DESIGN TECHNIQUES FOR BANDPASS FILTERS USING EDGE-COUPLED MICROSTRIP LINES ON FUSED SILICA*

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Abstract

This paper presents a simple computer model for edge-coupled microstrip line. The model includes the effects of unequal odd/even phase velocities, end-effect capacitance, and loss. The bandpass filter design procedure described herein uses the model to select final element values. Agreement for filters constructed on fused silica in comparison with their computer model is very good. Data are provided for a filter operating over 11.5 to 12.4 GHz. These results are obtained on the first mask and with no bench adjustment.

Introduction

Bandpass filters utilizing edge-coupled microstrip lines are normally designed without accounting for several important physical phenomena including end-effect capacitance, unequal odd/even phase velocities, and loss. This paper describes a simple computer model that includes these three effects. Final element values of the bandbass filter are selected by using computer simulations. Measurements of bandpass filters designed in this fashion and constructed on fused silica have shown excellent agreement with experimental results.

Development of Computer Model

The loss of a single section of edge-coupled microstrip is estimated simply by assuming uniform current flow with respective even/odd attenuation constants given by

$$\alpha_{EV(OD)} = R_S \frac{Y_{EV(OD)}}{2w}$$

where R_S is the sheet resistance $(\sqrt{W\rho\mu_0/2})$, and W is the line width. This simple estimate is justified in that it is physically reasonable and appears to give useful engineering results.

Reference 1 describes the 4-port behavior of a single section of lossless coupled microstrip. These results may be slightly extended to yield

$$Y_{11} = \frac{1}{2}\left[\frac{Y_{EV}}{\tanh(\gamma_{EV}L)}\right] + \left[\frac{Y_{OD}}{\tanh(\gamma_{OD}L)}\right] \quad (1)$$

$$Y_{12} = \frac{1}{2}\left[\frac{Y_{EV}}{\tanh(\gamma_{EV}L)}\right] - \left[\frac{Y_{OD}}{\tanh(\gamma_{OD}L)}\right] \quad (2)$$

$$Y_{13} = -\frac{1}{2}\left[\frac{Y_{EV}}{\sinh(\gamma_{EV}L)}\right] - \left[\frac{Y_{OD}}{\sinh(\gamma_{OD}L)}\right] \quad (3)$$

$$Y_{14} = -\frac{1}{2}\left[\frac{Y_{EV}}{\sinh(\gamma_{EV}L)}\right] + \left[\frac{Y_{OD}}{\sinh(\gamma_{OD}L)}\right] \quad (4)$$

where $\gamma_{EV(OD)} = \alpha_{EV(OD)} + j\beta_{EV(OD)}$ and the terminals are defined in Figure 1. The circuit model of a single section is completed by terminating ports 2 and 4 in their open-circuit capacitances:

$$I_2 = -j\omega C_{OC} V_2 \quad (5)$$

$$I_4 = -j\omega C_{OC} V_4 \quad (6)$$

Equations (1)–(6) are readily incorporated into a microwave circuit package as a 2-port call or command. Filter simulations using this model show that the unequal odd/even phase velocities cause a spurious response at twice the center frequency. The end-effect capacitance causes a translation of the passband downward in frequency. The loss effect causes passband dissipation and some smoothing of the filter response.

Bandpass Filter Design Procedures and Example

After the required filter response is specified, the odd/even impedances are deduced from Cohn.[2] The computer program of Bryant and Weiss[3-4] is used to find Y_{EV}, Y_{OD}, v_{EV}, and v_{OD} in terms of w, s, and H (substrate thickness). C_{OC} is estimated by assuming a single line of width w and using results from the literature.[5] Initial interaction lengths are selected by using Dell-Imagine's[6] criteria. The filter is then simulated by using a cascade of this model and the interaction lengths are further adjusted to obtain the desired response.

These techniques have been used to construct 10 different filters, covering frequencies from 9 to 15 GHz, on fused silica. The mask dimensions of a representative filter (N = 3, LAR = 0.2 dB, F_0 = 11.95 GHz, and BW = 0.9 GHz) are shown in Figure 2. The corresponding electrical parameters required by the computer model are listed in Table 1. C_{OC} has been increased approximately 10 percent over the single line width estimates in the literature. Part or all of these corrections may be due to dispersion which is not included in the model.

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Table 1. Electrical Parameters Required by the Computer Model

Quantity	Section	
	0, 1	1, 2
Z_{EVEN}	70.4 Ω	55.3 Ω
Z_{ODD}	39.1 Ω	45.3 Ω
Effective Even Dielectric Constant	3.0912	3.1360
Effective Odd Dielectric Constant	2.5532	2.7233
C_{OC}	0.018 pF	0.022 pF

The measured and predicted filter transmission response is shown in Figure 3. The 2- to 3-dB discrepancy out of band is not completely understood. The discrepancy on the high end of the band may be due to the onset of waveguide propagation, since the particular filter package used had its dominant TE_{10} frequency at approximately 14.5 GHz. The passband tranmission response is shown in Figure 4. The computer model of this filter predicts 0.4- to 0.6-dB passband loss. If a simple transmission loss of 0.2 were assigned to each launcher, then the measured response would appear fairly good. The measured center frequency of this filter based on the measured 3-dB points is 11.952 GHz. The predicted 2.6-dB frequencies are 11.39 and 12.53 GHz, respectively. The agreement in location of corner and center frequencies is felt to be remarkable.

The existence of the spurious response at twice the center frequency has been verified with a filter having a center frequency of 9.2 GHz. Ten different filter designs covering 9.2 to 14.7 GHz have been successfully investigated with these techniques. These filters have been constructed on fused silica; however, the techniques should be equally applicable to other substrate materials.

Conclusion

This paper describes a computer model for edge-coupled microstrip that includes the effects of unequal odd/even phase velocities, dissipative loss, and end-effect capacitance. The agreement between predicted and measured transmission response is good and the correlation between predicted and measured corner and center frequencies is very good. These techniques have proven so fruitful that bandpass filters are presently being directly designed into active circuits without separate mask layouts and testing.

Acknowledgments

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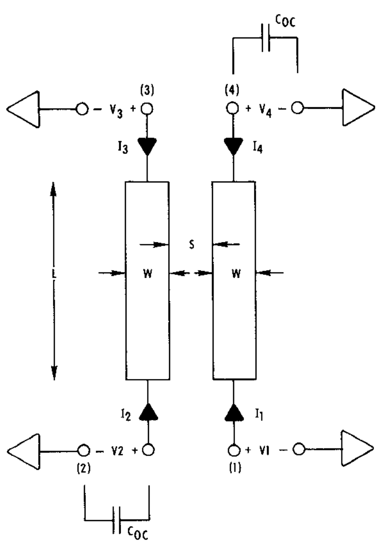

Figure 1. Terminal Definition of a Pair of Coupled Microstrip Lines

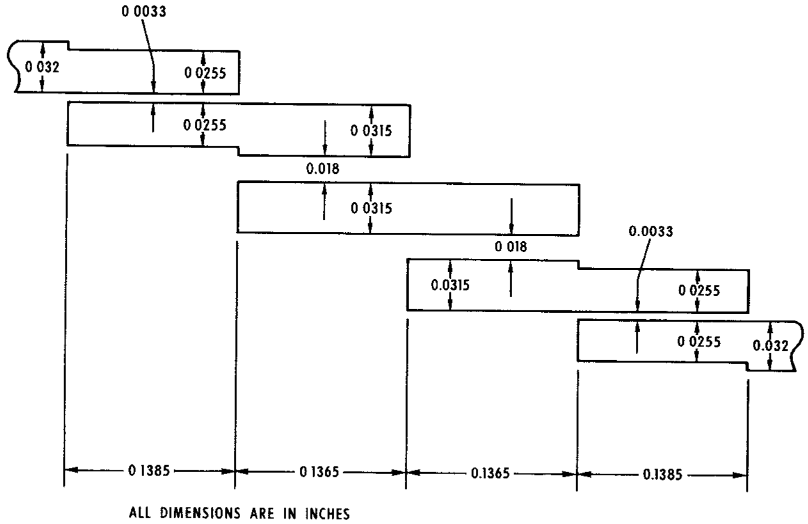

Figure 2. Filter Dimensions on 0.015-Inch Fused Silica

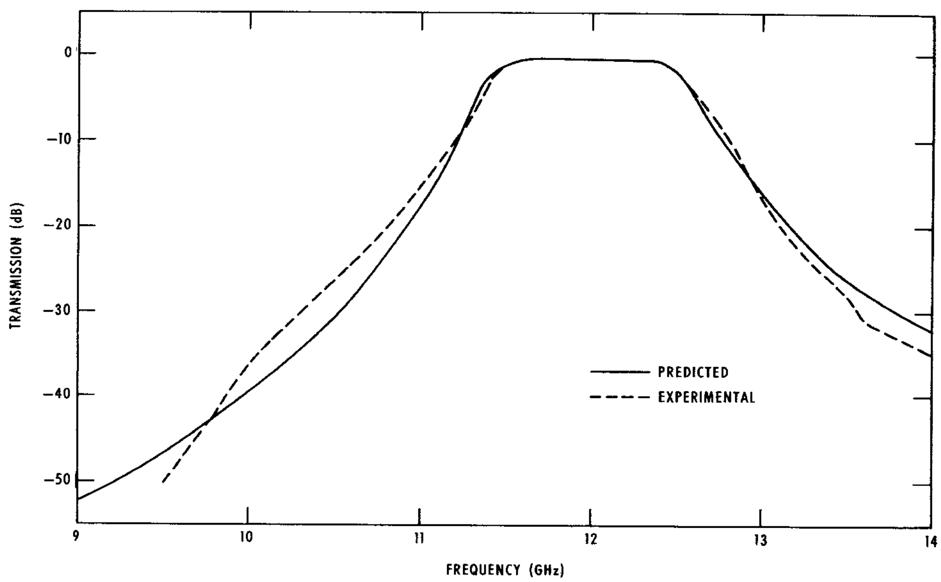

Figure 3. Experimental and Predicted Response for Example Filter

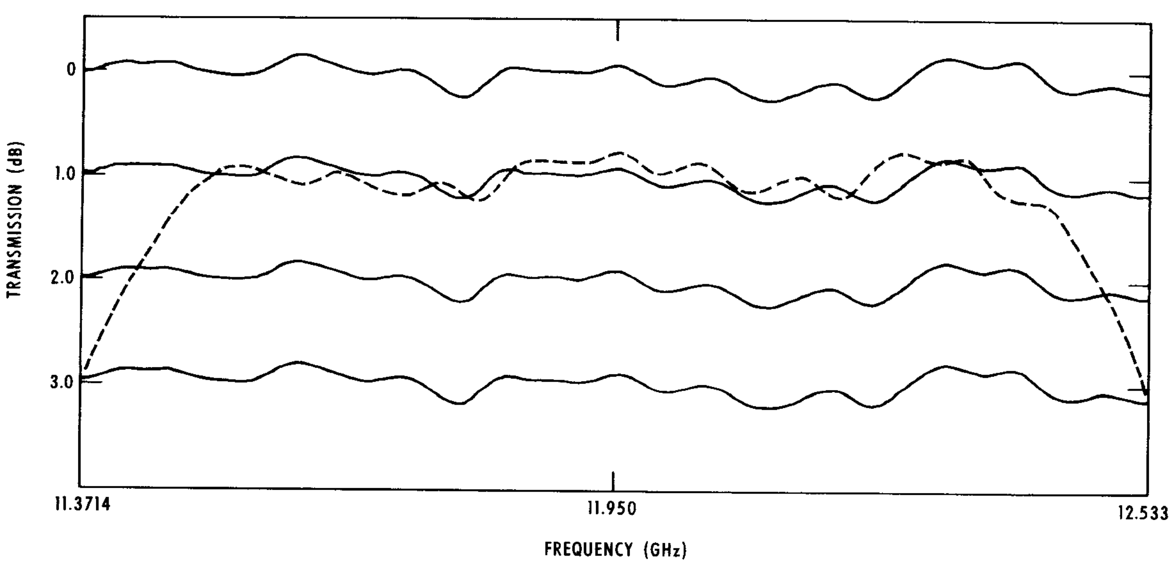

Figure 4. Measured Passband Response of Example Filter