Antenna Noise Temperature Contributions Due to Ohmic and Leakage Losses of the DSS 14 64-m Antenna Reflector Surface

T. Y. Otoshi
Communications Elements Research Section

This article presents approximate formulas useful for computing antenna noise temperature contributions due to ohmic and leakage losses of a parabolic antenna reflector surface. The total noise temperature contributions due to ohmic and leakage losses for the DSS 14 64-m antenna were calculated to be 0.1, 0.3, and 0.6 K at 2.295, 8.448, and 15.3 GHz, respectively.

I. Introduction

To reduce wind loading on large ground antennas for deep space communications, the reflector surface is usually perforated. A compromise must be made between porosity and acceptable degradation of RF performance because the amount of RF energy that leaks through the reflector surface is a function of porosity. On the outer 47% radius of the 64-m antenna at DSS 14, perforated panels having 51% porosity and 4.76-mm (3/16 in.)-diameter holes are used as the reflective surface material. The panels are painted with white thermal diffusion paint.

Reflector surface losses that increase antenna noise temperature are (1) ohmic losses of the metal and paint used as the reflective surface material, and (2) leakage loss of RF energy passing through the perforated surface. Most of the energy that leaks through the surface is absorbed by the ground environment. To obtain estimates of the noise contributions from these two types of absorptive losses, approximate formulas have been derived. These are presented in the following section.

II. Theoretical Formulas

For a zenith-oriented parabolic antenna with circular symmetry such as that shown in Fig. 1, the antenna noise temperature is

$$T_A = \frac{\displaystyle\int_0^{2\pi}\int_0^{\pi} T_b\,(\psi,\phi)P(\psi,\phi)\sin\psi d\psi d\phi}{\displaystyle\int_0^{2\pi}\int_0^{\pi} P(\psi,\phi)\sin\psi d\psi d\phi} \tag{1}$$

where

$T_b(\psi,\phi)$ = effective brightness temperature function as defined at the focal point F (Fig. 1), K

$P(\psi,\phi)$ = power per unit solid angle radiated by the feed or apparent feed at focal point F

ψ = polar angle

ϕ = azimuthal angle

For purposes of this study, it is convenient to let Eq. (1) be expressed in terms of contributions from specific sources as

$$T_A = T'_A + (\Delta T_A)_{OL} + (\Delta T_A)_{LL} \tag{2}$$

where

T'_A = total antenna temperature when the reflector surface has no ohmic and leakage losses, K

$(\Delta T_A)_{OL}$ = antenna noise temperature contribution due to reflector surface ohmic losses, K

$(\Delta T_A)_{LL}$ = antenna noise temperature contribution due to reflector surface leakage losses, K

It shall be assumed that the power per unit solid angle as radiated from the focal point is of the form (Ref. 1, Eq. 10, p. 263)

$$P(\psi,\phi) = \frac{1}{2\eta_0}\,[|A_1(\psi)|^2 \sin^2\phi + |B_1(\psi)|^2 \cos^2\phi] \tag{3}$$

where

$|A_1(\psi)|$ = E-plane amplitude pattern

$|B_1(\psi)|$ = H-plane amplitude pattern

η_0 = free space wave impedance

After substitutions of Eq. (3) and the appropriate brightness temperature functions into Eq. (1) and integrations with respect to ϕ, it can be shown that

$$(\Delta T_A)_{OL} \simeq \frac{\left(\dfrac{4R_S}{\eta_0}\right) T_P \displaystyle\int_0^{\psi_E} [1-\alpha(\psi)]\left[p_1(\psi)\sec\frac{\psi}{2} + p_2(\psi)\cos\frac{\psi}{2}\right]\sin\psi d\psi}{\displaystyle\int_0^{\pi} [p_1(\psi)+p_2(\psi)]\sin\psi d\psi} \tag{4}$$

and

$$(\Delta T_A)_{LL} = \frac{\displaystyle\int_{\psi_1}^{\psi_E} T_G(\psi)\,[t_{/\!/}(\psi)\,p_1(\psi) + t_{\perp}(\psi)\,p_2(\psi)]\sin\psi d\psi}{\displaystyle\int_0^{\pi}[p_1(\psi)+p_2(\psi)]\sin\psi d\psi} \tag{5}$$

where $(\Delta T_A)_{OL}$ and $(\Delta T_A)_{LL}$ were defined in Eq. (2) and

$$p_1(\psi) = \left|\frac{A_1(\psi)}{A_1(0)}\right|^2$$

$$p_2(\psi) = \left|\frac{B_1(\psi)}{A_1(0)}\right|^2$$

T_P = physical temperature of the reflector surface, K

R_S = surface resistivity of the reflector surface material, ohms/square. It is a function of frequency and electrical conductivity (Ref. 2).

$\alpha(\psi)$ = porosity of the reflector surface, ratio

$T_G(\psi)$ = effective ground noise temperature function (Ref. 3, Eq. 21, p. 210)

$t_{/\!/}(\psi)$ = leakage power loss ratio for an incident wave polarized with the E-field in the plane of incidence

$t_{\perp}(\psi)$ = leakage power loss ratio for an incident wave polarized with the E-field normal to the plane of incidence

ψ_1, ψ_E = polar angles defining boundaries of the solid and perforated reflector surface regions, respectively (Fig. 1)

For example, $\psi_1 = 34.8°$ and $\psi_E = 61.1°$ for the 64-m antenna and

$\alpha(\psi) = 0$ in the region $0 \le \psi \le 34.8°$

$\alpha(\psi) = 0.51$ in the region $34.8° < \psi \le 61.1°$

Referring to the geometry of Fig. 1, for a parabolic antenna whose surface is perforated periodically with circular holes (Ref. 4),

$$t_{/\!/}(\psi) \approx \left[\frac{8}{3}\frac{d}{\lambda_0}\alpha(\psi)\sec\frac{\psi}{2}\right]^2 \exp\left(-\frac{4\pi t}{1.706d}\right) \tag{6}$$

$$t_{\perp}(\psi) \approx \left[\frac{8}{3}\frac{d}{\lambda_0}\alpha(\psi)\cos\frac{\psi}{2}\right]^2 \exp\left(-\frac{4\pi t}{1.706d}\right) \qquad (7)$$

where d is the hole diameter, λ_0 is the free space wavelength, and t is the thickness of the metallic perforated surface material.

III. Numerical Results

Table 1 is a summary of computations of Eqs. (4) and (5) for the reflector surface of the 64-m antenna at DSS 14. For these computations, it was assumed that $p_1(\psi)$ and $p_2(\psi)$ are identical power patterns. This assumption is valid for the circularly polarized wave case or is approximately valid for the case where a dual-mode horn is the primary Cassegrainian feed operating in a linearly polarized mode. Numerical integrations were performed through the use of a computer program written by T. Cullen. The necessary illumination power pattern data for the 64-m antenna main reflector surface at various microwave frequencies was furnished by the Antenna and Propagation Group of the Communications Elements Research Section.

For the data in Table 1, it was assumed that the reflector surface is aluminum (1.75×10^7 mhos/m electrical conductivity) and is painted with 0.05-mm (0.002-in.)-thick VITA-VAR No. 15966 white thermal diffusion paint. The total electrical conductivity of the painted aluminum surface was reported to be 0.461×10^7 mhos/m (Ref. 5). Porosity, hole size, and plate-thickness data on the perforated surface material are given in Ref. 6. Additional parameters assumed were a reflector surface physical temperature of 283 K; a ground surface air temperature of 10°C (50°F); relative humidity of 60%; and ground electrical dielectric constant and electrical conductivity equal to 3.0 and 0.01 mhos/m, respectively.

Based on the described operating conditions, the total additional noise contributions to antenna temperature due to ohmic and leakage losses of the 64-m reflector surface are computed to be 0.1, 0.3, and 0.6 K at 2.295, 8.448, and 15.3 GHz, respectively. Due to increasing inaccuracies of Eqs. (6) and (7) as d/λ_0 approaches unity, the noise temperature computed for 15.3 GHz could be too low by as much as 0.4 K.

IV. Conclusions

Formulas have been presented for purposes of calculating noise temperature contributions due to RF porosity and metallic surface resistivity. The formulas are approximate but should prove useful for studying the effect of paint on the reflector surface or the effect of using a lossy metal, such as stainless steel, for the reflector surface material.

References

1. Otoshi, T., and Stelzried, C. T., "Antenna Temperature Analysis," in *Supporting Research and Advanced Development*, Space Programs Summary 37-36, Vol. IV, pp. 262–267. Jet Propulsion Laboratory, Pasadena, Calif., Dec. 31, 1965.
2. Ramo, S., and Whinnery, J. R., *Field and Waves in Modern Radio*. John Wiley & Sons, Inc., New York, 1953.
3. Otoshi, T., "Antenna Temperature Analysis," in *Supporting Research and Advanced Development*, Space Programs Summary 37-37, Vol. IV, pp. 207–210. Jet Propulsion Laboratory, Pasadena, Calif., Feb. 28, 1966.
4. Otoshi, T. Y., "A Study of Microwave Transmission Through Perforated Flat Plates," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. II, pp. 80–85. Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1971.

References (contd)

5. Pon, C. Y., "Final Report on Transmission Through Perforated Reflectors and Loss Due to Paint for the AAS/DSIF Program," *Dalmo Victor Report*. Dalmo Victor Company, Belmont, Calif., Dec. 28, 1961.

6. Otoshi, T. Y., and Lyon, R. B., "Improved RF Calibration Techniques: A Study of the RF Properties of the 210-ft-diam Antenna Mesh Material," in *The Deep Space Network*, Space Programs Summary 37-66, Vol. II, pp. 52–57. Jet Propulsion Laboratory, Pasadena, Calif., Nov. 30, 1970.

Table 1. Summary of zenith antenna noise temperature contributions due to ohmic and leakage losses for 64-m antenna

Frequency, GHz	Solid portion,[a] K		Perforated portion,[b] K			Total, K
	Aluminum ohmic loss	Additional paint ohmic loss	Aluminum ohmic loss	Additional paint ohmic loss	Leakage and ground absorption	
2.295	0.033	0.032	0.015	0.014	0.008	0.102
8.448	0.063	0.060	0.029	0.027	0.113	0.292
15.3	0.085	0.080	0.037	0.036	0.374[c]	0.612

[a]Solid portion $0 \leq \psi \leq 34.8°$.

[b]Perforated portion $34.8° < \psi \leq 61.1°$.

[c]Could be factor of 2 too small due to increasing inaccuracy of Eqs. (6) and (7) when hole diameter is not small compared to wavelength.

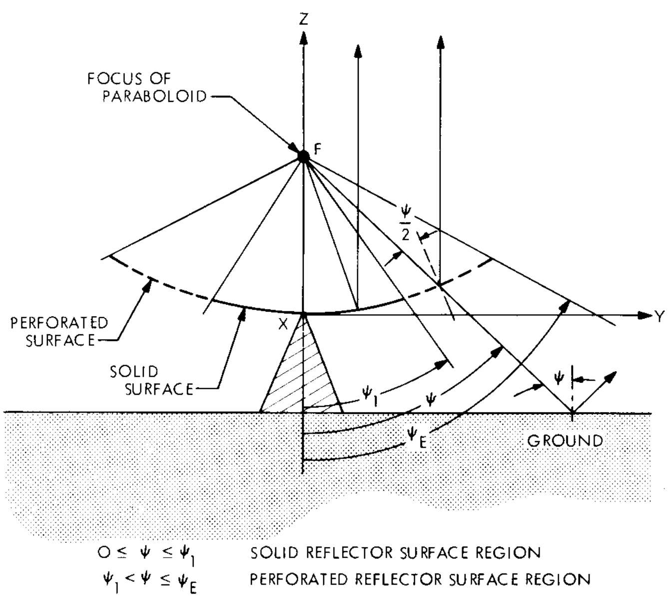

Fig. 1. Two-dimensional geometry of zenith-oriented parabolic antenna with feed (or apparent feed) located at the focal point