Further Studies of Microwave Transmission Through Perforated Flat Plates

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This article presents approximate formulas useful for predicting transmission loss characteristics of a circular hole array in a metallic flat plate having finite thickness. The formulas apply to perpendicular and parallel polarizations of an obliquely incident plane wave. The approximate formulas are experimentally verified by free space measurements made on a sample of the mesh material used on the 64-m antenna at DSS 14.

I. Introduction

Metallic plates having small round perforations are useful as reflective surface materials for spacecraft and ground antennas. Previous analytical work on mesh materials fabricated from flat aluminum plates having small round perforations has been reported in Ref. 1. The approximate formula given in Ref. 1 is useful for predicting transmission through a perforated plate of finite thickness when the incident plane wave is perpendicularly polarized (E-field is perpendicular to the plane of incidence).

To the authors' knowledge, there does not appear to be published information (theoretical or experimental) concerning the parallel polarization case behavior of perforated plates that are useful as reflector surface materials. To enable prediction of loss for the parallel polarization case, an approximate formula is presented in this article. Numerical values of transmission loss calculated from approximate formulas are compared to experimental values and also to numerical values obtained from more exact analytical methods.

II. Approximate Transmission Loss Formulas

For circular hole arrays having the geometry of Fig. 1 and an incident plane wave with the E-field polarized normal to the plane of the incidence (Fig. 2), the approximate expression for transmission loss is derived in Ref. 1 as

$$(T_{\mathrm{dB}})_{\perp} = 10 \log_{10} \left[1 + \left(\frac{3ab\lambda_0}{2\pi d^3 \cos\theta_i} \right)^2 \right] + \frac{32t}{d} \qquad (1)$$

where $a, b, d << \lambda_0$. The parameters a and b are the spacings between holes as shown in Fig. 1, d is the hole diameter, λ_0 is the free space wavelength, t is the plate thickness, and θ_i is the incidence angle.

Analysis of Eq. (1) will reveal that the perpendicular polarization transmission loss behavior of a circular hole array as a function of incidence angle is very similar to that of a two-dimensional thin conducting sheet in free space. Assuming that the circular hole array behaves in the same way as a thin conducting sheet for the parallel polarization case, then

$$(T_{\mathrm{dB}})_{//} = 10\log_{10}\left[1 + \left(\frac{3ab\lambda_0 \cos\theta_i}{2\pi d^3}\right)^2\right] + \frac{32t}{d} \tag{2}$$

where $a, b, d << \lambda_0$.

When incidence angles are small and when

$$\frac{3ab\lambda_0}{2\pi d^3} >> 1$$

then Eqs. (1) and (2) simplify even further to

$$(T_{\mathrm{dB}})_{\perp} \approx 20\log_{10}\left(\frac{3ab\lambda_0}{2\pi d^3}\right) + \frac{32t}{d} + 20\log_{10}\left(\frac{1}{\cos\theta_i}\right) \tag{3}$$

$$(T_{\mathrm{dB}})_{//} \approx 20\log_{10}\left(\frac{3ab\lambda_0}{2\pi d^3}\right) + \frac{32t}{d} - 20\log_{10}\left(\frac{1}{\cos\theta_i}\right) \tag{4}$$

It can be seen from Eqs. (3) and (4) that the transmission losses of the two polarization cases at an incidence angle of 30 deg will differ by about 2.5 dB. It should be emphasized that the formulas given by Eqs. (1)–(4) are only approximate and apply only for $a, b, d << \lambda_0$. When the hole diameter d becomes comparable to free space wavelength, then the corrections given in Ref. 2 should be applied.

III. Experimental Verification

For experimental verification of Eqs. (1) and (2), tests were conducted on a perforated plate sample having the same mechanical and electrical properties as the mesh used as the reflector surface on the outer 47% radius of the 64-m antenna at DSS 14. This mesh is characterized by a 60-deg hole pattern (Fig. 1):

$a = 6.35$ mm (¼ in.)

$d = 4.76$ mm (³⁄₁₆ in.)

$t = 2.29$ mm (0.090 in.)

Previous transmission loss tests on this mesh material were made by a TE_{10} waveguide method (Ref. 3). The TE_{10} waveguide method simulates the free space situation of an obliquely incident plane wave impinging upon an infinitely large sample of the mesh (see Fig. 2). However, simulation of free space measurements by the waveguide method is restricted to perpendicular polarization (E-field is normal to plane of incidence) and an incidence angle which is governed by the operating test frequency and the waveguide cutoff frequency.

Actual free space measurements are required to obtain experimental data for the parallel polarization case. The free space test setup that was employed may be seen in Fig. 3. The disadvantages of a free space setup are diffraction and multipath effects, and also the need for a large test sample. It is difficult to keep a large test sample mechanically flat over its entire surface. Multipath effects were reduced to about ± 0.1 dB by careful placement of absorbers (see Fig. 3) and by averaging the readings obtained when the receiving horn was moved along a rail.

The free space transmission measurements were made on the 64-m antenna mesh test sample with the hole patterns oriented so that the incidence plane was located at $\phi = 0$ deg (see Fig. 2). Experimental and theoretical values are shown in Fig. 4. Experimental values at 8.448 GHz were obtained through the use of a Hewlett-Packard 8410A Network Analyzer and Recorder System. The accuracy of the experimental values are estimated to be ± 0.5 dB. It can be seen that reasonably good agreement was obtained between experimental values and approximate theoretical values from Eqs. (1) and (2). Most of the disagreement between theory and experiment is attributed to rounded edges of the holes in the test sample formed during the hole punching process.

For additional verification, numerical values obtained by a more accurate theoretical method utilized by C. C. Chen (personal communication) are presented in Fig. 4. It can be seen that for the perpendicular polarization case, the numerical values calculated from approximate formulas and the computer solution values obtained from Chen are in excellent agreement (within 0.1 dB) for incidence angles up to 80 deg. For the parallel polarization case, the theoretical values deviate by about 1 to 2 dB at incidence angles larger than 40 deg. Chen's computer results also verified that the perpendicular and parallel polarization transmission losses for the 64-m antenna mesh material are independent of incidence plane angle ϕ (see Fig. 2) when the operating frequency is far below the cutoff frequency of the circular aperture.

Chen formulated the boundary value problem for the perforated plate in terms of Floquet and orthonormal mode functions and then numerically solved the problem by use of the method of moments and a digital computer (Ref. 4). Because Chen solves the perforated plate problem by rigorous analytical methods, his analyses apply to a large class of perforated plate problems and are not restricted to operating frequencies far below the cutoff frequency of the circular apertures. However, solution of Chen's equations requires the use of a computer program that has not been made available for general use. The approximate formulas presented in this article are amenable to desk calculator computations, and for highly reflective meshes the formulas are believed to be sufficiently accurate for obtaining numerical estimates of transmission loss.

IV. Conclusions

Good agreement was obtained between experimental and calculated values for transmission losses of the perforated plate used as the reflective surface material on the 64-m antenna. It appears that for highly reflective metallic perforated plates with transmission losses greater than 20 dB, the transmission losses for perpendicular and parallel polarizations can be predicted by approximate formulas to accuracies of about 0.2 dB and 2 dB, respectively, when the angles of incidence are less than 80 deg.

References

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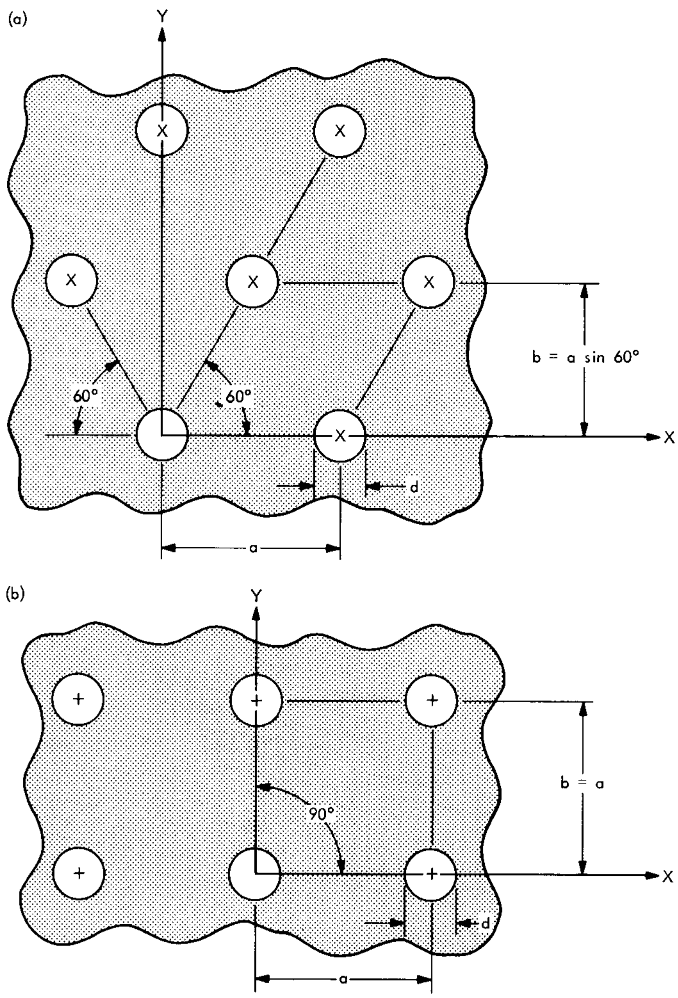

Fig. 1. Geometry for two-dimensional array of holes in a metallic flat plate having (a) 60-deg (staggered) and (b) 90-deg (square) hole pattern configurations

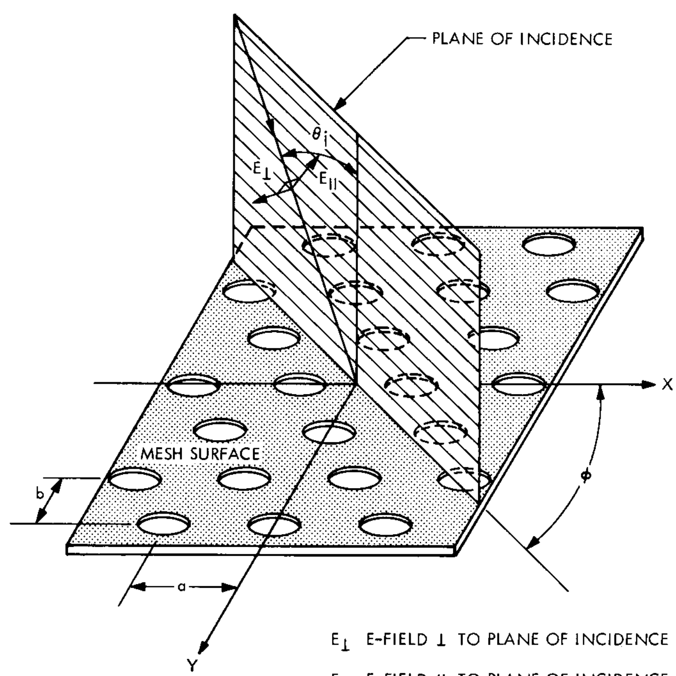

Fig. 2. Geometry of perpendicular and parallel polarizations of a plane wave incident on a perforated plate mesh sample

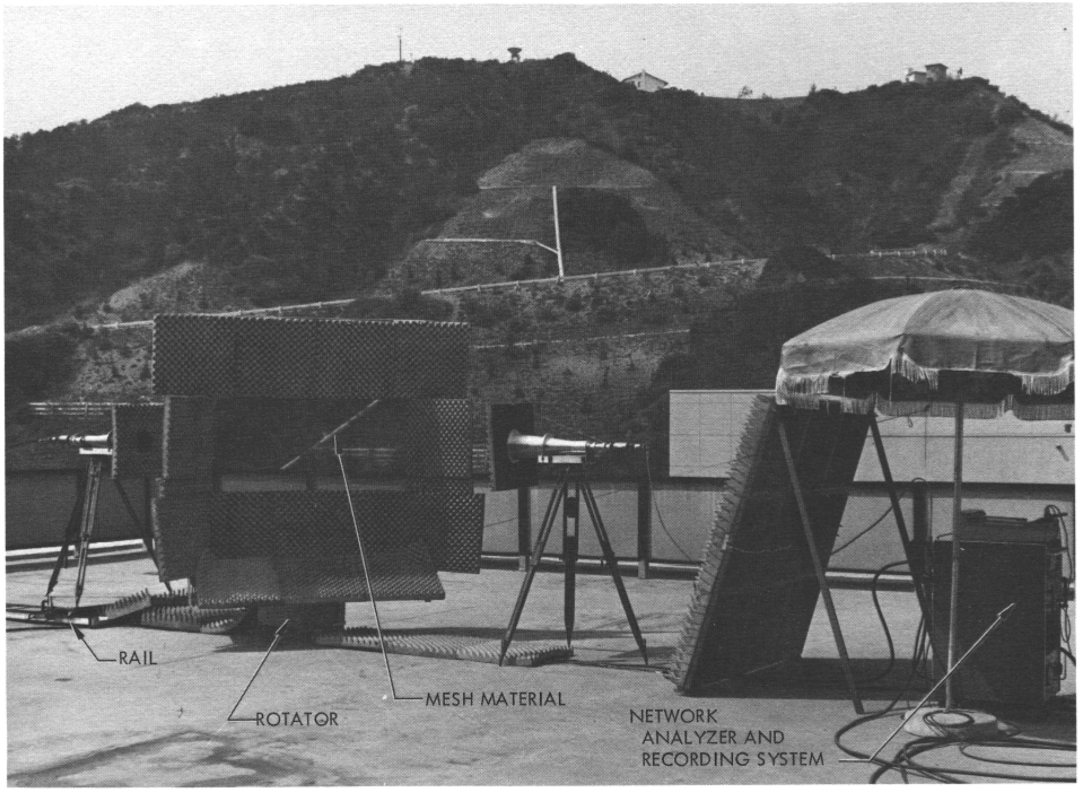

Fig. 3. Free space test setup for transmission loss measurements at 45-deg incidence angle

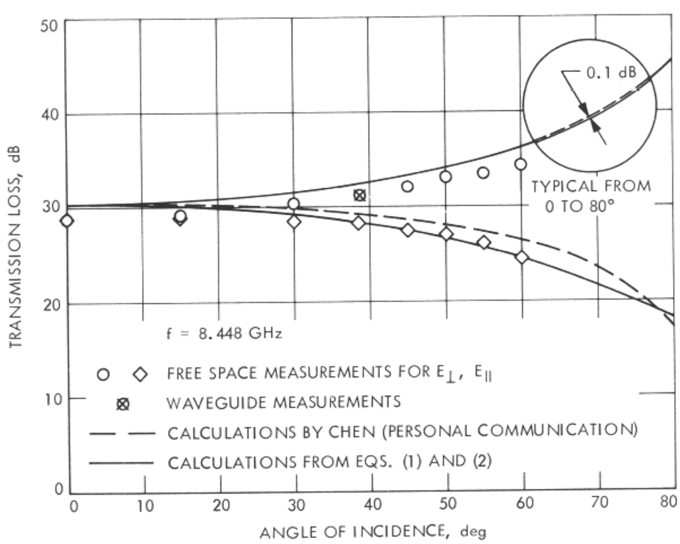

Fig. 4. Transmission losses of flat aluminum plate having same physical properties as mesh on 64-m antenna