E-PLANE FILTERS WITH FINITE-THICKNESS SEPTA

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Abstract

The effect of metalization thickness of the septum is incorporated into an efficient CAD program for E-plane filters. The method is mathematically exact and numerically efficient. The results agree well with experimental data.

Introduction

In previous paper [1] a computer-aided design (CAD) procedure has been introduced for a class of E-plane waveguide filters (Fig. 1). The metal septa used in the circuits, either stand-alone or printed on a substrate, were considered to be infinitesimally thin. This assumption is applicable only when the thickness of the septa is small compared to the wavelength, typically less than 0.3%. When a stand-alone metallic sheet is used or when the operating frequency is high, this criterion is difficult to satisfy and the thickness effect must be considered in the analysis to obtain an accurate design, especially at millimeter-wave frequencies.

In this paper the procedure in [1] is modified to take into account the thickness of the metal fins. Before describing the modification, the procedure for the program in [1] is briefly summarized.

The analysis portion of the CAD algorithm was divided into three steps. Step 1 tackles a single junction created by a septum in a wave-guide using the residue calculus technique [2]. A mathematically exact closed-form expression for the generalized scattering matrix characterizing this junction is obtained. This matrix contains information on all higher order modes as well as the dominant mode. The second step is to calculate the generalized scattering parameters for a finite-length septum by placing two junctions back to back and taking into account the multiple reflections between junctions due to the propagating modes as well as the evanescent modes. Finally, the scattering parameters for a composite filter circuit are obtained by combining all the septa in the structure. In what follows we present a modification of Step 1 and discuss how the filter response is affected by the thickness. Since Steps 2 and 3 are essentially unchanged, they will not be repeated here.

S-Parameters at the Edge of a Finite-Thickness Septum

Fig. 2a shows the generalized structure to be analyzed for a septum of thickness t. When $\varepsilon_2=1$, we have a unilateral fin-line structure in a waveguide of width a. For a bilateral structure, we make $\varepsilon_1 = \varepsilon_2$ and the yz plane is replaced with a magnetic wall to consider only one half of the waveguide of width 2a. The excitation field is assumed to be of TE_{po} type. Despite the modal expansions for the fields on either side of the interface z = 0, matching of the transverse components does not lead to a set of equations of the form solvable by the residue-calculus technique. However, the modal nature of the fields in the three regions suggests description of the junction in terms of generalized scattering matrices. The scattering matrices may be derived via the multiple-reflection method for a suitable auxiliary geometry.

The auxiliary geometry appropriate for the thick-septum junction is that of Fig. 2b. The conducting wall due to the thick septum is recessed into region III by δ_1 and two additional regions IV and V are created for analysis. The original structure can be recovered by reducing both δ_1 and δ_2 to zero. Notice that in this new structure, the characteristics of junctions at z = 0 (junction A) and z = δ_1 (junction B) are essentially the same as that of the zero-thickness septum junction whose exact scattering matrix description was given by the residue-calculus method. Let the scattering matrices for the junction A have the subscript a, i.e., S_{aij} (i,j = 1,2,4); and let those for the junction B have the subscript b, i.e., S_{bij} (i,j = 4,5,3). The scattering matrices for the composite junction, S_{ij} (i,j = 1,2,3) will have no subscript. Consideration of the multiple-reflection phenomena and reduction of δ_1, δ_2 to zero yields the representation, $\overline{S}$, for the composite scattering matrices as depicted in Fig. 3. Notice that S_{aij} etc. are matrices. For instance, S_{a12} (m,n) means the amplitude of the m-th mode in Region I generated at the junction A when the n-th mode with a unit amplitude is incident from Region II.

Once the $\overline{S}$ matrix is obtained, we proceed into Steps 2 and 3. We create the matrix of a finite-length septum (fin). S matrices of each fin so derived are now cascaded to generate the S matrix of the filter structure. When a filter is designed, we use this analysis program in an optimization routine. For an assumed set of design parameters, we calculate the S parameters of the filter. Parameters are changed systematically by means of an optimization routine until the desired filter characteriestics are obtained.

Results and Discussions

The computation needed for analysis involves a number of inversions and multiplications of matrices which are mathematically of infinite size and, therefore, must be truncated. The computation time can be significantly reduced by using the smallest scattering matrices that yield suitably accurate results. A convergence study shows that for most of the cases only **3 x 3** matrices are required. Some typical examples are shown in Tables 1 where the dominant scattering parameters of the junction created by a finite-thickness septum are calculated using matrices of sizes ranging from 1 x 1 to 6 x 6. It is clear that in this case 2 x 2 matrix calculation yields results accurate to the third digit.

Several E-plane filters employing septa of finite thickness have been designed and tested at microwave frequencies by Konishi, et al. [3] and Tajima, et al. [4]. The validity of the present analysis is also checked by using their design data to calculate the filter responses. The results are shown in Fig. 4 in comparison with their measurements. Good agreement is observed.

Since we gained confidence in this analysis, the thickness effect of the septum on the performance of the filter circuits is demonstrated by a filter designed with a purely metallic sheet. The performance of the bandpass filter is first optimized on a 5-mil thick sheet. Then using the same design parameters, the filter response is calculated for the filter circuits by varying the thickness of the metal sheet. The results are plotted in Fig. 5. The most noticeable effect is that the center frequency shifts upward approximately 150 MHz per 1-mil increase in thickness. This effect is mainly due to the fact that the increase of septum thickness effectively shortens the equivalent length of the resonators formed between two septa, and thus causes the resonant frequency to shift upward. In addition to this effect, the passband ripple increases perceptibly and the bandwidth shrinks due to the changes in coupling between resonators.

Conclusions

An efficient CAD algorithm is developed for E-plane filters with finitely thick metalization. The program is useful for millimeter-wave applications.

Acknowledgments

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References

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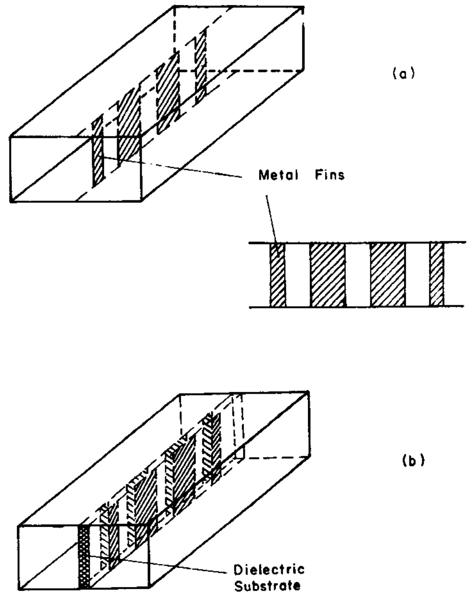

Fig. 1 E-plane waveguide filters. (a) Metal sheet, (b) Bilateral finline

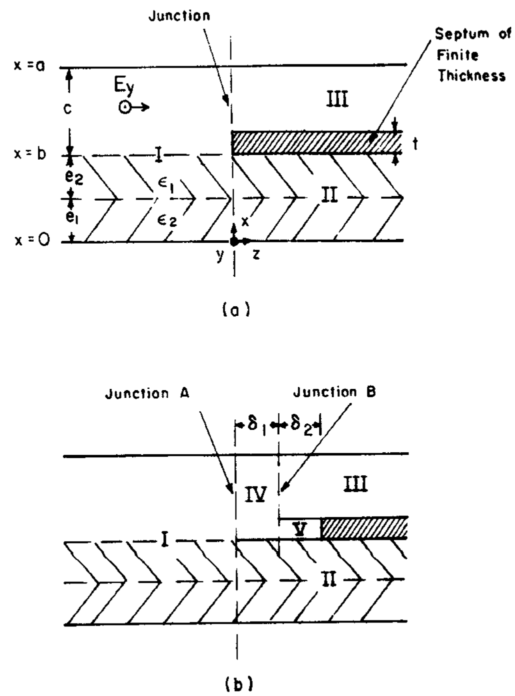

Fig. 2 Semi-infinite septum of finite thickness. (a) Geometry, (b) Auxiliary structure

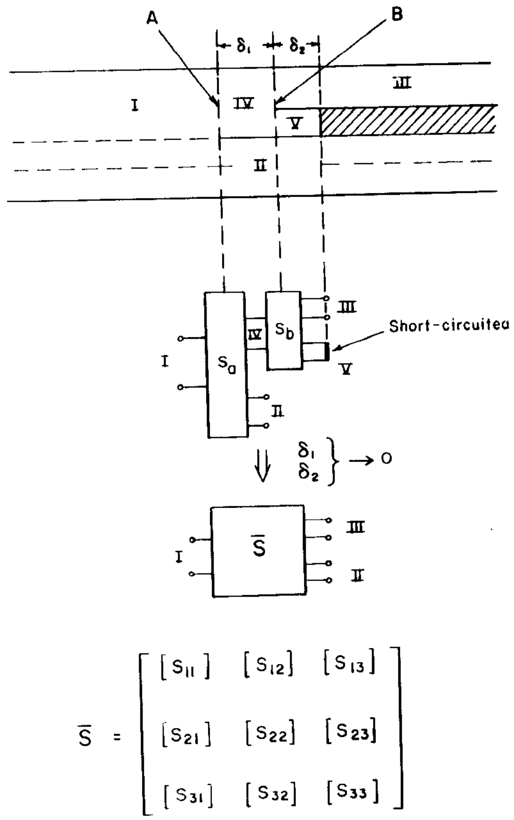

Fig. 3. Generalized scattering matrix characterizing a single junction

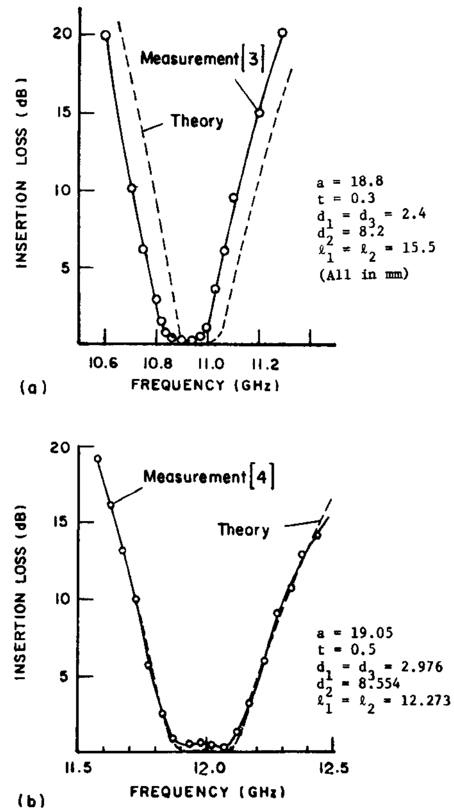

Fig. 4 Frequency response of E-plane filters using metal sheets of finite thickness

M	$S_{11}(1,1)$	$S_{31}(1,1)$	$S_{13}(1,1)$	$S_{33}(1,1)$
1	(1.000,2.489)	(.6895,1.244)	(1.029,-.326)	(.3836,-1.179)
2	(1.000,2.490)	(.6889,1.245)	(1.027,-.325)	(.3826,-1.179)
3	(1.000,2.490)	(.6888,1.245)	(1.027,-.325)	(.3823,-1.179)
4	(1.000,2.490)	(.6889,1.245)	(1.027,-.325)	(.3822,-1.179)
5	(1.000,2.490)	(.6889,1.245)	(1.026,-.325)	(.3821,-1.179)
6	(1.000,2.490)	(.6889,1.245)	(1.026,-.325)	(.3820,-1.179)

Table 1. Scattering parameters of semi-infinite septum of finite thickness

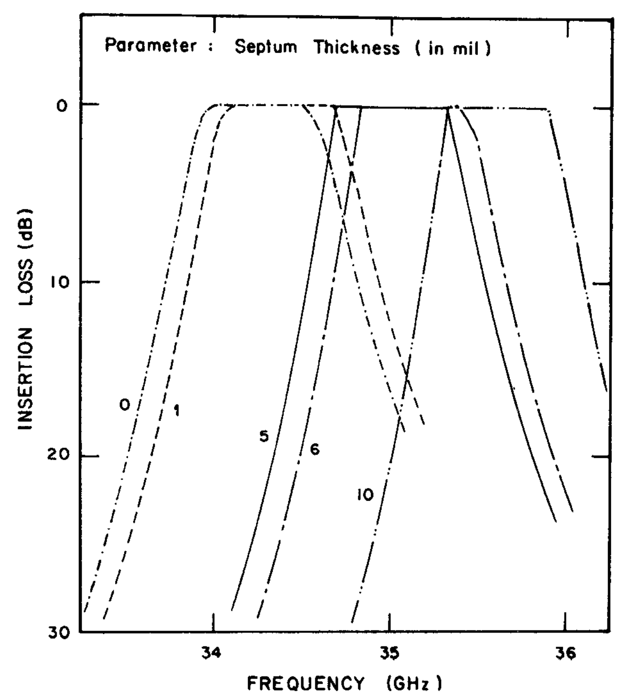

Fig. 5 Thickness effects on filter performance