Length Reduction of Evanescent-Mode Ridge Waveguide Bandpass Filters

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Abstract—**Length reduction of evanescent-mode ridge waveguide bandpass filters is investigated. A generalized filter configuration is proposed to reduce the filter length. It is found that the filter length can be reduced by enlarging the height of the evanescent waveguide. It is also found that the cutoff frequency of fundamental mode of the ridge waveguide has a considerable effect on the filter length.**

I. Introduction

Compared to rectangular waveguides, ridge waveguides [1], [2] have the advantages of wide fundamental-mode operation bandwidth, low cutoff frequency, and low wave impedance. In addition, there is a great deal of flexibility in ridge configuration according to different electrical and mechanical requirements [3]. Because of these advantages, ridge waveguides have found extensive applications in microwave active and passive components, one of which is the filter.

Evanescent-mode ridge waveguide filters have drawn considerable attention in the recent past because of their relatively wide spurious-free out-of-band response, compact size, and reduced weight. In [4]-[6] evanescent-mode ridge waveguide lowpass and bandpass filters are presented, where various ridge configurations are used and wide spurious-free out-of-band response is achieved. Recently, evanescent-mode ridge waveguide bandpass filters are implemented successfully in LTCC (Low Temperature Cofired Ceramics) [7], [8].

The length of evanescent-mode ridge waveguide bandpass filters has been a problem. In [6], serrations are introduced in the ridge waveguide to reduce the resonator length and suppress the spurious response. In this paper, the length reduction of evanescent-mode ridge waveguide bandpass filters is investigated. In the previous work, the evanescent waveguide (used as the impedance inverter) has the same cross section as the ridge waveguide (used as the resonator), as shown in Fig. 1(a). In this work, in order to reduce the filter length, a generalized filter configuration shown in Fig. 1(b) is proposed. In this new configuration, the cross sections of the evanescent waveguide and the ridge waveguide are not necessarily the same. It is found that the filter length can be reduced by enlarging the height of the evanescent waveguide. It is also found that the cutoff frequency of fundamental mode of the ridge waveguide has a considerable effect on the filter length.

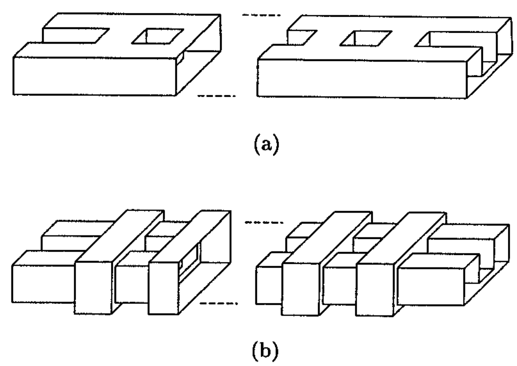

Fig. 1. Evanescent-mode ridge waveguide bandpass filters. (a) Conventional configuration. (b) Generalized configuration.

II. Modeling and Synthesis

For full-wave modeling, the evanescent-mode ridge waveguide bandpass filter shown in Fig. 1 is decomposed into the cascade connection of the discontinuity between the ridge waveguide and the rectangular waveguide shown in Fig. 2. The generalized scattering matrix of the discontinuity is obtained using mode matching method [9]. The overall generalized scattering matrix of the filter is then obtained using cascading procedure. Fig. 3 shows the comparison between mode-matching results and HFSS results for an one-pole ridge waveguide bandpass filter. A good agree-

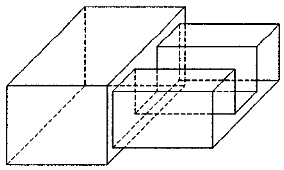

Fig. 2. Discontinuity between ridge waveguide and rectangular waveguide.

ment is observed.

For synthesis, in the evanescent-mode ridge waveguide bandpass filter, the impedance inverter is realized using the evanescent waveguide operating below the cutoff frequency of its fundamental mode, while the series resonator between the impedance inverters is realized using the ridge waveguide. In the practical design, the effect of the discontinuity between the ridge waveguide and the rectangular waveguide should be taken into account. The impedance inverter is composed of two identical such discontinuities cascaded together through a section of evanescent waveguide. The value of the impedance inverter can be obtained from its scattering parameters. The cross section and the length of the evanescent waveguide can be adjusted to achieve the synthesized value of the impedance inverter. Once the impedance inverter is determined, the length of the ridge waveguide is shortened to subtract the effect of the discontinuity between the ridge waveguide and the rectangular waveguide.

In the conventional configuration, since the evanescent waveguide has the same cross section as the ridge waveguide, the synthesized value of the impedance inverter is achieved by adjusting the length of the evanescent waveguide only. In the generalized configuration, the cross sections of the evanescent waveguide and the ridge waveguide are not necessarily the same. This provides two more degrees of freedom in achieving the synthesized value of the impedance inverter. By choosing an optimal cross section of the evanescent waveguide, the total filter length could be minimized.

III. Length Reduction

Using different cross-section configurations of the ridge waveguide and the evanescent waveguide, a five-section 10 GHz filter of bandwidth of 1 GHz and passband return loss of 20 dB is designed. For the purpose of LTCC applications, in the design the filter is assumed to be filled with the dielectric material of relative dielectric constant $\epsilon_r = 6$. The typical computed

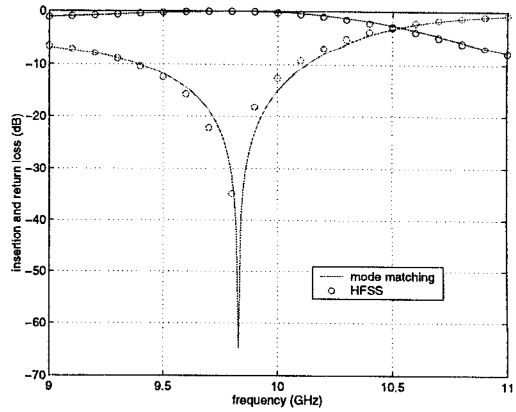

Fig. 3. Comparison between mode-matching results and HFSS results for an one-pole evanescent-mode ridge waveguide bandpass filter. The cross-section dimensions of the ridge waveguide in mils are: $a = 180$, $b = 80$, $s = 36$, and $d = 12$. The cross-section dimensions of the evanescent waveguide in mils are: $a' = 180$ and $b' = 140$. Refer to Fig. 5 for the cross-section dimension notations. The lengths of the evanescent waveguide and the ridge waveguide are 14 and 6 mils, respectively. The filter is assumed to be filled with the dielectric material of relative dielectric constant of $\epsilon_r = 6$.

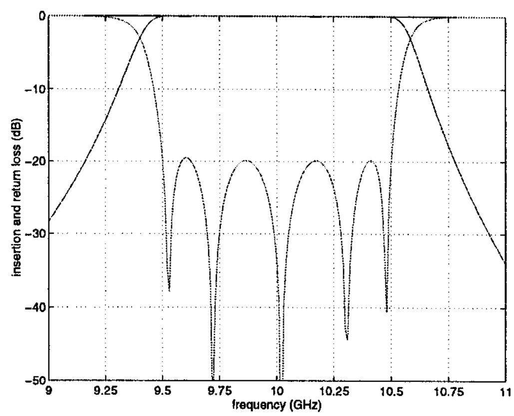

Fig. 4. Computed response of the filter.

response of the filter is shown in Fig. 4.

The cross-section configuration of the ridge waveguide is usually determined according to its fundamental-mode operation bandwidth, power handling capacity, and attenuation property. However, it will be seen later that the cutoff frequency of fundamental mode of the ridge waveguide has a considerable effect on the filter length.

Table I gives the dimensions of the filter designed using different cross-section configurations of the ridge waveguide and the evanescent waveguide. The dimen-

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TABLE I

Dimensions of the evanescent-mode ridge waveguide bandpass filter. Dimensions are given in mils. R represents the length reduction in percentage. Refer to Fig. 5 for the dimension notations. The evanescent waveguide has the same width as the ridge waveguide ($a' = a$).

b'	l'			l			L	R
	1 (6)	2 (5)	3 (4)	1 (5)	2 (4)	3		
$a = 120$, $b = 54$, $s = 48$, $d = 8$, $f_c = 8.38$ GHz								
b	25.49	59.46	72.65	117.37	96.56	93.75	837	
75	18.39	50.64	65.83	112.40	83.70	79.65	742	11%
100	15.58	43.60	58.32	105.56	76.11	71.60	670	20%
$a = 122$, $b = 56$, $s = 48.8$, $d = 8.2$, $f_c = 8.18$ GHz								
b	26.38	64.17	78.64	101.83	80.64	78.25	782	
86	17.98	52.89	69.91	93.85	65.63	61.98	663	15%
110	15.73	46.27	62.23	90.59	62.70	58.96	614	21%
$a = 140$, $b = 65$, $s = 56$, $d = 10$, $f_c = 7.27$ GHz								
b	33.93	94.42	115.24	54.28	36.35	35.10	704	
95	23.24	81.52	106.24	52.28	29.89	28.35	615	13%
125	18.94	68.59	93.58	50.60	28.25	26.40	546	22%

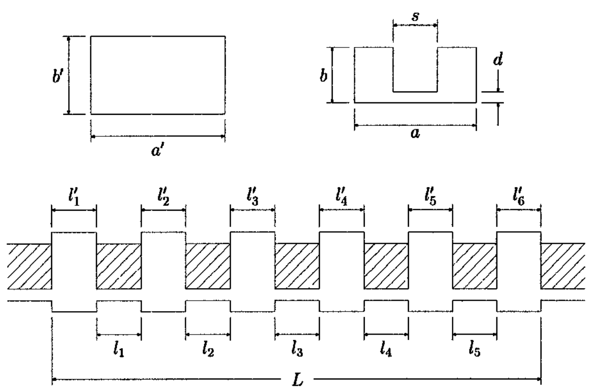


Fig. 5. Dimension notations used in Table I for the five-section evanescent-mode ridge waveguide bandpass filter.

sion notations used in the Table are given in Fig. 5. Three ridge waveguides are used. The main difference of the three ridge waveguides is the cutoff frequency of fundamental mode f_c. The first one has the highest f_c (8.38 GHz), the third one the lowest (7.24 GHz), and the second one in between (8.18 GHz). In the Table, for each ridge waveguide, three evanescent waveguides of different heights (and the same width as the ridge waveguide) are used. The first row for each ridge waveguide lists the length dimensions of the filter using the evanescent waveguide having the same cross section as the ridge waveguide ($b' = b$)

From Table I, it is found that enlarging the height of the evanescent waveguide can reduce the lengths of both ridge waveguide and evanescent waveguide, and hence the total length of the filter. More than 20% length reduction (denoted as R in Table I) for all three ridge waveguides can be achieved.

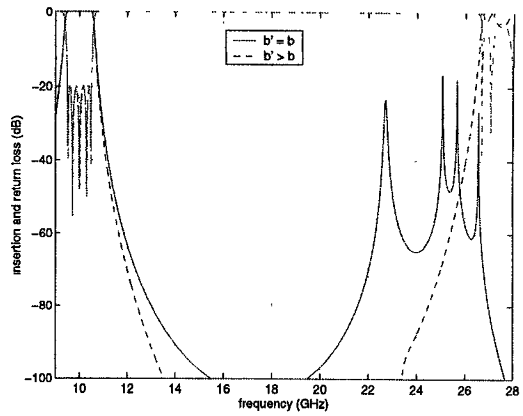
From Table I, it is also found that the cutoff frequency of fundamental mode of the ridge waveguide has a considerable effect on the filter length. The filter length can be reduced using the ridge waveguide of lower cutoff frequency. Another interesting observation is that the cutoff frequency of fundamental mode of the ridge waveguide determines the length ratio of the ridge waveguide to the evanescent waveguide. When the cutoff frequency is close to the filter band, the ridge waveguide length is larger than the evanescent waveguide length. With the cutoff frequency moving away from the filter band, the ridge waveguide length decreases, and the evanescent waveguide length increases. Finally, when the cutoff frequency is (relatively) far from the filter band, the evanescent waveguide length is much larger than the ridge waveguide length. Actually the concept of evanescent-mode waveguide bandpass filters [10], [11] refers to this case, in which compared with the evanescent waveguide, the ridge waveguide is so small that it can be viewed as a capacitive screw. When the ridge waveguide length is larger than the evanescent waveguide length, the filter operates more like the coupled cavity filter with the evanescent waveguide as the coupling element. Although the filter length can be reduced using the ridge waveguide of lower cutoff frequency, in practice, however, since the ridge waveguide length cannot be too small due to the fabrication difficulty, the length reduction is limited.

It is found that enlarging the width of the evanescent waveguide has little effect on the length reduction of the filter or even increases the filter length in some cases. A reasonable explanation is that the evanescent waveguide becomes less "evanescent" with an enlarged width. It is also found that using the evanescent waveguide having smaller width than the ridge waveguide could reduce the evanescent waveguide length. However the ridge waveguide length is increased, and the total length of the filter is not reduced.

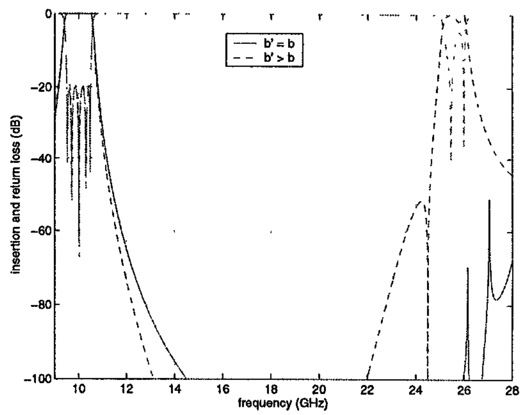
Figs. 6(a) and (b) show the spurious responses of the filters using the ridge waveguides of $f_c = 8.18$ GHz and $f_c = 7.27$ GHz (dimensions are given in Table I), respectively. It is seen that enlarging the height of the evanescent waveguide has no definite effect on the spurious response of the filter.

IV. Summary

Length reduction of evanescent-mode ridge waveguide bandpass filters is investigated. A generalized filter configuration is proposed to reduce the filter length. It is found that the filter length can be reduced by enlarging the height of the evanescent waveguide. It is also found that the cutoff frequency of fundamental mode of the ridge waveguide has a considerable effect on the filter length.



(a)



(b)

Fig. 6. Spurious response of two filters. (a) The filter dimensions are given in Table I for the ridge waveguide of $f_c = 8.18$ GHz. The solid line is for $b' = b = 56$ mils. The dashed line is for $b' = 110$ mils. (b) The filter dimensions are given in Table I for the ridge waveguide of $f_c = 7.27$ GHz. The solid line is for $b' = b = 65$ mils. The dashed line is for $b' = 125$ mils.

References

[1] S. B. Cohn, "Properties of ridge waveguide," *Proc. IRE*, vol. 35, pp. 783-788, Aug. 1947.

[2] S. Hopfer, "The design of ridged waveguides," *IRE Trans. Microwave Theory Tech.*, vol. MTT-5, pp. 20-29, Oct. 1955.

[3] A. M. K. Saad, "A unified ridge structure for evanescent-mode wideband harmonic filters: analysis and applications," in *17th European Microwave Conf. Proc.*, Rome, Italy, 1987, pp. 157-162.

[4] A. M. K. Saad, "Novel lowpass harmonic filters for satellite application," in *IEEE MTT-S Int. Microwave Symp. Dig.*, San Francisco, CA, May 1984, pp. 292-294.

[5] A. M. K. Saad, J. D. Miller, A. Mitha, and R. Brown, "Analysis of antipodal ridge waveguide structure and application on extremely wide stopband lowpass filter," in *IEEE MTT-S Int. Microwave Symp. Dig.*, San Diego, CA, May 1986, pp. 361-363.

[6] A. M. K. Saad, A. Mitha, and R. Brown, "Evanescent mode-serrated ridge waveguide bandpass harmonic filters," in *16th European Microwave Conf. Proc.*, Dublin, Germany, 1986, pp. 287-291.

[7] J. Gipprich, D. Stevens, M. Hageman, A. Piloto, K. A. Zaki, and Y. Rong, "Embedded waveguide filters for microwave and wireless applications using cofired ceramic technologies," in *Proc. Int. Symp. Microelectron.*, San Diego, CA, Nov. 1998, p. 23.

[8] Y. Rong, K. A. Zaki, M. Hageman, D. Stevens, and J. Gipprich, "Low-temperature cofired ceramic (LTCC) ridge waveguide bandpass chip filters," *IEEE Trans. Microwave Theory Tech.*, vol. 47, pp. 2317-2324, Dec. 1999.

[9] C. Wang and K. A. Zaki, "Full-wave modeling of generalized double ridge waveguide *T*-junctions," *IEEE Trans. Microwave Theory Tech.*, vol. 44, pp. 2536-2542, Dec. 1996.

[10] G. F. Craven and C. K. Mok, "The design of evanescent mode waveguide bandpass filters for a prescribed insertion loss characteristics," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-19, pp. 295-308, Mar. 1971.

[11] R. V. Synder, "New application of evanescent mode waveguide to filter design," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-25, pp. 1013-1021, Dec. 1977.