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A Study of Microwave Leakage Through Perforated Flat Plates

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Abstract—**A simple formula useful for predicting leakage through a circular hole array in a metallic flat plate is presented. A correction is given for plate thickness. The formula is applicable to arrays having either a 60° (staggered) or 90° (square) hole pattern, but is restricted to the case of 1) an obliquely incident plane wave with the E field polarized normal to the plane of incidence, and 2) large transmission loss. When theoretical values were compared to experimental data obtained on test samples having transmission losses greater than 20 dB, the agreement between theory and experiment was typically better than 1 dB at S band and 2 dB at X band.**

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 microwave reflectivity and transmission properties of wire grid type meshes [1]–[6]. Kaplun *et al.* [2] and Mumford [4] present curves useful for predicting transmission through wire grid meshes at normal incidence. To this author's knowledge, similar types of curves are not available for predicting transmission through flat plate meshes having round hole perforations. Theoretical work has been done by Chen [7] on the general problem of reflection and transmission properties of a thin conducting sheet perforated periodically with circular holes. His treatment applies to a general case of arbitrary incidence and polarization, but is mainly intended to be useful for investigating behavior in the resonance region where transmission losses are small.

It is the purpose of this correspondence to present a simple theoretical formula that can be useful for predicting transmission through circular hole arrays when the transmission losses are high (10 dB or greater). A correction is included for plate thickness. This formula is verified by experimental data obtained by both waveguide and free-space measurement techniques.

Theoretical Formula

For the case of a normally incident plane wave, an array of small holes in a thin metallic sheet behaves as an inductive susceptance in shunt with a TEM mode transmission line. Assuming the array has no resistive losses, the normalized shunt admittance is [8], [9]

$$\frac{Y}{Y_0} = -j\left(\frac{3ab\lambda_0}{\pi d^3}\right) \tag{1}$$

where

- a, b spacings between holes (Fig. 1)
- d hole diameter
- λ_0 free-space wavelength

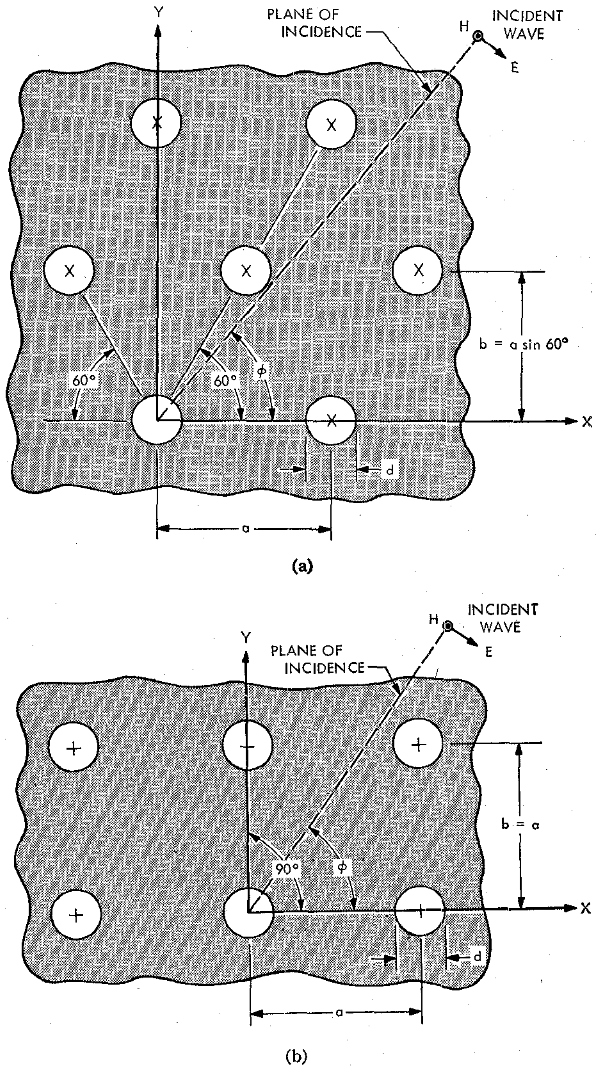

Fig. 1. Geometry for two-dimensional array of holes in metallic flat plate. (a) 60° (staggered) hole pattern configuration. (b) 90° (square) hole pattern configuration.

and $d < a,b \ll \lambda_0$. It should be pointed out that the quantity in parentheses in (1) is equivalent to the first term shown in Culshaw [9, eq. (25)]. The summation term in [9, eq. (25)] is a small correction term that can generally be neglected when $a,b,d \ll \lambda_0$.

Generalizing (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[1] is

$$T_{\text{dB}} = 20 \log_{10}\left(\frac{3ab\lambda_0}{2\pi d^3 \cos\theta_i}\right) + \frac{32t}{d} \tag{2}$$

where

- θ_i angle of incidence
- t plate thickness

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

The last term of (2) is a plate thickness correction term that was derived by analyzing the basic cell of the circular hole array as a π network and by treating the small hole as a circular waveguide beyond cutoff. The treatment follows that given by Marcuvitz [11] except that, for the derivation of (2), the expression for normalized susceptance applicable to the circular hole array was used.

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[1] The term transmission loss as used here is equivalent to the term attenuation defined by Beatty [10]. It is the insertion loss of the mesh when placed in a nonreflecting system.

TABLE I

COMPARISON OF EXPERIMENTAL AND THEORETICAL TRANSMISSION LOSS DATA FOR FLAT PERFORATED PLATES WITH ROUND HOLES

Test Frequency, MHz	θ_i, deg	Hole Pattern (Fig. 1), deg	$\frac{d}{\lambda_0}$	Porosity,[b] %	$\frac{t}{d}$	Theoretical Transmission Loss, dB	Measured Minus Theoretical Transmission Loss, dB
2300	0[a]	60	0.04	10.08	0.345	50.4	-2.4
			0.04	22.67	0.345	43.4	-2.6
			0.07	10.08	0.197	40.8	0.0
			0.07	22.67	0.197	33.8	-0.5
			0.10	10.08	0.138	35.8	-0.9
			0.10	22.67	0.138	28.8	-1.0
2388	35.1	60	0.025	30.37	0.400	48.3	-0.4
			0.025	33.07	0.632	55.0	0.0
			0.025	40.52	0.496	48.9	-0.8
			0.025	49.61	0.632	51.5	-0.8
			0.038	51.01	0.085	30.2	-0.9
			0.038	51.01	0.480	42.8	-0.6
			0.051	25.12	0.316	41.3	-0.4
			0.051	49.61	0.316	35.3	-0.4
			0.076	25.02	0.211	34.4	-0.5
			0.076	50.01	0.211	28.4	-0.1
			0.076	51.01	0.227	28.7	0.1
			0.101	24.76	0.158	30.3	-1.0
			0.101	49.91	0.158	24.2	-0.9
2388	35.1	90	0.025	24.90	0.632	57.5	0.7
			0.025	49.79	0.632	51.4	-1.2
			0.051	25.13	0.316	41.3	1.0
			0.051	49.79	0.316	35.3	0.1
			0.076	24.83	0.211	34.5	-0.5
			0.076	47.34	0.211	28.9	0.4
			0.101	24.84	0.158	30.3	-1.3
			0.101	49.95	0.158	24.2	-1.0
8448	38.5	60	0.045	50.00	0.048	28.1	2.8
			0.045	50.00	0.256	34.8	2.8
			0.089	30.37	0.400	37.7	-1.7
			0.089	40.31	0.496	38.3	-1.0
			0.134	51.01	0.085	19.6	-1.9
			0.134	51.01	0.480	32.3	-1.3
			0.134	51.01	1.000	48.9	-1.1

[a] Data at normal incidence obtained by Dalmo Victor Co. in free space test setup [13].

[b] Percent porosity = $\left(\frac{\pi d^2}{4ab}\right)(100)$.

Equation (2) can be easily put into graphical form [12] that is useful for design purposes.

EXPERIMENTAL VERIFICATION

Table I is a comparison of theoretical and experimental data on transmission through perforated flat plates. All test samples were fabricated from flat aluminum plates. The samples tested represent circular hole arrays having either 60° or 90° hole patterns, hole diameters varying from 1.59 to 13.06 mm, porosities varying from 10 to 51 percent, and plate thicknesses varying from 0.08 to 4.76 mm.

Most of the test results were obtained through a TE_{10} mode waveguide method whose validity is discussed by several authors [14], [15]. Fig. 2 shows some of the waveguide samples tested in WR 430 and WR 112 insertion-loss measurement systems. Details of the waveguide samples and measurement techniques employed can be found in [16], [17]. The accuracy of the waveguide results in Table I is estimated to be ± 0.5 dB. The free-space test data obtained from [13] are included for additional verification purposes. The estimated accuracy of the free-space measurements was stated to be about ± 0.5 dB.

Theoretical values for Table I were calculated through the use of (2). It can be seen that the agreement between theoretical and experimental results is typically better than 1 dB at 2388 MHz and 2 dB at 8448 MHz. When broad-band test data from an automatic network analyzer were compared to theoretical values, the same type of agreement was also obtained at other S- and X-band frequencies [17].

The waveguide test samples for the data in Table I were cut so that the hole pattern was oriented at angles $\phi = 0$ or 90° with respect to the plane of incidence (Fig. 1). Tests on some samples at different hole pattern orientation angles showed that, for practical purposes, the transmission loss was independent of the orientation angle. Although the hole pattern orientation can be changed in the waveguide tests, it should be emphasized that the data presented here are

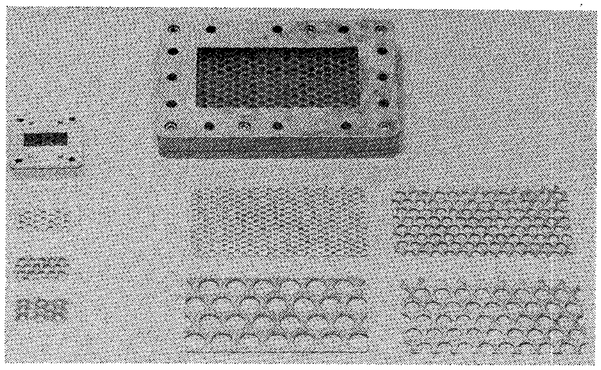

Fig. 2. WR 112 and WR 430 waveguide sample holders and test samples.

still limited to the free-space configuration where the E field is polarized normal to the plane of incidence. At present, there does not appear to be published experimental data on the transmission loss of perforated plates for the parallel-polarization case at various incidence angles. Analyzing the mesh as an equivalent solid thin sheet, however, one would not expect the transmission losses for the two polarization cases to differ by more than 2.5 dB when the angles of incidences are less than 30°.

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 1) an obliquely incident plane wave where the E field is polarized normal to the plane of incidence and 2) large transmission losses (10 dB or greater). Even with the stated restrictions, the formula presented is useful for predicting leakage through antenna surfaces and RF shields.

ACKNOWLEDGMENT

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