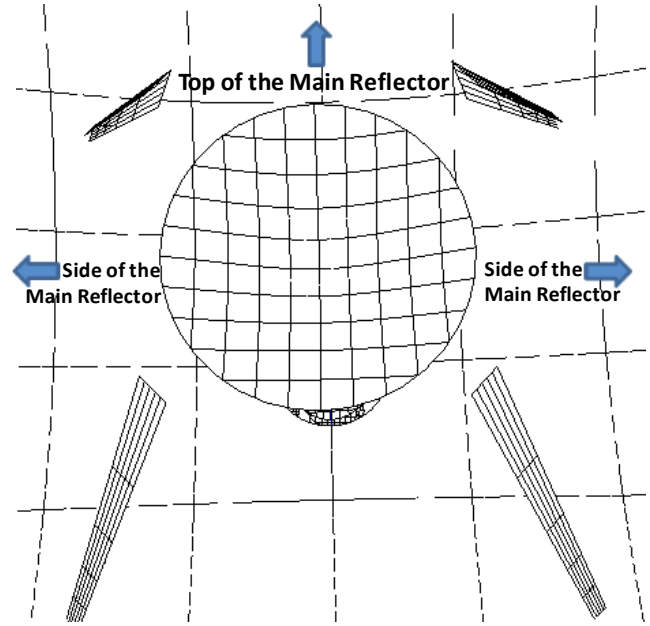

Figure 8: Realized 30° edged RF shields with respect to the subreflector and strut structure.

The RF shields were manufactured from light weight material (0.125” Al) and were installed at DSS-26, a 34m BWG antenna at NASA's Goldstone DSN facility in California. A measurement of ground illumination was taken before and after installation of the 30° RF shields (Figure 10). The measurement was completed using a number of Narda Field Strength Meter NBM-550. The designated area was surveyed in sections by four personnel with probes held approximately 1.5 m above the ground level.

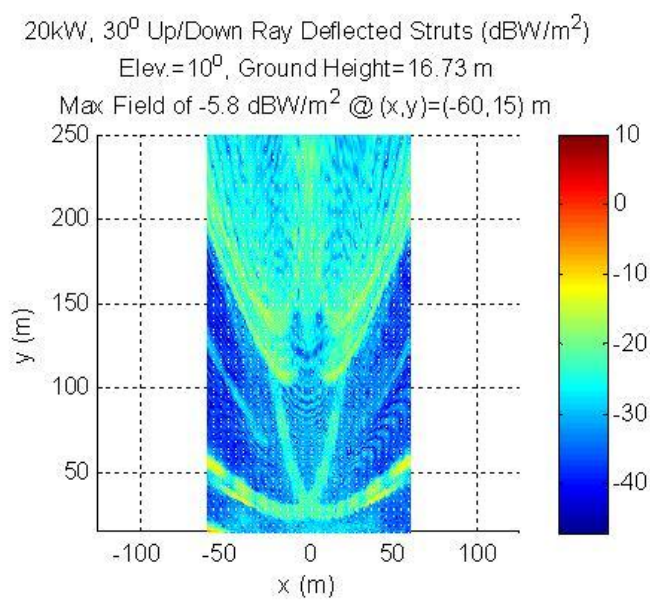

Figure 9: Near-field ground illumination after placing the 30° RF shield

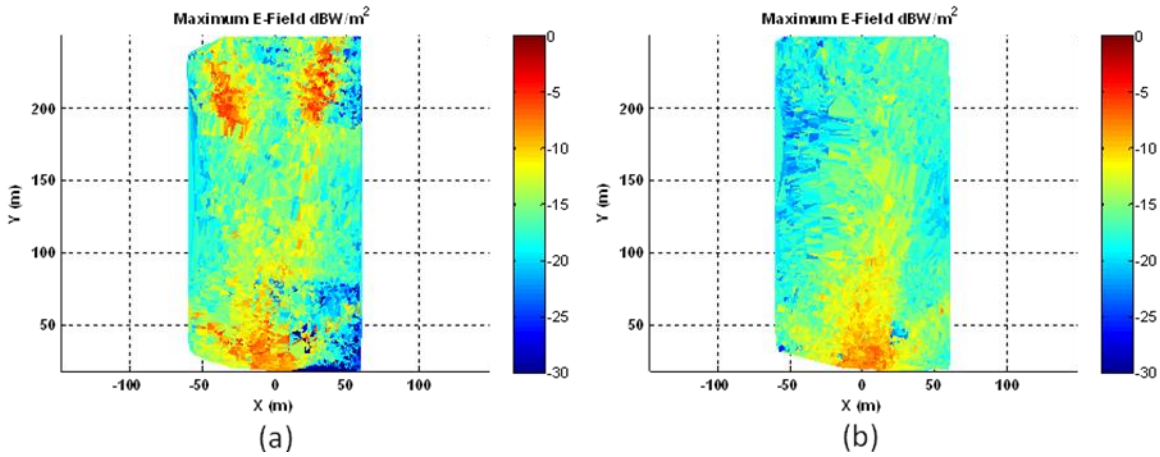

Figure 10: A comparison between near-field ground illumination before (a) and after (b) placing the 30° RF shields.

Measurement after the modification clearly displays the removal of the far-out lobes. Differences between calculated and measured results can be attributed to several factors including uneven ground elevation, field sample/averaging by the meter, and the terrain vegetation not considered in the analysis. Furthermore, the measured pattern corresponds to an actual antenna elevation of 11° plus an additional ground slope of 3° away from the antenna which is the primary factor in the location of far-out lobes visible in Figure 10(a).

To further verify that the strut modification has not degraded the key antenna noise temperature parameter, the antenna noise temperature vs. antenna elevation angle was measured and is displayed in Figure 11. The noise temperature near the design point at low elevation angles (10°-15°) is significantly improved by a much as 1.5K. This is direct verification of the calculation predicting that the ground illumination is reduced by a factor of 6. Furthermore, noise temperature is reduced by more than 0.5 K over the entire range of the elevation angles due to the reduction in strut scattering.

I. Conclusion

The strut structure of the NASA's DSN 34 m BWG antenna was modified by introducing an RF shield that reduces near-field RF exposure while simultaneously improving the antenna noise temperature.

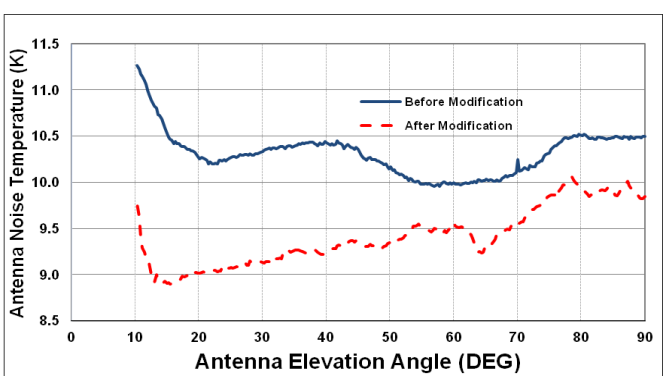

Figure 11: Measurement of noise temperature vs. antenna elevation.

The RF shield is a low-cost solution which maintains the structural integrity of the mechanical support. The RF ground exposure is reduced by nearly 15 dB in the far-out lobes. This is more than adequate to offset for the planned operational transmit power increase of the DSN 34m antenna from 20 kW to 80 kW. Furthermore, the RF shields have reduced the antenna noise temperature between 0.5 K to 1.5 K over the entire range of antenna elevation angles.

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