

Study of Narrow-Band Dichroic Plates With Circular, Rectangular, or Pyleguide Apertures

J. C. Chen

Ground Antennas and Facilities Engineering Section

The dichroic plate considered in this article is a metal plate perforated with arrays of apertures such that electromagnetic waves of certain frequencies pass through the plate and other frequencies are reflected. The shape of the apertures is an important contributor to the performance of the dichroic plate. An S/X dichroic plate, which passes X-band (8.4–8.45 GHz) and reflects S-band (2.0–2.32 GHz), is chosen for a case study. A comparison of the performance of dichroic plates of the same thickness and array pattern is presented for three different aperture shapes: circular, Pyleguide, and rectangular.

I. Introduction

Consider an S/X dichroic plate illuminated by a circularly polarized wave; this wave is formed as a combination of two orthogonal linearly polarized waves (TE and TM polarizations). If the apertures on the dichroic plate are symmetric, such as circular or square shapes, and the circularly polarized wave travels in the direction normal to the plate, then the relative phase difference of the two linearly polarized waves remains the same after the wave hits the plate. This means that the transmitted and the reflected waves are still circularly polarized. On the other hand, for oblique incidence, the relative phase difference between TE and TM polarizations will be changed after the wave leaves the plate, resulting in the transmitted and reflected waves being elliptically rather than circularly polarized (depolarization). Since oblique incidence is required in the Deep Space Network, an incident angle of

30 deg from the normal direction of the plate was chosen for this case study (Fig. 1).

The S/X dichroic plate on the DSS-14 70-m antenna was originally designed with circular apertures. Then the depolarization was improved by replacing the circular apertures with Pyleguide apertures by P. D. Potter in 1973 [1]. The results of the circular- and Pyleguide-aperture computations and measurements by Potter are discussed below. Furthermore, results of a theoretical design study of a dichroic plate with rectangular apertures are also included.

II. Circular Apertures

Circular apertures were originally used because they were easy to machine and the characteristics of the circu-

lar waveguide modes were well known. The first design of an S/X dichroic plate was a 3.576-cm-thick metal plate perforated with 2.273-cm-diameter circular apertures on a 60-deg skew grid with 2.388-cm spacing [Fig. 2(a)] [1]. A depolarization problem was found in this dichroic plate design. Calculations, using the C. C. Chen Holey Plate Computer Program, showed that the plate resonant frequencies were 8.481 and 8.363 GHz for TE and TM polarizations, respectively. A differential phase shift of 11.3 deg and an ellipticity of 1.75 dB were computed at the operating frequency of 8.415 GHz. The actual measured ellipticity was 1.84 dB. The reflected energy level was measured to be -18.6 dB at 8.415 GHz.

III. Pyleguide Apertures

A Pyleguide, a circular waveguide with a pair of flats on opposite sides, was introduced to solve the depolarization problem. Because one dimension is shorter than the other for a Pyleguide aperture, the cutoff frequencies are different for TE and TM polarizations. Since there was no computer program to analyze a dichroic plate with Pyleguide apertures, the size of the apertures was determined from the cutoff wavelengths of the Pyleguides, which corresponded to the resonant frequencies (8.481 GHz and 8.363 GHz) of the original circular-aperture plate. The Pyleguide aperture was 0.013 cm larger than the original circular aperture, and the flat depth was 0.043 cm [Fig. 2(b)]. The Pyleguide apertures were only a small change from the original circular apertures. The Pyleguide holes were made with a tolerance of ± 0.005 cm. The phase shift was 3 deg and the ellipticity was 0.4 dB. The reflected power average level for the Pyleguide dichroic plate was -24.5 dB at 8.415 GHz [1]. The performance was improved by using Pyleguide rather than circular apertures.

IV. Rectangular Apertures

A dichroic plate with rectangular apertures has enough degrees of freedom to minimize the depolarization of the circularly polarized incident wave. A computer program based on a modal matching method was written to calculate the transmission and reflection coefficients of a dichroic plate with rectangular apertures [2]. The experiments on the test dichroic plates showed that calculated and measured resonant frequencies of the dichroic plate were within 0.3 percent, which indicates good accuracy of the software. The study of the dichroic plate with rectangular apertures in this article was based on this computer program, while the dichroic plates with circular or Pyleguide apertures discussed above were built and tested by Potter [1]. An optimization program was integrated

with the rectangular-aperture dichroic plate program to accelerate the time-consuming process of optimizing the size of the rectangular apertures.

The optimization program finds the minimum of a user-defined cost function of several variables. Each variable is constrained between an upper bound and a lower bound. The function is first evaluated at the initial values of variables given by the users. Then the function is recalculated at different values of the variables. The program continues to search for a new set of variables until the local minimum of the function is found or until any one of the variable boundary constraints is broken. In this case, the variables were the dimensions of the apertures and the cost function was a function of the reflection loss of both the TE and TM polarizations, and the relative phase shift between them. Since several local minima may exist, the optimization process should be repeated with different initial values in order to find the absolute minimum.

The dimensions of the rectangular apertures were determined using the following method. First, the boundary constraints for the dimensions of rectangular apertures A_x and A_y were found. The aperture should be larger than the cutoff size for the lowest frequency of the passband, and smaller than the unit cell:

$$\frac{c}{2f_l} < A_x \leq D_x - w_{\min}$$

$$\frac{c}{2f_l} < A_y \leq D_y' \sin \Omega - w_{\min}$$

where c is the speed of light, f_l is the lower frequency of the passband, and w_{\min} is the minimum wall thickness of the apertures. The wall of the aperture has to be thick enough to support the plate. Ω is the skew angle, and D_x and D_y' are the dimensions of the unit cell (Fig. 1).

Second, the aperture was set to be square, $A_x = A_y$, so only one variable was optimized. The program searched for the optimized square aperture $A_1 = A_x = A_y$.

Third, A_x was fixed to the optimized square aperture dimension A_1 , and A_y was varied as the optimization variable. The optimized value of A_y was A_2 .

Finally, using A_1 and A_2 as the initial values, both A_x and A_y were optimized (Fig. 3). The optimization program searched for only the local minimum; therefore it was necessary to repeat the procedure (starting from the second step) to assure that optimum aperture size was achieved.

A 1.925-cm by 1.951-cm rectangular aperture was found using the optimization program for a 3.576-cm-thick dichroic plate on a 60-deg skew grid with 2.388-cm spacing [Fig. 2(c)]. Figures 4 through 6 show the transmission coefficients for TE and TM polarizations, the relative phase shift between TE and TM polarizations, and the ellipticity from 7 to 9 GHz. The calculations show a reflection loss of 0.000 dB for TE polarization and 0.001 dB for TM polarization, a relative phase shift of 2.0 deg, and ellipticity of 0.3 dB at 8.415 GHz. The conductivity loss was estimated to be 0.01 dB based on a 3.576-cm-long, 1.925-cm by 1.951-cm rectangular waveguide.

V. Summary and Conclusion

The results of this case study show that the apertures of unequal dimensions (rectangular or Pyleguide) produced a better axial ratio than the symmetric apertures (circular) for the case of oblique incidence with a circularly polarized wave. The performance of a dichroic plate with rectangular apertures was easier to optimize than that with Pyleguide apertures since an accurate computer program for a dichroic plate with rectangular apertures was avail-

able. Table 1 shows insertion loss, relative phase shift, ellipticity, and maximum reflected power of the dichroic plate with circular, Pyleguide, and rectangular apertures at 8.415 GHz. The maximum reflected power level at 8.415 GHz for the dichroic plate with rectangular apertures is expected to be slightly better than -24.5 dB. The grating lobes depend on the array pattern of the dichroic plate. Since in this case study the array pattern remains the same, the grating lobes are the same for these three configurations.

The reflected power from the dichroic plate resulted in increased temperature in the antenna system. The maximum noise temperature contribution from ground radiation was 0.7 K at 8.415 GHz for the 70-m antenna. While in the beam-waveguide-antenna pedestal room (300 K for DSS 13), the maximum noise temperature contribution of the dichroic plate was 1.06 K. The horn radiation pattern is not a perfect plane wave. Part of the horn radiation strikes the plate at angles other than the design angle; as a consequence extra reflections are created which result in an increased noise temperature. Further study using a plane wave expansion of the horn pattern would allow the reflected power to be predicted theoretically.

References

- [1] P. D. Potter, "Improved Dichroic Reflector Design for 64-m Antenna S- and X-Band Feed Systems," *The Deep Space Network Progress Report*, JPL Technical Report 32-1526, vol. XIX, Jet Propulsion Laboratory, Pasadena, California, pp. 55-62, February 15, 1974.
- [2] J. C. Chen, "Analysis of a Thick Dichroic Plate with Rectangular Holes at Arbitrary Angle of Incidence," *TDA Progress Report 42-104*, vol. October-December 1990, Jet Propulsion Laboratory, Pasadena, California, pp. 9-16, February 15, 1991.
- [3] T. Y. Otoshi and M. M. Franco, "Dual Passband Dichroic Plate for X-band," *TDA Progress Report 42-94*, vol. April-June 1988, Jet Propulsion Laboratory, Pasadena, California, pp. 110-134, August 15, 1988.

Table 1. The performance of S/X dichroic plates at 8.415 GHz.

Parameter	Aperture		
	Circular	Pyleguide	Rectangular
Insertion loss, dB			
TE	—	0.009 ^a	0.010 ^b
TM	—	0.004	0.011
Relative phase shift, deg	11.3 ^c	3.0	2.0
Ellipticity, dB	1.84	0.4	0.3
Reflected power level, ^d dB (max)	-18.6	-25.4	—

^a The insertion loss of the dichroic plate with a Pyleguide aperture is achieved by experiments [3].

^b The calculated insertion loss of the dichroic plate with rectangular apertures includes the reflection loss and conductivity loss, but not the loss due to surface roughness.

^c The relative phase shift and ellipticity of the dichroic plate with circular or Pyleguide apertures are determined experimentally [1].

^d The reflected power level is achieved by experiments.

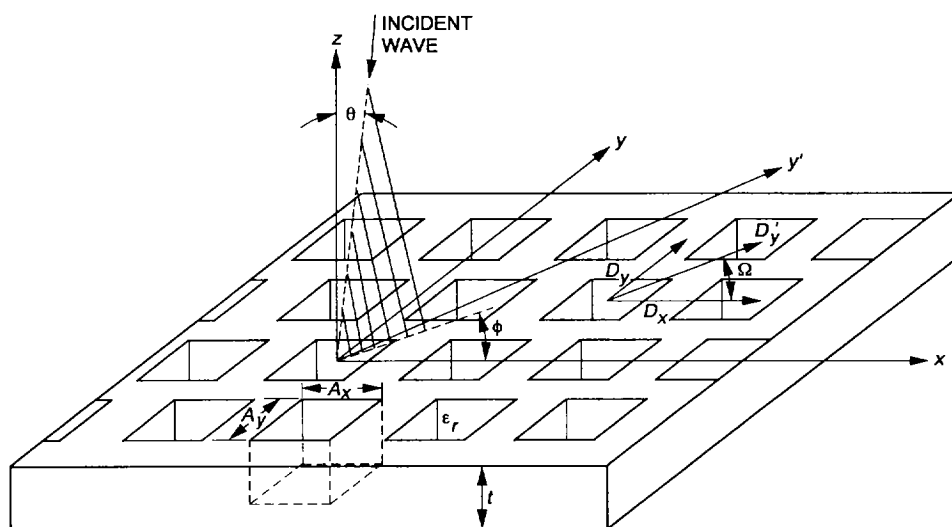


Fig. 1. Geometry of X/Ka dichroic plate.

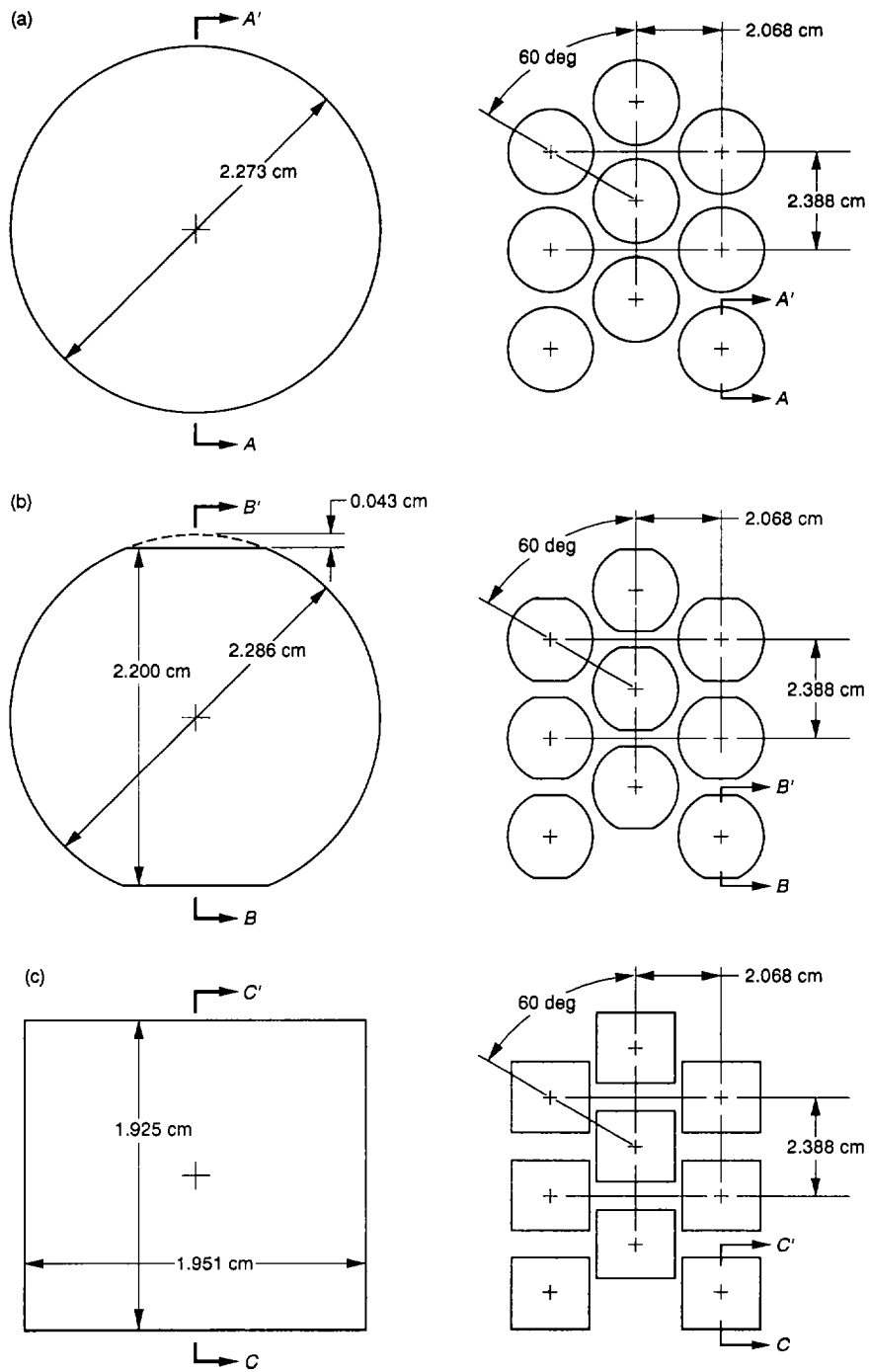


Fig. 2. Apertures: (a) circular; (b) Pyleguide; and (c) rectangular.

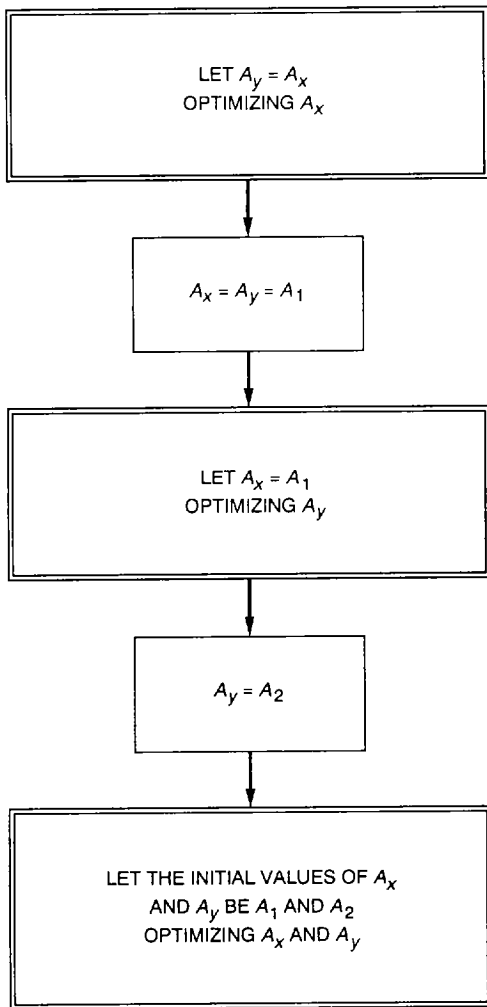


Fig. 3. Method for finding an optimized rectangular aperture for a dichroic plate.

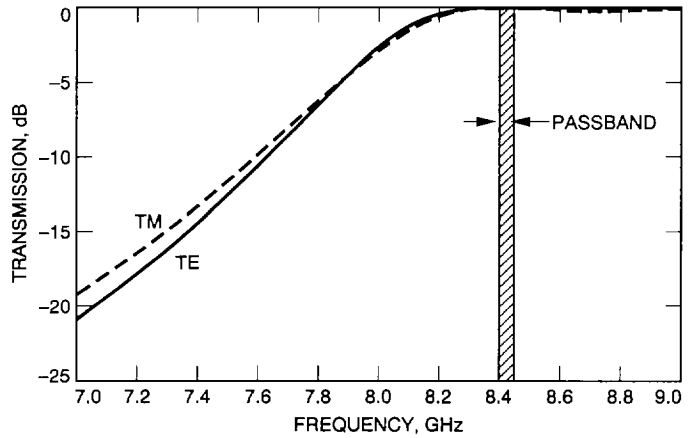


Fig. 4. Transmission coefficient versus frequency for X/S dichroic plate with rectangular apertures for TE and TM polarizations.

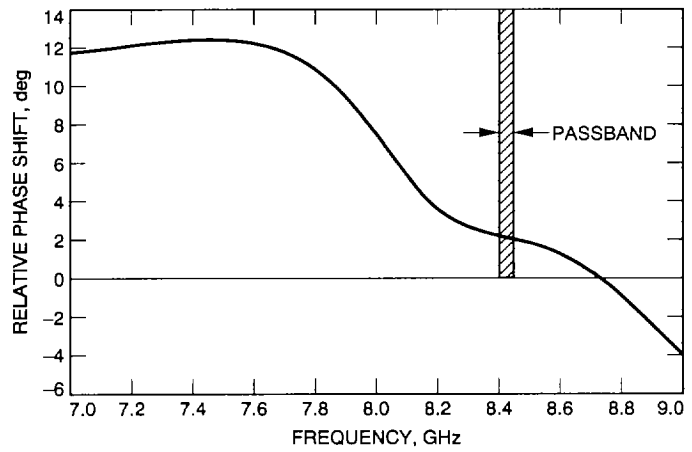


Fig. 5. Relative phase shift between TE and TM polarizations versus frequency for X/S dichroic plate with rectangular apertures.

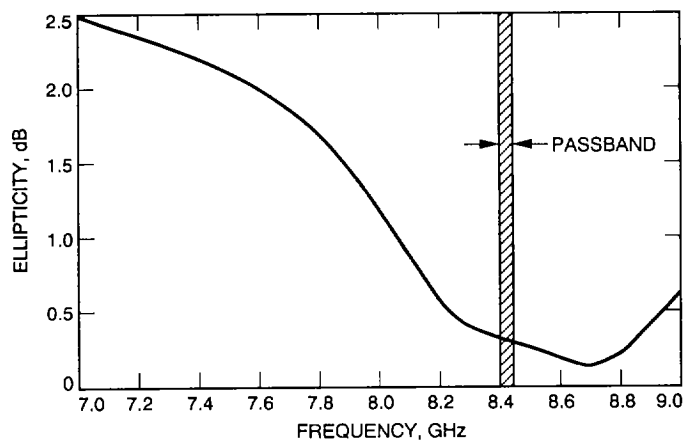


Fig. 6. Ellipticity versus frequency for X/S dichroic plate with rectangular apertures.