A Study of Microwave Transmission Through Perforated Flat Plates

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This article presents a simple formula and graph useful for predicting the transmission loss of a circular hole array in a metallic flat plate having either a 60- (staggered) or 90-deg (square) hole pattern. The formula is restricted to the case of an obliquely incident plane wave with the E-field polarized normal to the plane of incidence. The theoretical formula was experimentally verified by testing samples having hole diameters varying from 1.6 to 12.7 mm, porosities varying from 10 to 51%, and plate thicknesses varying from 0.08 to 2.3 mm. The agreement between theory and experiment was typically better than 1 dB at S-band and 2 dB at X-band.

I. Introduction

To those involved with the development of low-noise antennas for deep-space communications and radio astronomy, the subject of leakage through antenna mesh materials is of great interest. This subject is also of interest to those concerned with microwave radiation hazards due to leakage through various types of mesh materials. Meshes have many applications; some examples are reflective surfaces on antennas, Fabry–Perot interferometers, microwave oven doors, RF screen rooms, and RF protective garments.

Meshes are usually of two types: (1) meshes formed by wire grids, and (2) meshes formed by round holes in a flat metallic plate. A significant amount of experimental and theoretical work has been done on the study of microwave transmission properties of wire grid-type meshes (Refs. 1–5). Using existing experimental data, Mumford (Ref. 4) has derived an empirical formula and nomograph for predicting transmission through wire grid meshes at normal incidence. To this author's knowledge, a similar type summary of experimental results has not been made for transmission through flat plate meshes having round hole perforations. It is the purpose of this article to present a simple theoretical formula applicable to perforated flat plates. This formula is verified by experimental data obtained by both free-space and waveguide measurement techniques.

II. Theoretical Formula and Graph

For the case of a normally incident plane wave, an array of small holes in a metallic sheet behaves as an inductive susceptance in shunt with a TEM (transverse electromagnetic) transmission line. The normalized susceptance of this array is given as (Ref. 6)

$$\frac{B}{Y_0} = \frac{3ab\lambda_0}{\pi d^3} \qquad (1)$$

where

a,b = spacings between holes (see Fig. 1)

d = hole diameter

λ_0 = free-space wavelength

Equation (1) is valid when the hole diameter is small compared to the hole spacings a and b. For the case where a and b approaches d, the corrections described in Ref. 6 can be applied.

Generalizing Eq. (1) to the case of an obliquely incident plane wave with the E-field polarized normal to the plane of incidence and also accounting for the effect of plate thickness, the approximate expression for transmission loss is

$$T_{\text{dB}} = 10 \log_{10}\left[1 + \frac{1}{4}\left(\frac{3ab\lambda_0}{\pi d^3 \cos\theta_i}\right)^2\right] + \frac{32t}{d} \qquad (2)$$

where

θ_i = angle of incidence

t = plate thickness

and $d,a,b \ll \lambda_0$.

The last term of Eq. (2) is the plate thickness correction term given by Marcuvitz (Ref. 7) and was derived by treating the small hole as a circular waveguide beyond cutoff. It should be pointed out that Marcuvitz's transmission loss equation (Ref. 7) for a thick circular aperture in rectangular waveguide and Eq. (2), above, for the array of small holes give results that differ by about 5 dB.

The percent porosity of a mesh is usually known or can be easily calculated for a 60- or 90-deg hole pattern from the expression

$$P_{\%} = \left(\frac{\pi d^2}{4ab}\right)(100) \qquad (3)$$

where a and b are the dimensions shown in Fig. 1. Substitution of Eq. (3) into Eq. (2) results in an equation from which a general plot of the type given in Fig. 2 can be made. The curves in Fig. 2 are useful for predicting transmission loss of meshes having either the 60- or 90-deg hole pattern, but are valid only for the case where the E-field is normal to the plane of incidence. Using the mesh on the DSS 14 64-m (210-ft) antenna as an example, at 2295 MHz and 30-deg angle of incidence, the following values are applicable:

$$P_{\%} = 51.0$$

$$\frac{d}{\lambda_0} = 0.0365$$

$$\cos\theta_i = 0.866$$

$$\frac{t}{d} = 0.480$$

Then the intersection of $x = 51\ (0.0365)\ (0.866) = 1.61$ and $t/d = 0.48$ on the graph gives a transmission loss of 43 dB. An estimate of the contribution to zenith antenna

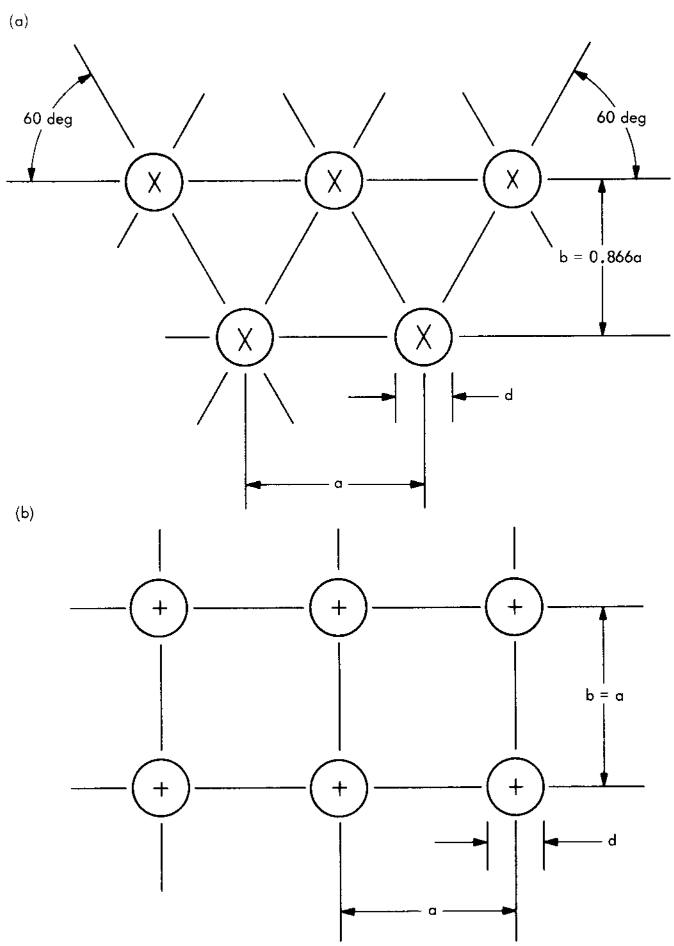

Fig. 1. Hole pattern configurations: (a) 60 deg (staggered) and (b) 90 deg (square)

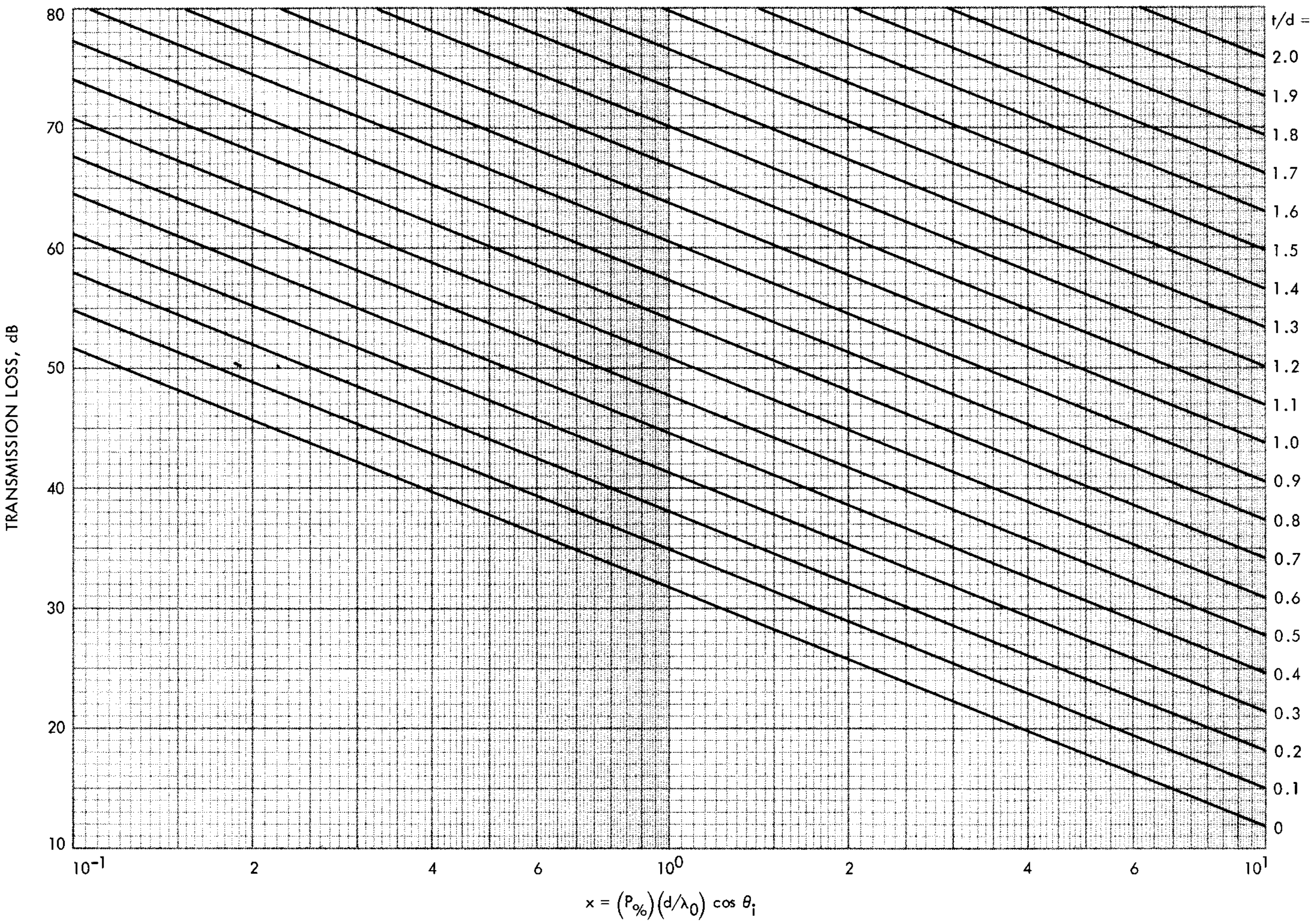

Fig. 2. Transmission loss curves for perforated flat plates having 60- or 90-deg hole pattern (E-field normal to plane of incidence)

noise temperature due to leakage through this mesh would be 0.06 K.

III. Experimental Verification

Table 1 is a summary of experimental results obtained by waveguide and free-space measurement techniques. The mesh test samples were made from flat aluminum plates having 60- and 90-deg hole patterns, hole diameters varying from 1.6 to 12.7 mm, porosities varying from 10 to 51%, and plate thicknesses varying from 0.08 to 2.3 mm.

Waveguide measurements were performed by JPL[1] using a network analyzer and techniques described in Ref. 8. Test samples previously described in Ref. 9 were remeasured. Some of these samples are shown in Fig. 3. The accuracy of the waveguide measurements is estimated to be ±0.5 dB.

For additional verification, free-space measurement data from a Dalmo Victor Co. report (Ref. 10) are included. The estimated accuracy of the free-space measurements was stated to be about ±0.5 dB.

Theoretical values for Table 1 were calculated through the use of Eq. (2). It can be seen that the agreement between theoretical and experimental results is typically better than 1 dB at S-band and 2 dB at X-band. Some of the deviations at X-band are attributed to increasing inaccuracy of the waveguide method when the number of basic cells in the waveguide sample becomes small and the sample is not imaged to the waveguide walls.

[1]Measurements were performed by R. B. Lyon of the JPL Communications Elements Research Section.

Table 1. Comparison of experimental and theoretical transmission data for flat perforated plates with round holes

Test frequency, MHz	θ_i, deg	Hole pattern, deg	$\frac{d}{\lambda_0}$	Approximate porosity, %	$\frac{t}{d}$	Theoretical transmission,[a] dB	Measured minus theoretical transmission, dB	Comments
2300	0	60	0.04	10.0	0.345	50.3	−2.3	Dalmo Victor data (Ref. 10)
			0.04	22.6	0.345	43.3	−2.5	
			0.07	10.0	0.197	40.8	0	
			0.07	22.6	0.197	33.8	−0.5	
			0.10	10.0	0.138	35.8	−0.9	
			0.10	22.6	0.138	28.8	−1.0	
2388	35.1	60	0.025	30	0.400	48.3	−0.4	
			0.025	33	0.632	54.9	0.1	
			0.025	40	0.496	48.9	−0.8	
			0.025	50	0.632	51.5	−0.8	
			0.038	51	0.085	30.2	−0.9	
			0.038	51	0.480	42.9	−0.7	DSS 14 64-m antenna
			0.051	25	0.316	41.3	−0.4	
			0.051	50	0.316	35.4	−0.5	
			0.076	25	0.211	34.4	−0.5	
			0.076	50	0.211	28.4	−0.1	
			0.076	51	0.227	28.8	0	
			0.101	25	0.158	30.6	−1.3	
			0.101	50	0.158	24.3	−1.0	
2388	35.1	90	0.025	25	0.632	57.5	0.7	
			0.025	50	0.632	51.4	−1.2	
			0.051	25	0.316	41.3	1.0	
			0.051	50	0.316	35.3	0.1	
			0.076	25	0.211	34.5	−0.5	
			0.076	47.3	0.211	28.9	0.4	
			0.101	25	0.158	30.3	−1.3	
			0.101	50	0.158	24.3	−1.1	
8448	38.5	60	0.045	50	0.048	28.1	2.8	
			0.045	50	0.256	34.8	2.8	
			0.089	30	0.400	37.7	−1.7	
			0.089	40	0.496	38.3	−1.0	
			0.134	51	0.085	19.7	−2.0	
			0.134	51	0.480	32.3	−1.3	DSS 14 64-m antenna

[a]Based on precise values of hole diameter and spacings.

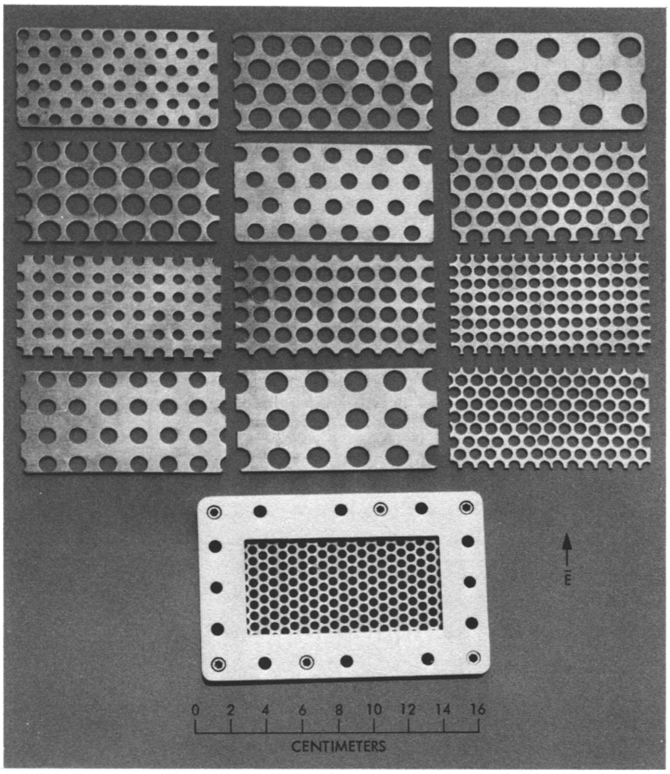

Fig. 3. WR 430 test samples and test sample holder

The waveguide test samples for the data in Table 1 were cut so that the hole pattern would be oriented with respect to the E-field as indicated in Fig. 3. Tests on some samples at other orientation angles showed that for practical purposes, the transmission loss is independent of the orientation angle (see Ref. 8, p. 56).

It should be re-emphasized that the data presented in this article are applicable to the free-space configuration where the E-field is polarized perpendicular to the plane of incidence. At present, there does not appear to be published experimental or theoretical data on the transmission loss of perforated plates for the parallel polarization case. Based strictly on an equivalent plane sheet theory, however, one would not expect the transmission losses of the perforated plates for the two polarization cases to differ by more than 3 dB when the angles of incidences are less than 30 deg.

IV. Conclusions

Good agreement has been obtained between experimental and theoretical values for transmission losses of perforated flat plates having various hole diameters, porosities, and plate thicknesses. The theoretical formula is restricted to the case of an obliquely incident plane wave where the E-field is polarized normal to the plane of incidence. Even with this stated restriction, the formula and curves presented in this article are useful for predicting leakage through antenna surfaces and RF shields.

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