Microstrip Bandstop Filters Using L- and T-Shaped Resonators

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Abstract **- Bandstop filters in microstrip technology are introduced. The filters are based on a T-shaped resonator located between two identical L-shaped resonators; all of them are coupled to a main microstrip line, and separated by sections of transmission lines with appropriate length. According to ABCD matrix analysis, carried out for commensurate resonators, this structure produces two transmission zeros in the stopband as well as three reflection zeros in the passbands. X-band and Ku-band bandstop filters are designed based on the proposed method with bandwidths of 1.06 GHz and 0.97 GHz at mid-band frequencies of 9.72 GHz and 14.77 GHz, respectively. Both filters are prototyped and measured. Good agreement between simulated and measured results demonstrates the reliability and robustness of the design method.**

Index Terms — L resonator, T resonator, microstrip filter, bandstop filter.

I. Introduction

Bandstop filters and their bandpass counterparts play important roles in front ends of wireless communication systems. Different methods are used to design bandstop filters, including traditional approaches such as bandstop stubs [1] and defected ground structures [2]. Newer methods include non-resonating nodes filters, extracted pole techniques [3], signal interference methods [4], and coupled resonator filters [5]. Among all available bandstop filter technologies, microstrip filters have the lowest manufacturing cost and weight which make them suitable for low-power applications.

Most of the traditional microstrip bandstop filters suffer from narrow bandwidth. Therefore, some wideband microstrip bandstop filters have been reported recently containing short- or open-ended parallel coupled line sections. In [6], a compact wide stopband filter with three transmission zeros (TZs) in the stopband is introduced. The filter is constructed by using single quarter-wavelength resonators and a section of anti-coupled lines with short circuits at one end. Another general circuit configuration for wide bandstop filters based on cross coupling is presented in [7]. A very compact wide bandstop filter is also reported in [8] using two coupled lines sections in parallel. An interesting bandstop filter is introduced in [9] based on signal interference techniques. The structure in [9] is formed by an open-ended coupled line connected in parallel to a transmission line. Another novel transmission line configuration is proposed in [10] to design a sharp-rejection wideband bandstop filter.

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A compact parallel-coupled transmission line section, connected at both ends, is presented in [4] to obtain five transmission zeros in the stopband.

In this paper, we introduce wide bandstop filters consisting of a microstrip transmission line loaded with a T-shaped and two L-shaped resonators. The analytic investigation shows that the filter produces two TZs in the stopband as well as three reflection zeros (RZs) in the lower and upper passbands. This method is a good substitute for wide bandstop filter designs using parallel coupled line sections, especially when tight coupling values are not realizable due to manufacturing limitations. In addition, the design process is simpler than filters using coupled line sections with shorted transmission lines. Despite the C- and S-band wideband bandstop filters mentioned before, the new filters presented in this paper are designed to work at X- and Ku-band frequencies.

II. Filter Design

A microstip transmission line loaded with a commensurate L resonator is modeled by a coupled line section connected to a commensurate open circuit stub at one end. Fig. 1a shows the circuit and Fig. 1b the extracted equivalent circuit in the *s*-domain [1].

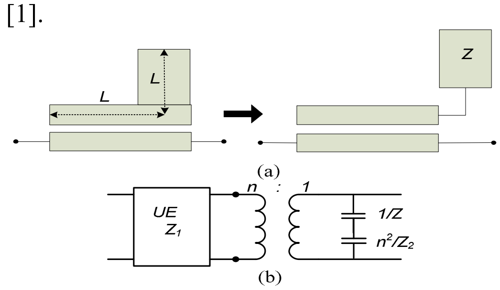

Figure 1. Commensurate L resonator (a) and its equivalent circuit in the s-domain (b).

The variable *s* is simply converted to regular frequency, *f*, by applying

$$s = j\tan\left(\frac{\pi}{2}\frac{f}{f_0}\right) \quad (1)$$

where f_0 is the frequency at which the commensurate length, *L*, is $\lambda_0/4$. Quantities *n*, z_1, z_2 and *z* are the equivalent circuit parameters calculated from the physical characteristics of the circuit including the spacing between coupled lines, width and lenght of the L resonator's arms, substate height, dielectric constant and thickness of metalization. For details, the reader is referred to [1]. The unit element (*UE*) is also a transmission line section with characteristic impedance $Z_1=1/Y_1$ and length L, whose admittance matrix

$$Y_{UE11}=Y_{UE22}=Y_1/s\ ,\quad Y_{UE12}=Y_{UE21}=-\sqrt{1-s^2}\,Y_1/s \qquad (2)$$

is converted to its ABCD matrix representation for cascading all line sections of a filter.

Fig. 2a shows a microstrip filter on RT/Duroid 6002 substrate with thickness of 0.508 mm. It consists of two identical commensurate L resonators separated by a section of transmission line. Its equivalent circuit is depicted in Fig. 2b. The characteristic impedance of the microstrip line section is Z_0=50 Ω, and the dimensions of the resonators are chosen appropriately to create a stopband at 9.80 GHz.

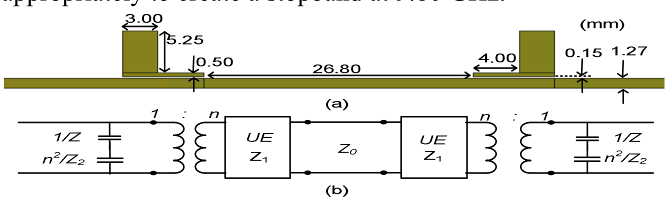

Figure 2. Bandstop filter created by two commensurate L resonators (a) and its equivalent circuit (b).

The scattering parameters of this circuit, calculated by ABCD matrices, are shown in Fig. 3 along with simulated results in CST. The structure produces two identical TZs in the stopband and several out-of-band RZs.

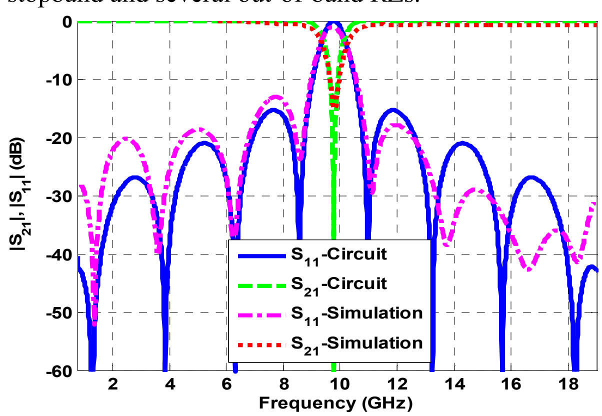

Figure. 3. Equivalent-circuit and CST responses of the filter in Fig. 2.

A T-shaped resonator and its equivalent circuit are obtained by treating it as two back-to-back L resonators as shown in Fig. 4. The dimensions of the T resonator are chosen to obtain a stopband at 9.5 GHz. The equivalent circuit response of this T resonator is compared to that of CST in Fig. 5, and good agreement is observed.

ABCD matrix analysis shows that combining the two L resonators in Fig. 2 with the T resonator in Fig. 4 results in a new bandstop filter with two TZs in the stopband and three RZs in the upper and lower passbands. The simulations show (not presented here due to lack of space) that the locations of three of the RZs presented in Fig. 3 can be effectively controlled by the physical dimensions of the filter so that a return loss better than 10 dB is achievable in the passbands. Note that the other RZs shown in Fig. 3 move to frequencies far from the stopband (as is shown for one of them in Fig. 7).

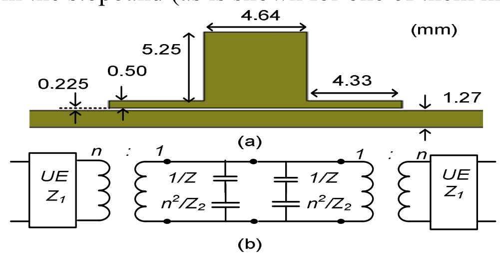

Figure 4. The inverse T resonator (a) and its equivalent circuit (b).

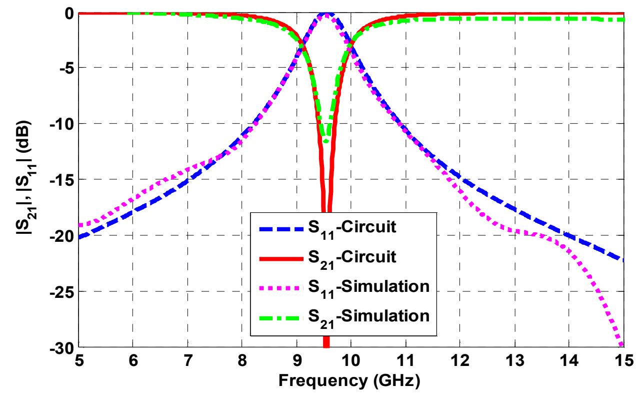

Figure 5. Equivalent-circuit and CST responses of the filter in Fig. 4.

Fig. 6 represents the final design of the filter. In comparison to Fig. 2 and Fig. 4, a few dimensions are slightly optimized. The simulated scattering parameters of the proposed filter are shown in Fig. 7 with the equivalent-circuit response for comparison. The CST simulation confirms the location of RZs and TZs predicted by the equivalent circuit model. The center frequency of the filter is 9.72 GHz which is in between the resonant frequencies of the T and L resonators. The bandwidth of the filter is 1.06 GHz.

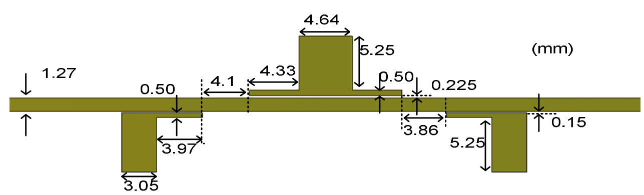

Figure 6. Final configuration of the designed filter.

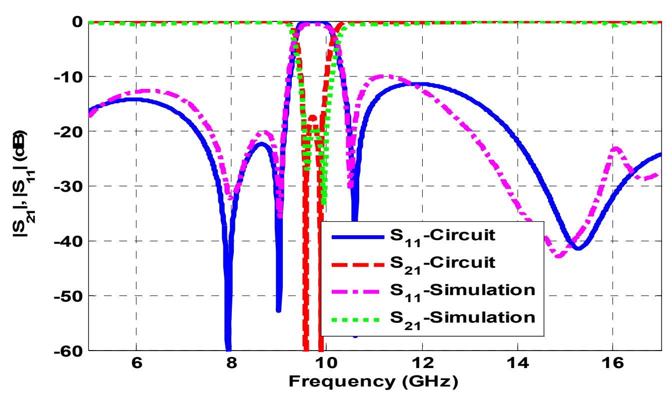

Figure 7. Equivalent-circuit and CST responses of the filter in Fig. 6.

III. Experimental Results

A top view of the prototyped filter is depicted in Fig. 8. A Thru-Reflect-Line (TRL) calibration kit is used to deembed the effects of transitions to coaxial ports.

Fig. 9 shows the comparison between simulated and measured results. Good agreement is observed. The locations of the simulated TZs and RZs are well reproduced in the measurements. The measured stopband attenuation is better than 16 dB, and the return loss in the lower passband is better than 12 dB while that in the upper passband is better than 10 dB.

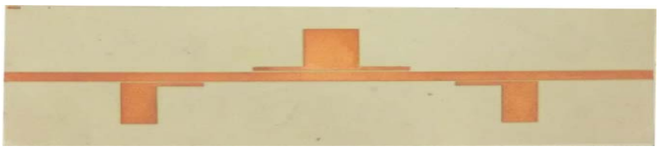

Figure 8. Prototyped commensurate microstrip wideband bandstop filter.

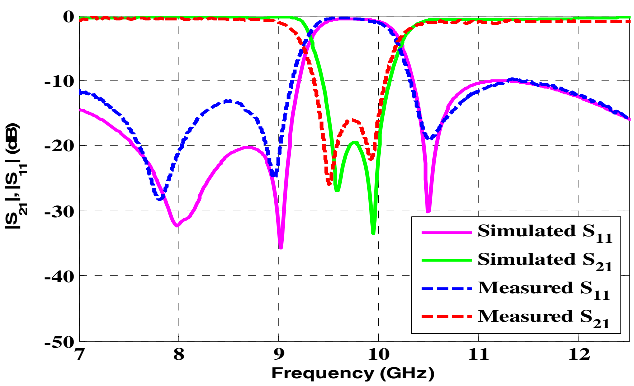

Figure 9. Simulated and measured responses of the filter with commensurate resonators in Fig. 8.

The analytic investigation is carried out based on commensurate resonators. However, CST simulations show that also non-commensurate L- and T-shaped resonators are capable of creating wideband bandstop filters with three RZs. A non-commensurate filter, with center frequency of 14.77 GHz and bandwidth of 0.97 GHz, is designed and prototyped as shown in Fig. 10.

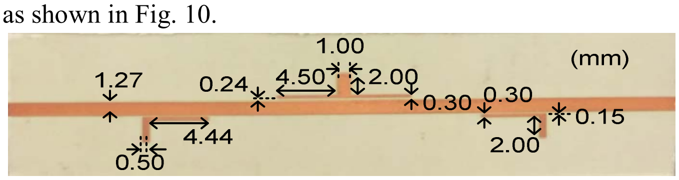

Figure 10. Prototyped non-commensurate microstrip bandstop filter.

Fig. 11 compares the measured responses of the filter with simulations. The locations of the simulated TZs and RZs are well confirmed by measurements. The stopband attenuation is better than 22 dB. The return loss in both lower and upper passbands is better than 10 dB.

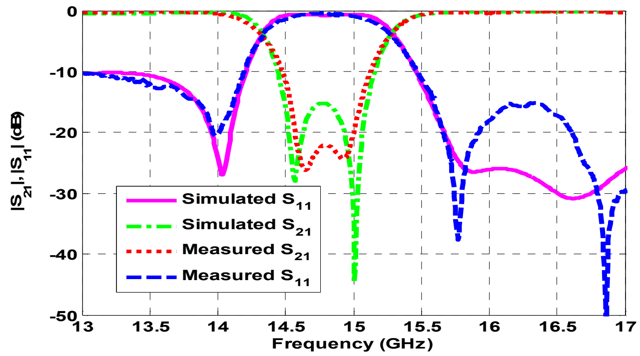

Figure 11. Simulated and measured scattering parameters of the non-commensurate microstrip filter in Fig. 10.

IV. Conclusion

A microsrtip configuration is introduced to realize relatively wide bandstop filters with three RZs. The reliable design process, beside the filter's low profile, weight, and manufacturing cost, makes this filter a good candidate for wide stopband applications especially in comparison with similar filters based on parallel coupled lines sections. Filters with commensurate and non-commensurate resonators are prototyped and measured. Good agreement between measured and simulated results demonstrates the robustness and reliability of the design method.

V. References

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