New Parallel λ/2-Microstrip Line Filters With Transmission Zeros at Finite Frequencies

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Abstract- **The paper presents a new class of λ/2-microstrip line filters with transmission zeros at finite frequencies. The filters take advantage of the difference between the propagation constants of the even and odd modes of two symmetric coupled microstrip lines to generate the transmission zeros in addition to the reflection zeros of the passband. A simple model is used to show that the transmission zeros are not due to cross-coupling of non-adjacent resonators but rather to internal anti-resonances in the structure. The results obtained from a full-wave solution using a commercial software package are in good agreement with those of the model. Examples of filters with transmission zeros in the lower or upper stop-bands are presented.**

***Index Terms*—Bandpass filters, elliptic function filters, filter synthesis, transmission zeros.**

I. INTRODUCTION

Elliptic and pseudo-elliptic filters are implemented by providing additional cross or bypass couplings between non-adjacent resonators to generate the required transmission zeros. In microstrip technology, resonators which allow both electric and magnetic coupling are used in designing these class of filters. A convenient class of resonators for this kind of applications exploits capactive gaps in rectangular rings to both reduce the dimensions and provide the needed electric coupling [1].

Filters using identical parallel microstrip lines seem to have been first proposed by Matthaei for high temperature superconductors [2] and [3]. A version of these filters where the resonators are staggered was also porposed by Matthaei and coworkers and others [1], [4] and [5]. The filters reported in [3] and [4] do not exhibit finite transmission zeros, at least such transmission zeros were not visible in the reported results. On the other hand, the filters reported in [5], where the resonators are staggered, exhibit one or more transmission zeros in the upper stop-band. No transmission zeros in the lower stop-band were reported for this type of filters.

In this paper, we present filters similar to those in [2] but which exhibit transmission zeros at finite frequencies. Transmission zeros in the lower or upper stop-band are generated by properly choosing the positions of the input and output. It is also shown that finite transmission zeros in multiple resonators can be resolved by staggering the resonators. To understand the origin of these transmission zeros, a simple model of a second-order filter with one transmission zero is used. It is found that the transmission zero is not due to cross-coupling but rather to internal anti-resonances in the structure. This result is then used as a basis for the design of a second order filter with two transmission zeros. The results obtained from the model are in good agreement with those obtained from the commercial software package.

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II. SECOND ORDER FILTER WITH ONE ZERO BELOW PASSBAND

We first consider a second order filter whose dimensions and layout are shown in Figure 1. This structure was first simulated using a commercial software package, namely IE3D from Zeland Software Inc. The results are shown in Figure 2 as the sold lines. The second order response of the filter and the presence of a transmission zero in the lower stop-band are clearly visible.

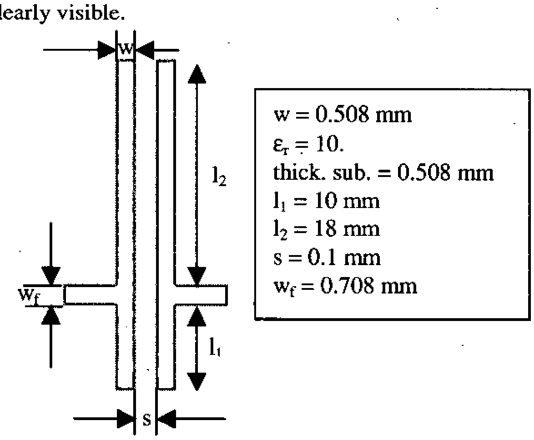


Fig.1 Layout and dimensions of second order filter with one transmission zero in the lower stop-band.

To understand the origin of the observed transmission zero in the lower stop-band, a simple model of this structure was used. It is assumed that the structure is lossless and that there is interaction only between the two resonators. In particular, we assume that none of the resonators is bypassed or cross-coupled. It is also assumed that the feeding lines are of negligible width. Under these assumptions, the structure can be modeled as two sections of two coupled symmetric microstrip lines of lengths l_1 and l_2. It can, therefore, be represented by its even and odd modes. Let Y_{0e}, Y_{0o}, β_e and β_o be the

0-7803-7695-1/03/$17.00 © 2003 IEEE

characteristic admittances and propagation constants of the two modes. If we neglect the additional reactances of the T-junctions at the input and the ouput, the structure can be represented by its admittance matrix. A straightforward analysis leads to the following results

$$y_{12} = y_{21} = \frac{jY_{0e}}{2}[\tan(\beta_e l_1) + \tan(\beta_e l_2)] - \frac{jY_{0o}}{2}[\tan(\beta_o l_1) + \tan(\beta_o l_2)] \quad (1)$$

$$y_{11} = y_{22} = \frac{jY_{0e}}{2}[\tan(\beta_e l_1) + \tan(\beta_e l_2)] \quad \frac{jY_{0o}}{2}[\tan(\beta_o l_1) + \tan(\beta_o l_2)] \quad (2)$$

These parameters are converted to an ABCD matrix which is cascaded with the ABCD matrices of the lines at the input and the output. It is necessary to take the input and output lines into account since their characteristic impedance may not be equal to the normalization impedance (50 Ω). Finally, the scattering parameters are calculated from the ABCD parameters using standard expressions [6].

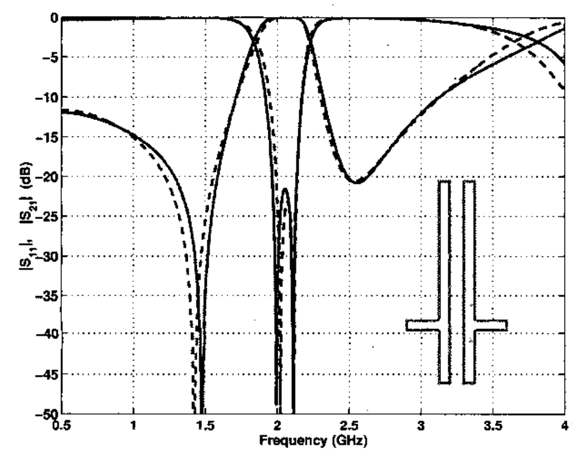


Figure 2. Response of the filter in Fig.1. Solid lines: full-wave analysis (IE3D), dashed lines: analytic TEM model using even and odd modes of lines. The transmission zero is predicted by the model although it contains no cross-coupling.

For the structure whose dimensions are given in Figure 1, a full-wave simulation leads to the following values at 2 GHz: $Z_{0e} = 1/Y_{02} = 65.79$ Ω, $Z_{0o} = 1/Y_{0o} = 33.06$ Ω, $\beta_e = 0.1191$ rad/mm and $\beta_o = 0.1066$ rad/mm. Using these values in equations 1-3, and ignoring the dispersion in the characteristic admittances and the propagation constants of the two modes, we get the results shown in Figure 2 as the dashed lines. These results are in good agreement with those of the full-wave simulation. The slight differences are attributed to the difference between the effective and physical lengths of the lines and the rough modeling of the T-junctions. A very important consequence of this result is that the transmission zero is not caused by the cross or bypass coupling since the model does not contain any additional coupling between the input and the second resonator or the output and the first resonator. In fact the transmission zero is due to an internal anti-resonance in the structure and corresponds approximately to the appearance of a short circuit at the ports due to the even mode. Indeed, for the even mode, the section of length l_2 which is terminated in an open circuit (ideally) looks like a short circuit at the frequency where $\beta_e(f_z)=\pi/(2l_2)$. Using the values above, and assuming that the effective dielectric constant is independent of frequency, this simple approximate relation gives f_z = 1.55 GHz. This value compares favorably with exact value of 1.48 GHz.

Another equally important implication of this result is that it may be possible to exploit the other internal anti-resonances to generate other transmission zeros to further enhance the attenuation in the stop-band. In fact, the shape of the hump in the upper stop-band in Figure 2 suggests the presence of non-resolved transmission zeros; the cutoff rate is simply too strong for a second order filter with only one transmission zero in the lower stop-band.

Figure 3 shows the response of a second order filter which is implemented by using the same structure but which has two transmission zeros. To adjust the in-band return loss it was necessary to control the lengths of the feeding lines and their width (the scattering parameters are normalized to 50 Ω). The width of the feeding lines is w_f=1.27 mm and their length is 5.67 mm. The separation between the parallel lines is s=0.069 mm and their width is w=0.508 mm (50 Ω lines).

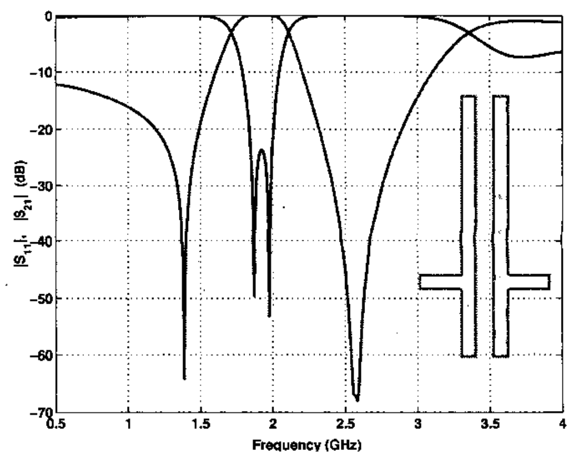


Figure 3. Response of second order filter with two transmission zeros. The dimensions are given in the text..

A closer examination reveals that the transmission zero in the upper stop-band is actually two transmission zeros which are not well resolved. To resolve them the width and length of the feeding lines adjusted to w_f = 1.58 mm and l=6.35 mm, respectively. The other dimensions of the structure are l_1 = 8.13 mm, l_2 = 18.14 mm and s = 0.069 mm. The response of such a filter is shown in Figure 4 where the two transmission zeros above the passband have been resolved. Note that these results are also predicted by the analytical model. The lengths of the lines l_1 and l_2 must be adjusted to take into account the difference between the effective and physical lengths due to the capacitances at the end of the lines. These agree well with those obtained by full-wave simulation.

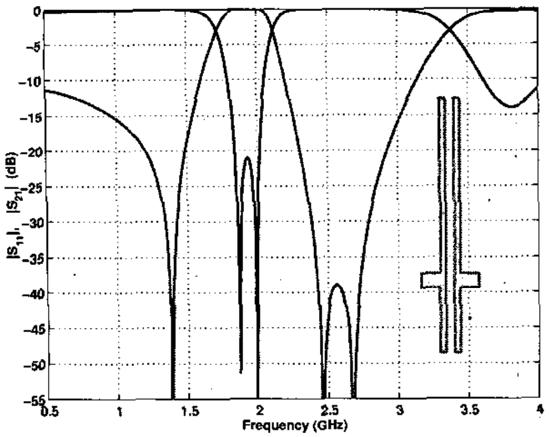
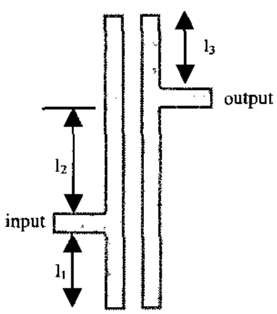


Figure 4. Response of the filter in Figure 3 when the two transmission zeros above the passband have been resolved. The dimensions are given in the text.

III. Second Order Filter with One Zero above Passband

To guarantee the flexibility of the filters designed using parallel coupled microstrip lines, it is necessary to be able to place the transmission zero on either side of the passband. Although the previous structure was able to generate transmission zeros above and below the passband simultaneously, we examine next structures which generate transmission zero in the upper stop-band.

To move the transmission zero of the filter in Figure 1 to the upper stop-band, either the input or the output is moved as shown in Figure 5. The response of this filter is shown in Figure 6 by the solid lines. These results, which were obtained from a full-wave simulation using the commercial software package IE3D, clearly show the two reflection zeros as well as the transmission zero in the upper stop-band. However, the full-wave simulation does predict some loss due mainly to metallic losses in the strip and ground place. The in-band insertion loss is 0.5 dB. The loss due to radiation is minimal. Obviously, the insertion loss can be improved by using superconductors.



w = 0.508 mm
ε_r =10
thick. die. = 0.508 mm
l_1 = 10.7 mm
l_2 = 7.43 mm
l_3 = 10.7 mm
s = 0.59 mm
w_f = 0.56 mm

Figure 5. Layout and dimensions of second order filter with one transmission zero in the upper stop-band.

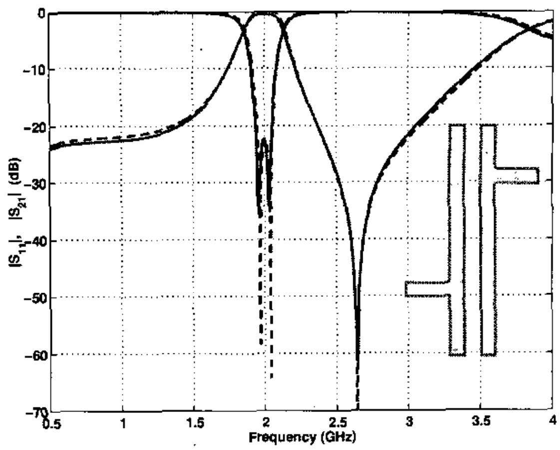


Figure 6. Response of filter in Figure 4. Solid lines: full-wave simulation (IE3D), dashed lines: analytic model based on even and odd modes of two coupled symmetric microstrip lines.

To determine whether the transmission zero in this filter is due to cross-coupling or internal anti-resonances, an analytical model similar to the one developed for the previous filter was derived. In this case, the filter can be viewed as three sections of two coupled symmetric microstrip lines. The parameters of the even and odd modes of the lines were obtained from a full-wave analysis (IE3D) and were then used to extract the admittance matrix of the structure which is used to determine the scattering parameters. The results obtained from this model are shown in Figure 6 as the dashed lines. The full-wave results and those of this model are in good agreement as this figure shows. A consequence of this is the fact that the transmission zero is not due to cross-coupling but rather to an internal anti-resonance as in the previous filter.

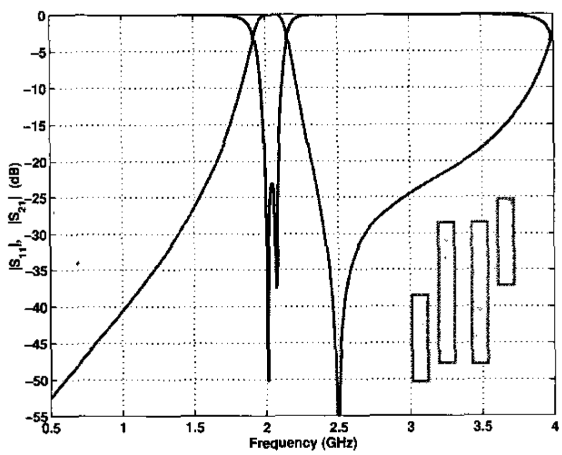


Figure 7. Alternative realization and response of a second order filter with a transmission zero above the passband.

Another simple geometry which can be used to implement a second order filter with one transmission zero in the upper stopband is shown in Figure 7 along with its full-wave simulated response. Here the input and output lines are replaced by sections of microstrip lines which are edge-coupled to the two resonators. This configuration offers another alternative to that in Figure 1 for basically the same specifications.

IV. Third Order Filter

Next, we examine a third order filter using parallel half wavelength microstrip resonators with a pseudo-elliptic response.

The structure used to implement this response is shown in Figure 8. To accommodate the required couplings, and generate the two transmission zeros, it was necessary to stagger the resonators (c.f., Figure 8).

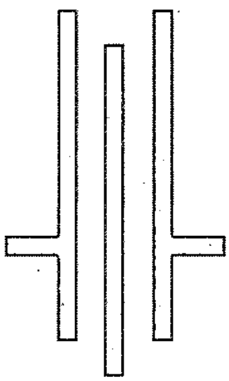


Figure 8. Layout for 3[rd] order filter with two transmission zeros.

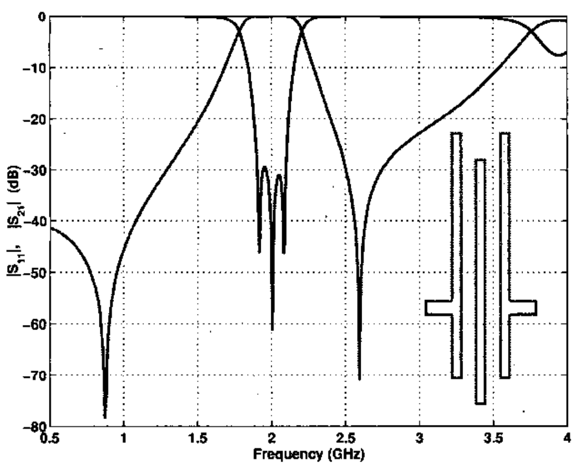


Figure 9. Simulated response of 3-resonator filter with two transmission zeros.

A third order filter with one transmission zero in the lower stop-band and one in the upper stop-band was designed and accurately simulated. Its response is shown in Fig. 9. The presences of the two transmission zeros and the three reflection zeros are evident. Higher-order filters were also designed using parallel half wavelength microstrip resonators and will be discussed during the presentation.

Another point which was not addressed here is the effect of radiation on the performance of these filters. The full-wave simulation takes into account the presence of radiation which is found to be minimal for the investigated cases. The radiation loss may become more significant for higher-order filters where metallic shielding becomes necessary [7].

V. Conclusions

New microstrip pseudo-elliptic filters which require no via holes or additional cross-couplings were introduced. The necessary transmission zeros are generated by exploiting internal anti-resonances when the input and output are properly placed. The transmission zeros can be generated on either side of the passband and can be moved from one side to the other by changing the location of the input and the output. The results of full-wave simulation were validated by direct comparison with an analytical solution of second order filters with a transmission zero either in the upper or lower stopband.

VI. References

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