An Accurate CAD Algorithm for E-Plane Type Bandpass Filters Using a New Passband Correction Method Combined with the Synthesis Procedures

Jae-Bong Lim *, Chung-Woong Lee ** and Tatsuo Itoh ***

*Department of Electronics Engineering, Kookmin University, Seoul 136-702, Korea
**Department of Electronics Engineering, Seoul National University, Seoul, Korea
***Department of Electrical and Computer Engineering, The University of Texas at Austin, Austin, TX78712

Abstract

A CAD algorithm using a new passband correction method combined with the synthesis procedures is presented for an accurate design of E-plane type bandpass filters. The proposed method gives a solution for the passband deviation problems associated with the conventional synthesis method. The passband correction factors are derived from the actual insertion losses of a pre-designed filter at the band-edge frequencies. Validity of the new method was confirmed by computer simulations and experimental measurements of the filters designed by this method.

Introduction

The design method of E-plane type bandpass filters based on the synthesis procedures is strongly preferred in order to reduce the computation efforts[1-4]. However, the actual bandwidth of the designed E-plane type filters by the conventional synthesis method deviates considerably from the specified one [2]. Thick inserts such as thick all-metal or bilateral E-plane structures can be used to reduce the discrepancy, but the results are still unsatisfactory [2]. An alternative way is to introduce a correction factor which compensates the frequency dependence of E-plane type discontinuities. In the E-plane type filters, the correction factor cannot be expressed in an analytical form since such a quantity is a complicated function of both frequency and E-plane strip widths.

In this paper, we propose a new CAD algorithm using passband correction factors for an accurate design of E-plane type bandpass filters. These correction factors compensate the frequency dependence of E-plane type discontinuities to solve the passband deviation problem associated with the synthesis method. In order to define the passband correction factor, we used a numerical approach instead of an analytical approach. Starting with a pre-designed filter by Levy's theory[5] and Rhodes' formula[6], we can express the passband correction factor as a function of frequency only. In this algorithm, only two passband correction factors are required and calculated from the actual insertion losses of the pre-designed filter at the specified band-edge frequencies. E-plane structures are analyzed by the variational method [1,4]. The developed CAD program was implemented on a personal computer.

Derivation of Passband Correction Method

When the passband ripple ε, the lower and upper band-edge frequencies, f_1 and f_2, and the number of resonators, n, are given, the insertion loss characteristics of a waveguide bandpass filter with a Chebyshev characteristic is well known [5] and given by

$$L = 10 \log \{ 1+\varepsilon^2 T_n^2 [\frac{\alpha}{m} \sin\frac{\pi\lambda_{go}}{\lambda_g}] \} \qquad (1)$$

where $m=\lambda_{go}/\lambda_g$ is the frequency dependence of K-inverters. The factor α and the guide-wavelength λ_{go} at the center frequency are determined by the procedures in [5].

First, an E-plane type bandpass filter is pre-designed by the conventional synthesis method [5,6]. The actual insertion losses y_1 and y_2 (dB) at f_1 and f_2 are found by calculating the filter response by a field theoretical method, specifically by the variational method[4] in this paper. In practice, the difference between the strip widths of a pre-designed filter and those of a final filter is found to be so small that the frequency dependence is assumed to be independent of these strip width variations. Thus starting with a pre-designed filter by the synthesis procedures, we can represent the passband correction factor as a function of frequency only as described below.

Assume that the actual frequency dependence of the E-plane discontinuity is $M=m\Delta(f)$, where $\Delta(f)$ is defined as the passband correction factor that we try to find. Then the actual insertion losses of the pre-designed filter are represented by

$$L_{actual} = 10 \log \{ 1+\varepsilon^2 T_n^2 [\frac{\alpha}{M} \sin\frac{\pi\lambda_{go}}{\lambda_g}] \}$$
$$= 10 \log \{ 1+\varepsilon^2 T_n^2 [\frac{\alpha}{\Delta(f)} \frac{\lambda_g}{\lambda_{go}} \sin\frac{\pi\lambda_{go}}{\lambda_g}] \} \qquad (2)$$

where the α and the λ_{go} have the same values as in eq.(1). At the specified band-edge frequencies, eq.(2) must satisfy following condition.

$$10 \log \{ 1+\varepsilon^2 T_n^2 [\frac{1}{\Delta(f_i)}] \} = y_i \quad \text{at} \quad f_i, \quad \text{for } i = 1, 2 \qquad (3)$$

From eq.(3), we can calculate the passband correction factors, $\Delta(f_1)$ and $\Delta(f_2)$, at the specified band-edge frequencies. Since our final goal is that the actual insertion loss characteristics L_{actual} of a final E-plane filter have the same passband characteristics as the L of eq.(1) which is the given specification, α and λ_{go} in eq.(2) must be recalculated from the following two equations (4) and (5), so that eq.(2) satisfies the specified passband ripple, $10 \log\{1+\varepsilon^2\}$(dB), at both f_1 and f_2.

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$$\frac{\lambda_{g1}}{\Delta(f_1)} \sin\frac{\pi\lambda_{go}}{\lambda_{g1}} + \frac{\lambda_{g2}}{\Delta(f_2)} \sin\frac{\pi\lambda_{go}}{\lambda_{g2}} = 0 \qquad (4)$$

$$\alpha = \Delta(f_1) \Big/ \frac{\lambda_{g1}}{\lambda_{go}} \sin\frac{\pi\lambda_{go}}{\lambda_{g1}} = -\Delta(f_2) \Big/ \frac{\lambda_{g2}}{\lambda_{go}} \sin\frac{\pi\lambda_{go}}{\lambda_{g2}} \qquad (5)$$

With the new α and the new λ_{go}, eq.(2) predicts accurately the insertion loss characteristics of the final filter around the passband,which are coincident with the prediction of eq.(1).

Filter Design Procedures Using the Passband Correction Method

For given specifications such as the passband ripple, the band-edge frequencies, and the number of cavities, the design procedures of E-plane type bandpass filters using the proposed passband correction method are summarized as follows;

1) Design an E-plane bandpass filter by the conventional synthesis procedures in [3].

2) By a field theoretical analysis method, calculate the actual insertion losses y_1 and y_2 of the pre-designed E-plane filter at the specified band-edge frequencies, f_1 and f_2.

3) Calculate the passband correction factors ,$\Delta(f_1)$ and $\Delta(f_2)$, using eq.(3).

4) Calculate the new λ_{go} and the new α from eq.(4) and eq.(5) respectively.

5) Finally, design the final E-plane filter using Rhodes' formula [3,6] with the new α.

Numerical Results and Experiments

For the verification of the presented method, we designed unilateral E-plane bandpass filters at X-band. The design data and the results are shown in Table 1.

Compared with the specified 100 MHz bandwidth and 0.2 dB ripple, the actual bandwidth and the actual insertion losses at the specified band-edge frequencies of the pre-designed filter (no. 1) are 70.8MHz, 6.60 dB and 3.88 dB respectively. On the other hand, those of the filter(no.2) designed by this method are 100.1 MHz, 0.20 dB and 0.19 dB respectively which are much closer to the specified values. In Fig.4, the simulated passband characteristics of the filter designed by this method (no.2 in Table 1) are compared with those of the filter designed by the synthesis method (no.1 in Table 1) which is identical to the pre-designed filter. The computer simulated characteristics were calculated by the variational method [4]. It is evident that the results by this design method agree very well with the prediction. Fig.5(a) compares the simulated characteristics of the filters no.3 and no.4 in table 1. The filters designed by the synthesis method (no.3) and by this method(no.4) have been fabricated and measured. Fig.5(b) depicts the measured results.

Conclusions

In order to solve the passband deviation problems associated with the synthesis method in the design of E-plane type bandpass filters, we proposed a passband correction method combined with the synthesis procedures. Unilateral E-plane bandpass filters have been designed and fabricated at X-band. Validity of the new method was confirmed by computer simulations and experimental measurements. The developed CAD algorithm is very efficient in computation since this algorithm is basically based on the synthesis method. This CAD program can be executed on a personal computer. The proposed method is believed very useful also for the design of direct-coupled cavity type waveguide filters with axial length variations.

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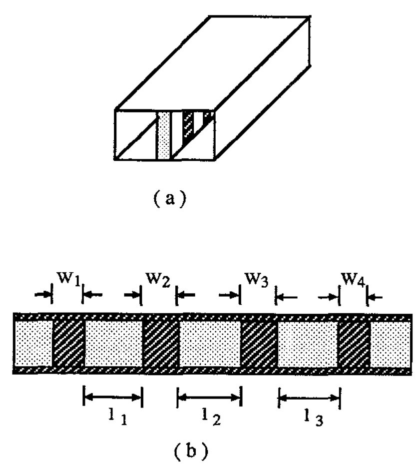


Fig. 1 (a) The structure of E-plane type bandpass filters.
(b) E-plane type Inserts.

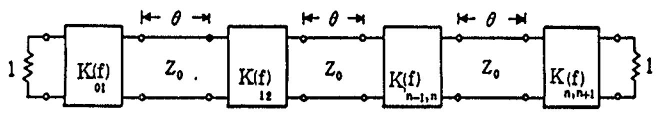


Fig. 2 The equivalent circuits of E-plane type bandpass filters represented with K-inverters.

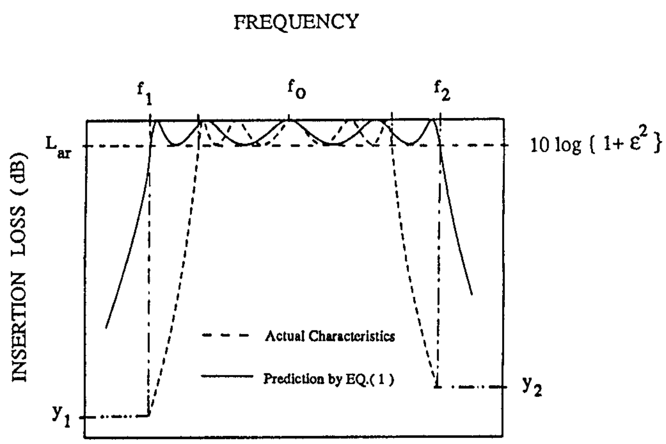


Fig. 3 Passband deviation of a E-plane type bandpass filter designed by the synthesis method.

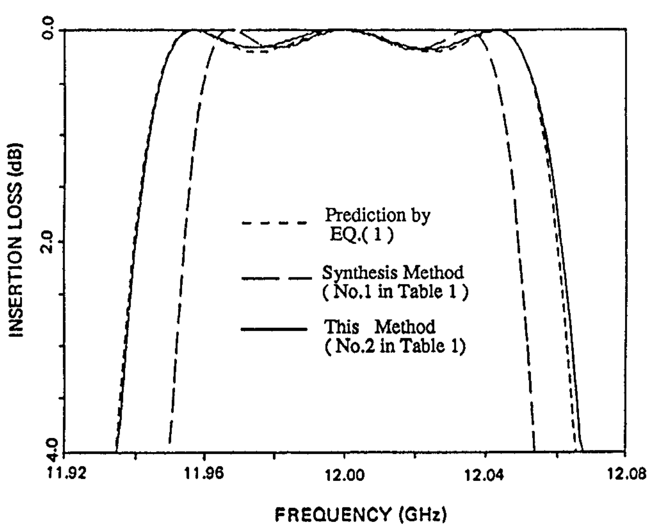
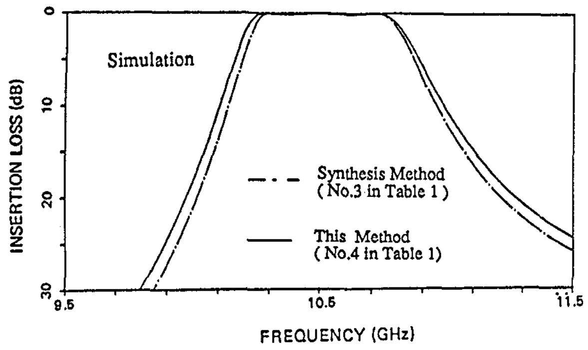
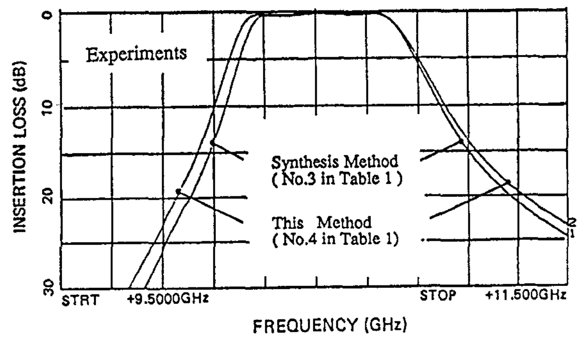


Fig.4 Simulated insertion loss characteristics of the unilateral E-plane bandpass filters near the passband. (No.1 and No.2 in Table 1)



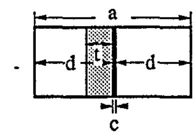
(a)



(b)

Fig.5 Measured insertion loss characteristics of the unilateral E-plane bandpass filters (No.3 and No.4 in Table 1)
(a) Simulated insertion losses, (b) Measured insertion losses.

Table 1 Design data of Unilateral E-plane bandpass filters.
0.2 dB, 3 - resonators Chebyshev type
a=900 mil, c= 0.5 mil, t=15 mil, ε_r=2.06 (CuFlon)



a) Specified Passband : 11.95 - 12.05 GHz (100 MHz)

No	Design method	f_0 (GHz)	Actual insertion loss(dB) at f_1	Actual insertion loss(dB) at f_2	Actual Bandwidth (MHz)	Dimensions of Inserts (mm) $W_1 = W_4$	$l_1 = l_3$	$W_2 = W_3$	l_2
1	Synthesis	11.9997	6.60	3.88	70.8	12.922	7.673	31.426	7.624
2	This method	11.9970	0.20	0.19	100.1	11.398	7.700	28.303	7.632

b) Specified Passband : 10.25 - 10.75 GHz (500 MHz)

No	Design method	f_0 (GHz)	Actual insertion loss(dB) at f_1	Actual insertion loss(dB) at f_2	Actual Bandwidth (MHz)	Dimensions of Inserts (mm) $W_1 = W_4$	$l_1 = l_3$	$W_2 = W_3$	l_2
3	Synthesis	10.4883	0.86	0.31	467.5	3.330	11.659	9.887	11.657
4	This method	10.4786	0.18	0.19	502.2	3.143	11.685	9.461	11.687