STRUT CROSS SECTIONS FOR MINIMIZING NOISE TEMPERATURE IN REFLECTOR ANTENNAS

Fernando J. S. Moreira* and Aluizio Prata, Jr.
University of Southern California
Los Angeles, CA 90089-0271

Michael A. Thorburn
Jet Propulsion Laboratory
Pasadena, CA 91109-8099

A. Introduction

Symmetric reflector-antenna systems are widely used in numerous applications such as deep-space links, satellite communications, radio astronomy, radar, etc. In the majority of these applications, the system has either one or two reflectors, and in both cases the antenna entrance aperture is partially obstructed by the feed (single reflector), feed and subreflector (dual reflector), and their respective supporting structures (struts). This blockage decreases the overall antenna gain, increases the side-lobe and cross-polarization levels, and increases the antenna noise temperature. The electrical impact of the struts in the reflector-antenna performance has been investigated by several authors. Although considerably more emphasis has been placed on gain loss and co- and cross-polarization radiation pattern effects [1]–[3], recently several authors have also been specifically concerned with the strut contribution to the antenna noise temperature [4],[5]. Of particular interest is the minimization of the pointing-orientation dependence of the antenna noise temperature, a critical effect in radio-astronomy measurements of the cosmic microwave background radiation [5].

Invoking the reciprocity principle between the antenna receive and transmit modes of operation, it can be shown that, on reception, the noise-temperature contribution of the strut comes from its scattering towards the relative warm ground. This scattering is produced by the quasi-planar wave leaving the main reflector and by the quasi-spherical wave emanating from the subreflector (or feed). For physically-large shaped dual-reflector antennas designed for optimum gain and noise performance, simple ray-tracing considerations indicate that the plane-wave scattering is the dominant strut-noise source. Due to this, only the strut plane-wave scattering is considered here. Also, multiple reflections of energy between the struts and the other reflector-antenna elements are ignored since they constitute second order effects.

The main interest of the present work is in the determination of optimum (i.e., minimum noise) all-metallic strut cross sections, without detriment of their mechanical function. This is accomplished by optimizing the strut cross-section geometry to reduce the plane-wave scattering towards ground. However, with some modifications, the techniques presented below can also be used to reduce the strut noise associated with the spherical wave scattering.

B. Strut Noise Temperature Contribution

The accurate calculation of the strut contribution to the antenna noise temperature is somewhat involved. Here a simplified model is used, accounting only for the plane-wave scattering and assuming a constant cross-section strut. It requires the finite-length strut power scattered towards a given direction, which can be obtained

0-7803-2009-3/94/$4.00 © 1994 IEEE.

recalling that the finite-length strut still radiates, for observation points located not too far from its surface, as an infinite-length one. The infinite-length strut scattering can be determined by standard Method-of-Moments techniques [1]. So, the power ΔP_{st} scattered by the strut inside an azimuthal angular sector of width $\Delta\phi$ is [6]

$$\Delta P_{st}(\phi) \;=\; S^S(\phi)\; L\, \sin\theta_c\; \rho\; \Delta\phi \;=\; \frac{\Delta T(\phi)\; \Delta P_{in}}{T_E(\phi)}, \tag{1}$$

where $S^S(\phi)$ is the infinite-length strut scattered power density, P_{in} is the total power radiated by the antenna, ΔT is the contribution of ΔP_{st} to the antenna noise temperature, T_E is the environmental noise temperature (in Kelvins), and the geometric parameters L, ρ, and θ_c are depicted by Fig. 1. Using Eq. 1 the noise temperature contribution T of a single strut can then be written as

$$T \;=\frac{\rho\, L\, \sin\theta_c}{P_{in}} \int_0^{2\pi} S^S(\phi)\; T_E(\phi)\;\; d\phi. \tag{2}$$

The antenna scattered field is the summation of the strut and reflector contributions and, in general, both of them must be taken into account for determining the antenna noise temperature. Eq. 2 is then acurate only for regions where the reflector scattering is negligible in comparison to the one of the strut.

C. Strut Cross-Section Optimization

The minimization of the strut contribution to the antenna noise temperature is accomplished minimizing the strut scattering towards ground, since ground is the major source of thermal noise. Recalling that the infinite-long strut scattering can be described by a continuum cone of rays, the strut azimuthal directions corresponding to ground illumination can be determined using geometric concepts [6]. A scattering pattern weight W_ϕ (proportional to the corresponding noise contribution) can then be obtained for each one of N_ϕ discrete azimuthal scattering directions ϕ. The determination of these weights takes into account the reflector-antenna elevation-angle range and the relative strut orientation [6].

The next step is the proper representation of the strut cross section for the optimization procedure. This is done by defining N_P points connected sequentially by straight-line sections. These points are specified by their polar coordinates R_i and ϕ_i (Fig. 2). In order to minimize the computational burden, only the R_i coordinates are optimized. Size constraints are imposed by requiring that $R_{MIN} < R_i < R_{MAX}$ (Fig. 2), which indirectly set limits for mechanical strength and cost. Note that each straight-line section is further subdivided into smaller segments, when applying the Method-of-Moments technique. From the requirements mentioned above, a convenient objective function to be minimized is

$$F_{obj} \;=\; \sum_{s=1}^{N_\phi} W_\phi(\phi_s)\; \Big[W_E\; S_E^S(\phi_s) \;+\; W_H\; S_H^S(\phi_s) \Big] + \; W_R \sum_{i=1}^{N_P} F(R_i), \tag{3}$$

where $S_{E,H}^S$ are the infinite-long strut scattered power density for the E- (no magnetic field along the strut axis direction) and H-waves (no electric field along this direction), respectively, W_E and W_H are weights to stress the relevance of a particular wave polarization, $F(R_i)$ is a suitable penalty function for imposing the strut cross-section size constrains, and W_R is its associated weight.

D. Results and Conclusions

To demonstrate the strut optimization technique, a single strut located on the top of a reflector antenna is considered. The angle θ_c between the strut axis and the propagation direction of the quasi-plane wave leaving the main reflector is assumed to be 28.6° (Fig. 1). Geometric considerations indicate that for an inverted-Y reflector-antenna strut geometry, the main contribution to the strut noise temperature comes from the top strut [6], in which case the ground illumination corresponds to its backscattering region ($\phi \approx 270°$). The strut cross section is assumed symmetric about the $x = 0$ plane (Fig. 2), reducing by half the variables to be optimized. The half cross-section contour is represented by 10 straight segments, yielding 11 R_i values for the optimization procedure, which has parameters $W_E = W_H = W_R = 1$, $R_{MIN} = 2.54$ cm, and $R_{MAX} = 7.62$ cm. The optimization has been started with a diamond cross section with principal axis of 5.38 cm and 15.24 cm. The optimized cross section is depicted on Fig. 3, together with the starting diamond shape.

The scattering of infinite-length struts with four different cross-section geometries are shown by Figs. 4 and 5 for the E- and H-wave polarizations, respectively. They are: the optimized cross section, the starting diamond, a rectangle with $\hat{x}$ and $\hat{y}$ sides equal to 1.33 cm and 15.24 cm, respectively, and a circle with diameter 5.08 cm (the rectangle and circle have the same area). The improvement obtained on the antenna noise temperature can be determined using Eq. 2. The ratios between the noise temperatures of the optimized (T_O), diamond (T_D), and rectangular (T_R) cross sections, and the circular cross section (T_C), for several antenna elevation angles θ_o, are shown on Tab. 1. These results show that the optimum cross-section strut has a shape that approximates a diamond. They also indicate that significant noise temperature reduction can be achieved with an optimized strut.

References

[1] W. V. T. Rusch, "Applications of Two-Dimensional Integral-Equation Theory to Reflector-Antenna Analysis," Technical Memorandum 33-478, Jet Propulsion Laboratory, May 1971.

[2] W. V. T. Rusch, O. Sørensen, and J. W. M. Baars, "Radiation Cones from Feed-Support Struts of Symmetric Paraboloidal Antennas," IEEE Trans. Antennas and Propagat., **AP-30**, No. 4, pp. 786–790, July 1982.

[3] P. S. Kildal, E. Olsen, and J. A. Aas, "Losses, Sidelobes, and Cross Polarization Caused by Feed-Support Struts in Reflector Antennas: Design Curves," IEEE Trans. Antennas and Propagat., **36**, No. 2, pp. 182–190, February 1988.

[4] T. L. Landecker, M. D. Anderson, D. Routledge, R. J. Smegal, P. Trikha, and J. F. Vaneldik, "Ground Radiation Scattered from Feed Support Struts: A Significant Source of Noise in Paraboloidal Antennas," Radio Science, **26**, No. 2, pp. 363–373, March 1991.

[5] C. R. Lawrence, T. Herbig, and A. C. S. Readhead, "Reduction of Ground Spillover in the Owens Valley 5.5 m Telescope," accepted for publication in the Proceedings of the IEEE.

[6] F. J. S. Moreira and Aluizio Prata, Jr., "Optimum Strut Cross Sections for Reflector Antenna Applications," Technical Report, Dept. Elect. Engineering, USC, October 1993.

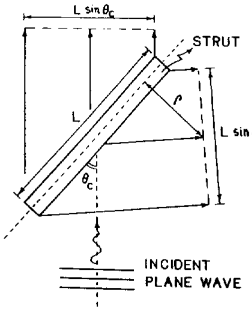

Fig. 1 – Scattering by a finite strut.

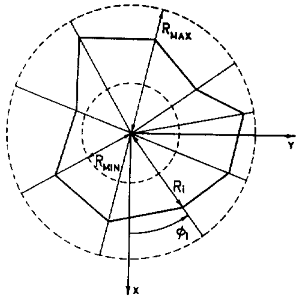

Fig. 2 – Cylindrical coordinate strut cross-section representation.

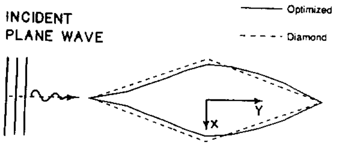

Fig. 3 – Cross section of the optimized strut.

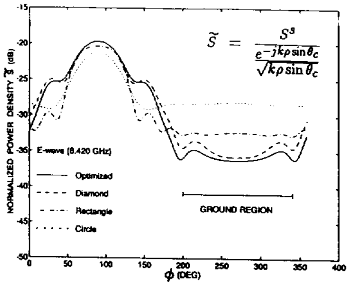

Fig. 4 – E-wave scattering.

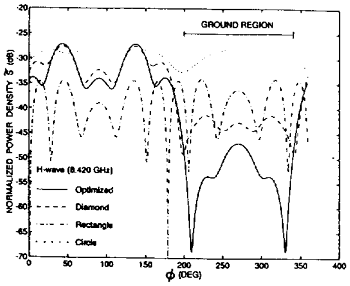

Fig. 5 – H-wave scattering.

Polariz.	θ_o	T_R/T_C	T_D/T_C	T_O/T_C
E-wave	60°	0.39	0.26	0.20
	30°	0.39	0.25	0.19
	10°	0.39	0.26	0.20
H-wave	60°	0.17	0.07	0.04
	30°	0.17	0.06	0.03
	10°	0.17	0.07	0.04

Tab. 1 – Noise-temperature ratios.