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A SIMPLIFIED METHOD FOR S-PARAMETER CALCULATIONS OF METAL SEPTUM WAVEGUIDE FILTERS

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ABSTRACT

This paper presents a combined field theoretical and measurement-oriented model for the performance evaluation and design of waveguide E-plane filters with all metal inserts. The analysis is based on both the variational method and general measurement techniques of scattering networks. Compared with previously published algorithms, this procedure is easy to program, uses less computer memory, and offers a better convergence behavior. The method is verified by comparing computed data with measured results of three Ka-band filter prototypes. Due to the accurate predictions of the model, good agreement is obtained.

I. INTRODUCTION

In the millimeter-wave frequency range, waveguide E-plane integrated circuit filters are well-known for their low losses, low cost and suitability for mass-production [1]-[3]. Several numerical methods for the computer-aided analysis and design of all-metal insert filters (c.f. Fig. 1) have been investigated [4-9]. However, these procedures are quite complex and, therefore, are CPU-time intensive. From a practical point of view, and in order to assist the application oriented engineer with basic design criteria, it is important to have a numerical technique available, which is CPU-time efficient as well as practical.

Therefore, this paper presents a simple and practical method for the analysis and design of metal septum E-plane waveguide filters. The procedure is based on a combination of scattering network measurement theory and the variational method [10]. The primary advantages of this combination are, first, that the algorithm can be easily formulated, and second, that the calculated scattering parameters include the interaction effects between the fundamental and higher-order modes at the waveguide-to-metal-septum discontinuity. Therefore, the physical dimensions of a filter can be easily obtained.

The procedure of this combined method is described as follows: First, the electromagnetic field at the discontinuity waveguide to metal septum is analyzed, and the reflection coefficients at that discontinuity are calculated using the variational method and introducing the electric and magnetic wall concepts. Second, the measurement concept of a scattering network is used to calculate the S_{11}-parameter of a metal septum directly from the results of the variational method. The final bandpass filter design is based on a distributed stepped-impedance filter model [4] which allows the computation of the physical dimensions of the structure.

II. THEORY

The E-plane bifurcated waveguide discontinuity with centered septum is shown in Fig. 2. Assuming a TE_{10} mode propagation in positive z direction in region I, the junction in the T1 plane produces fundamental and higher-order mode reflection and transmission, where the field configurations are of the $TE_{2m-1,0}$ type and $TE_{n,0}$ type in regions I and II, respectively. Because of the symmetry of this structure in z direction, it can be assumed that electric and magnetic walls are located in the T_0 plane for excitations from planes T_1 and T_2, respectively.

The electromagnetic field in region I can be expressed as :

$$\mathbf{E}_y^{(i)} = (e^{-\gamma_1 z} + \Gamma^{(i)} e^{\gamma_1 z})\phi_1(x) + \sum_{m=3,5,\cdots}^{\infty} a_m^{(i)} \phi_m(x) e^{\gamma_m z} \qquad (1)$$

$$\mathbf{H}_x^{(i)} = -Y_1(e^{-\gamma_1 z} - \Gamma^{(i)} e^{\gamma_1 z})\phi_1(x) + \sum_{m=3,5,\cdots}^{\infty} a_m^{(i)} Y_m \phi_m(x) e^{\gamma_m z} \qquad (2)$$

where $\Gamma^{(i)}$ refers to the input reflection coefficients with electric or magnetic wall at the T_0 symmetric plane. The field in region II reads:

$$\mathbf{E}_y^{(i)} = \sum_{m=1,2,\cdots}^{\infty} b_n^{(i)} \varphi_n(x) A_n^{(i)}(z) \qquad (3)$$

$$\mathbf{H}_x^{(i)} = \sum_{m=1,2,\cdots}^{\infty} Y_n b_n^{(i)} \varphi_n(x) B_n^{(i)}(z) \qquad (4)$$

ϕ_m, φ_n orthogonal function systems of modes.

Y_m, Y_n : the wave admittances of the modes.

a_m, b_n : wave amplitude coefficients.

Applying the interface continuity conditions of fields at the T1 plane, the TE_{10}-mode reflection coefficients $\Gamma^{(i)}$ with i=1, 2 can be obtained for the cases where T_0 is considered a electric or magnetic wall, respectively.

From the measurement theory of scattering network, it is known that for reciprocal, symmetrical and lossless circuits, the scattering coefficient at T_1 can be expressed as [11]:

$$S_{11} = (\Gamma_1 + \Gamma_2)/2 \qquad (5)$$

After obtaining the S_{11} parameters for the metal septums involved and applying the network theory based on the distributed stepped-impedance filter prototype designed for direct coupled cavity filters [4], the physical dimensions of a waveguide filter can be obtained.

III. NUMERICAL RESULTS AND EXPERIMENTS

Compared with other numerical methods presented in the literature [4-9], the computer-aided design routine based on this method significantly reduces the CPU time required for the design of a metal septum waveguide filter. This is mainly due to the facts that first, fundamental-mode propagation is assumed within the waveguide resonator sections and second, no optimization procedures are required for the computation of the physical dimensions of the filter. With m=15 and n=4 modes in regions I and II, respectively, for the calculation of the waveguide bifurcation discontinuity , the overall CPU time for the design of one set of filter dimensions is only two minutes on a Hitachi M340-S computer.

Fig. 3 shows a photograph of Ka-band metal insert prototypes together with the corresponding WR28 waveguide housing. The experiment results for the three different designs are shown in Figs. 4. Table 1 compares the theoretical data with experimental results. It is observed that the theoretical results agree well with experiments. However, the midband frequencies are slightly shifted upward, and the bandwidths, especially for the wide band design, are smaller than the theoretically predicted values. The main reason for these deviations lies in the fact that in order to reduce the execution time, the present algorithm omits a higher order power term in the network theory of [4] which affects the center frequency and bandwidth. For this method, the error in the center frequency is about 0.3% as can be seen from Table 1. In a practical design situation, however, these deviations can be incorporated in the design by specifying the desired frequency response accordingly.

IV. CONCLUSION

A combined procedure of variational method and measurement theory of scattering networks is presented for the analysis and design of metal septum E-plane waveguide filters. Compared with previously published methods, the advantages of the combination are its simplicity and the practical use for the whole analysis procedures. Therefore, it can easily be formulated and requires less CPU time. Experiments carried out in Ka-band agree well with theoretically predicted results.

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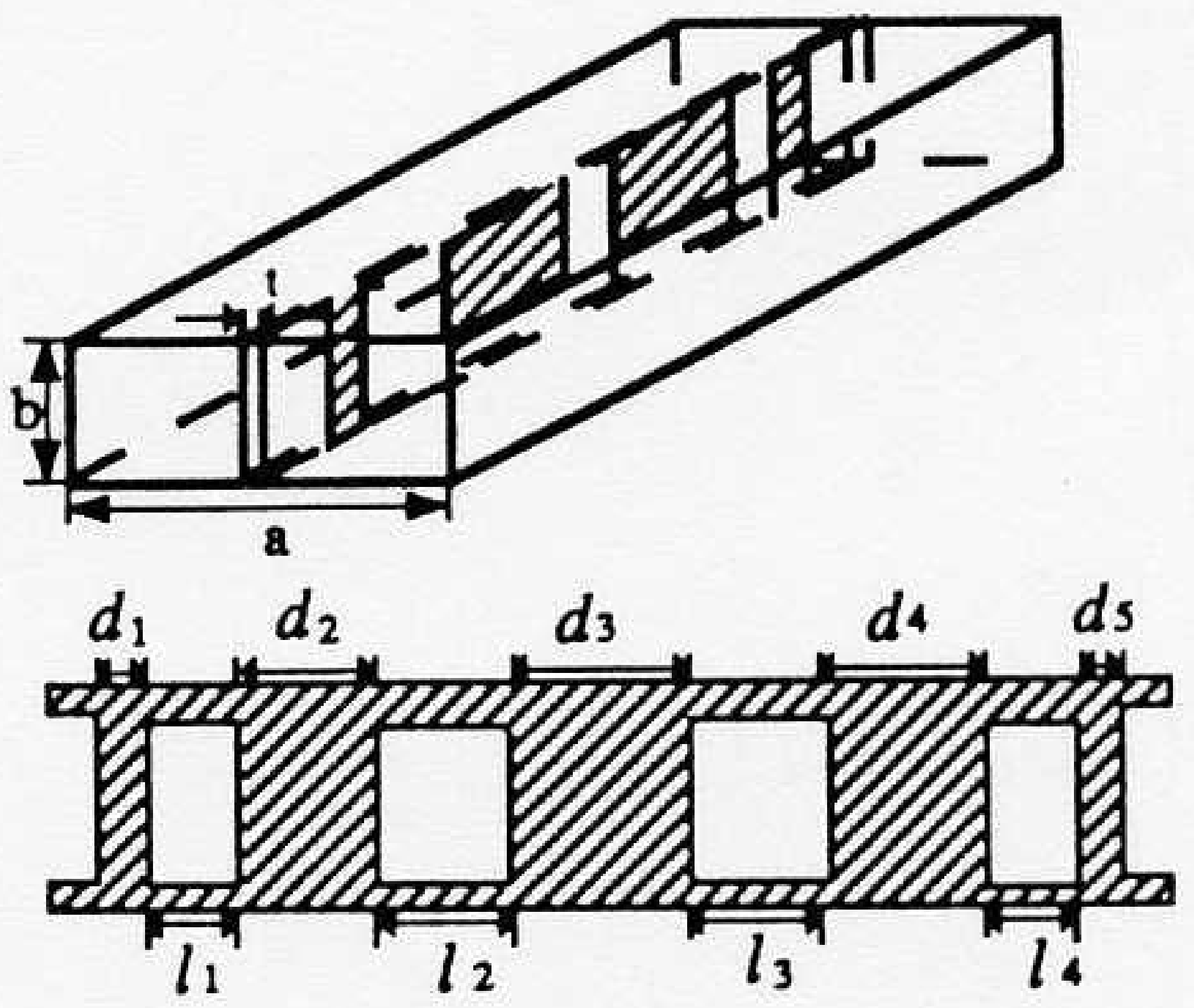


Fig. 1 Geometry of a E-plane filter with all metal insert

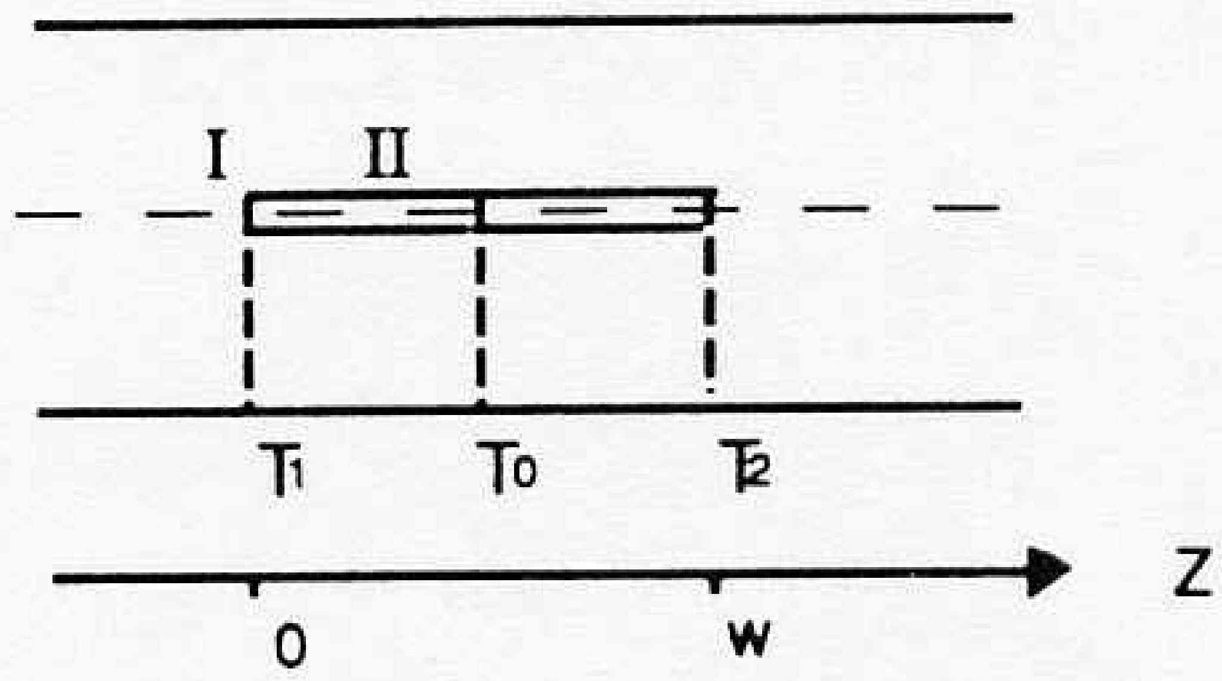


Fig. 2 Junction of waveguide bifurcation

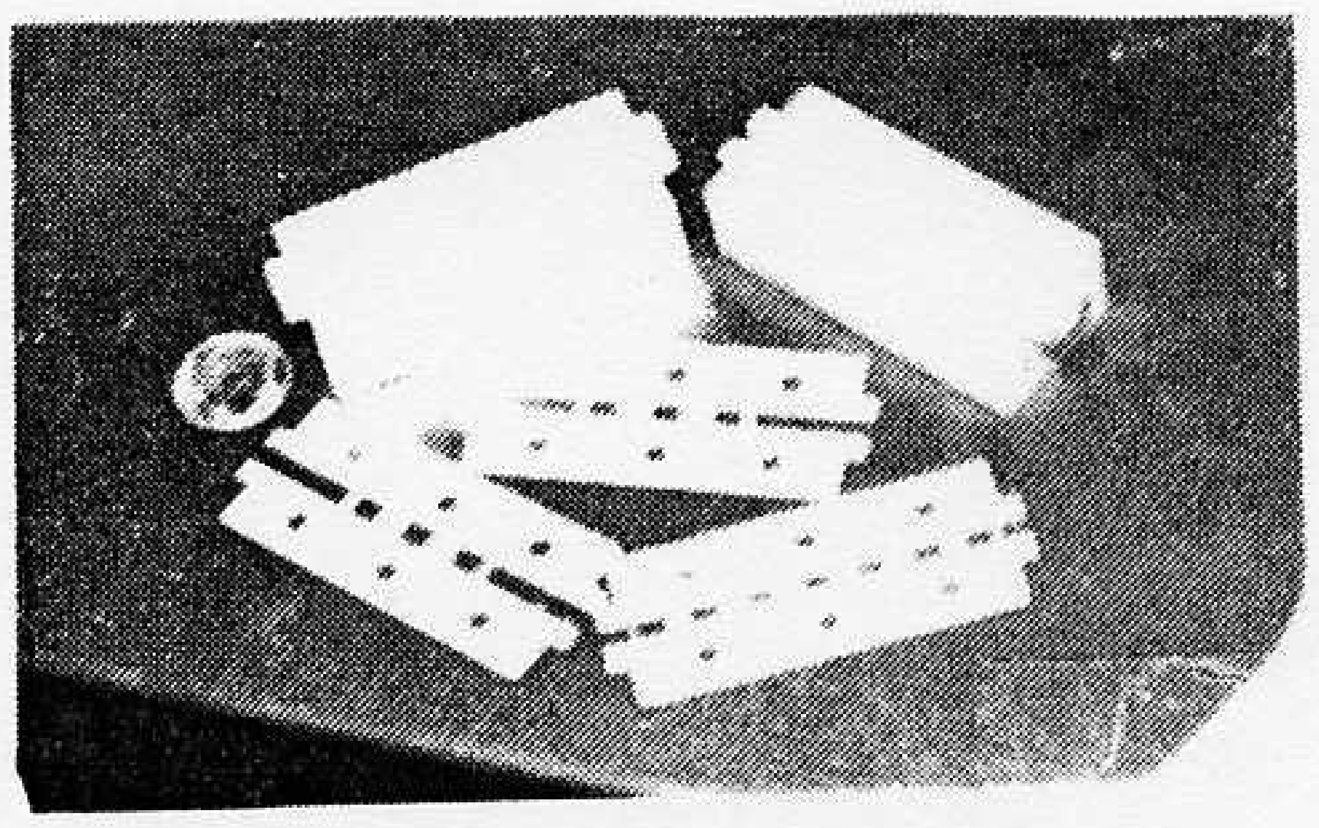
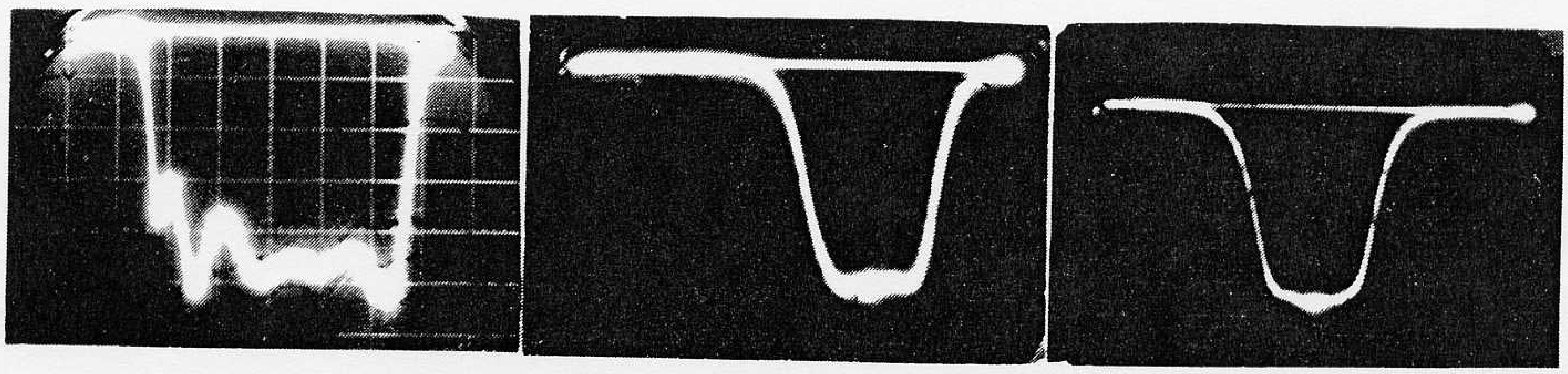


Fig. 3 Photograph of the Ka-band waveguide housing and metal fins

Table.1 Results of theory and experiments

data \ group		1	2	3
specifications	$f_o/(GH_z)$	32.50	32.60	32.35
	$\Delta f/(GH_z)$	2.70	0.83	0.52
	$x/(dB)$	1.70	0.10	0.02
	$R/(dB)$	20.00	20.00	20.00
	$f_s/(GH_z$	31.00	31.40	31.40
dimensions (mm)		$l_1=l_{15}=0.50$ $l_2=l_{14}=4.62$ $l_3=l_{13}=2.80$ $l_4=l_{12}=4.70$ $l_5=l_{11}=3.15$ $l_6=l_{10}=4.71$ $l_7=l_9=3.20$ $l_8=4.71$ $t=0.50$	$l_1=l_7=1.25$ $l_2=l_6=4.55$ $l_3=l_5=4.50$ $l_4=4.65$ $t=0.50$	$l_1=l_7=1.30$ $l_2=l_6=4.68$ $l_3=l_5=4.65$ $l_4=4.78$ $t=0.50$
experiments	$f_o/(GH_z)$	32.69	32.80	32.57
	$\Delta f/(GH_z)$	0.95	0.29	0.28
	$x/(dB)$	1.75	0.35	0.12
	$R/(dB$	> 20 Fig 4.1	> 20 Fig. 4.2	> 20 Fig. 4.3
Freq. ranges(GHz)		32.0-33.37	32.35-33.15	32.07-32.94



(1) (2) (3)

Fig. 4 Measured results for band-pass responses of the E-plane filters at Ka-band, WR28(a=7.112mm, b=3.556mm). Horizontal axis: frequency range(c.f. Table.1). Vertical axis: insertion loss(22 dB at top, 0dB at bottom).