Pseudoelliptic microwave bandpass filters with three transmission zeros in quadruplet topology with frequency-dependent couplings

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Abstract

This paper discusses the properties of microwave bandpass filters with three finite transmission zeros realized in the quadruplet topology with frequency-dependent couplings. Firstly, the advantages of introducing dispersive couplings into a quartet section are discussed in terms of the number of realizable transmission zeros. Next, the sensitivity of filters characteristics with three transmission zeros (in terms of perturbed couplings) with constant and dispersive couplings are presented. Finally, two examples of a waveguide X band quadruplet with three transmission zeros implemented using dispersive direct and crosscoupling are presented to prove theoretical considerations.

1. Introduction

Microwave bandpass filters are one of the most important components in each terrestrial and satellite communication systems. Generally, the role of this circuits is to separate assumed frequency bands and to protect overall system from spurious frequencies [1]. The common way of improving filter selectivity is introducing one or more transmission zeros (TZ). In classical approaches, (under the assumption that all couplings are invariant with frequency) to obtain a transmission zero, one has to use crosscoupling (i.e. coupling between non-adjacent resonators) in the network [2]. This technique is widely used by filter designers for decades. However, introducing crosscouplings in a filter is not the only way of implementing transmission zero. For instance extracted pole structures are one option. One can also use topologies in which the source/load is coupled to more than one resonator. Another approach involves resonant couplings that are frequency-dependent. It has been shown that taking into account the frequency-dependence of couplings allows the realization of more transmission zeros (TZs) in comparison to filters designed in the conventional way [3-7]. This gives designers a new opportunity to improve filter responses in well-known topologies in a relatively simple way. One such "well known topology", frequently used in filter applications, is a quadruplet. In this arrangement, the coupling scheme consists of four directly coupled resonators and one crosscoupling (in most cases between the first and the fourth resonator). Since a quadruplet is often used as a building block of higher order filters in this paper we examine this structure in more detail and show the potential of using frequency-dependent couplings in a quartet section in comparison to classical designs. To this end we have concentrated on quadruplets with pseudoelliptic bandpass characteristics with three transmission zeros.

2. Analysis

Fig. 1 presents a typical quad-section configuration. When all couplings are frequency-invariant, a quadruplet realizes a symmetrical pair of imaginary (or real) transmission zeros [1] leading to pseudoelliptic filters with symmetrical characteristics. To break the symmetry of the characteristic, a coupling between the first and the third resonator has to be added [1]. However, introducing such diagonal coupling (sometimes called nested) makes a design and manufacturing more complex. As mentioned previously, to improve the flexibility of the topology (in terms of the number of transmission zeros) one can change the character of a selected coupling from constant to frequency-dependent. When the direct coupling between the second and the third resonator (from Fig.1) is made frequency-dependent, two imaginary transmission zeros are possible and no nested coupling is needed. In this case, the positions of TZs (i.e. on the lower or upper stopband) depends on the sign of a slope parameter of the dispersive coupling and the sign of the crosscoupling (capacitive or inductive). Making also the crosscoupling dispersive, enables an additional transmission zero, which in total leads to three transmission zeros. It can be proved that this is the maximum number of transmission zeros that this network can handle [9]. Three transmission zeros can also be achieved in a quadruplet with constant couplings but only when more than one coupling leading in/out from source/load to the resonators. It is interesting to compare this solution with the circuit using dispersive coupling. In [10] it was pointed out that filters with

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dispersive couplings exhibit lower characteristic sensitivity for coupling coefficients perturbation. No results have been however presented to support this claim. To validate this for quadruplets we have compared the responses of two quartet sections realizing three transmission zeros. For each case, a series of fifty scattering characteristics has been generated with a uniform distribution of the perturbed couplings (the constant part was varied in a within ± 5% of the nominal value of each coupling).

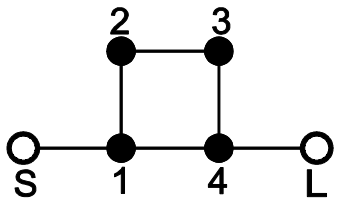


Figure. 1 Quadruplet topology (black circles denotes resonators, S,L – source, load, respectively)

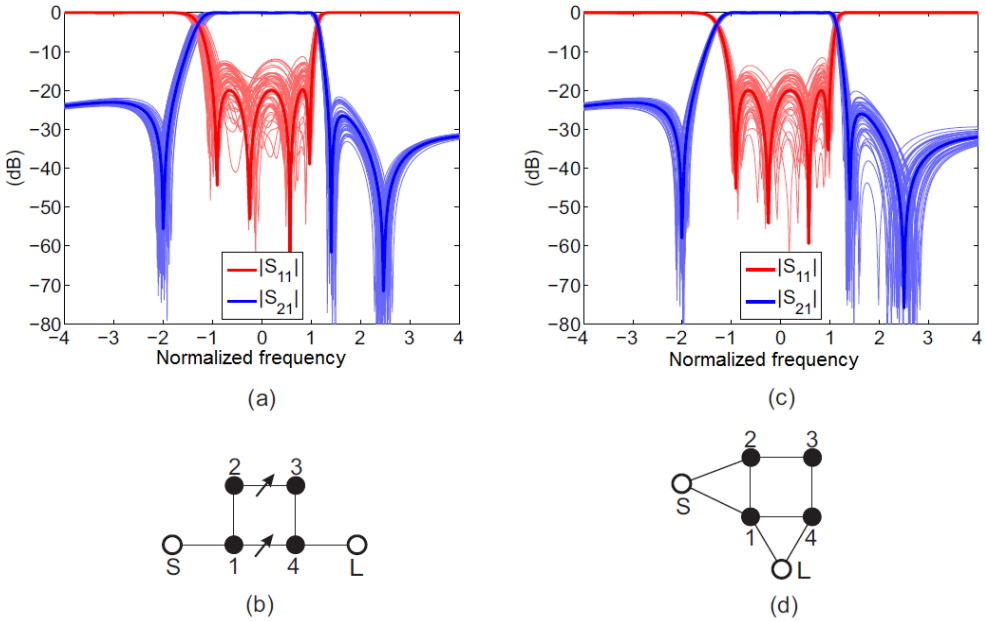


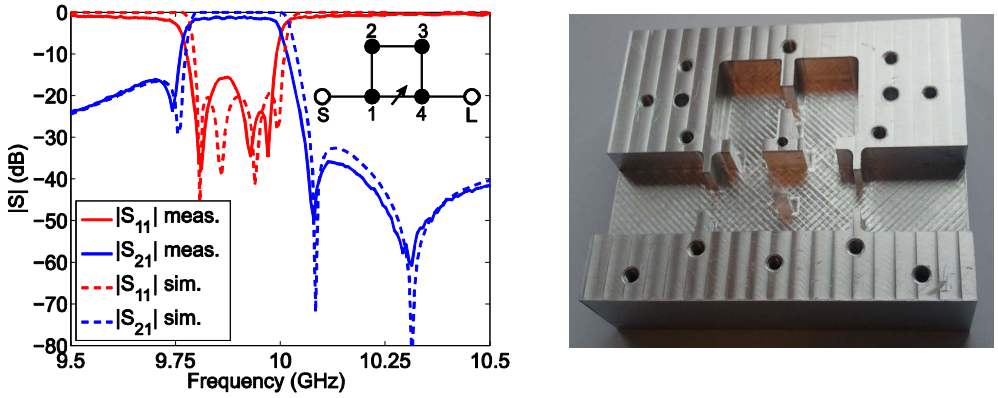
Figure. 2 (a) Sensitivity analysis for a quartet section with dispersive couplings, (b) quadruplet with dispersive couplings, (c) sensitivity analysis for a quartet section without dispersive couplings, (d) quadruplet with additional couplings from source/load

Figures 2 (a), (c) present the sensitivity analysis of scattering parameters performed for circuit with and without frequency-dependent couplings from Fig. 2 (b), (d), respectively (dispersive couplings are indicated by lines crossed by an arrow). For the dispersive case the return loss level was degraded to 11.3 dB in the worst case and the following spread of transmission zeros was obtained (starting from the lowest transmission zero): 15%, 12.8% 14.36%. For the circuit with constant couplings, the performed test revealed that the return loss level was degraded to 11.6 dB but the zeros have been found to move by 13% ,19.93%, 33.52 %, which is by far larger variation that in the dispersive case. These simulations prove that a quadruplet with frequency-dependent couplings has more "stable" response than the conventional structure.

3. Experimental and numerical verification

To validate theoretical aspects of a quadruplet configuration discussed in the previous sections and prove that quadruplets with dispersive couplings with three transmission zeros are feasible at microwave frequencies two X band applications will be presented. The first one has a center frequency of 9.9 GHz, and a bandwidth of 200 MHz with 20 dB return loss level. All direct couplings are assumed to be constant, however the character of cross coupling was changed from constant to dispersive (see the topology shown in the inset in Fig. 3). This modification leads to three asymmetrically placed transmission zeros with the following positions: f_1 = 9.76 GHz, f_2 = 10.09 GHz and f_3 = 10.31

GHz. Note, that in this case positions of the TZs were chosen in such a way that only one dispersive coupling is needed. To synthesize the impedance matrix for this filter an algorithm presented in [4] was used. Constant couplings were realized in a form of inductive H-plane irises. To implement dispersive couplings an incomplete height conducting post [11] was used. Fig. 3 (a) shows the comparison between the measured and the simulated scattering parameters. As can be seen, the filter band has been narrowed by approximately 20 MHz from the upper frequency edge, which gives a fractional bandwidth equal to 0.018. Also, it can be observed that return loss exhibits maximally 4.2 dB level difference in the frequency range from 9.84 GHz to 9.89 GHz. This discrepancy is mainly caused by manufacturing tolerances which lead to detuning the first and the last resonator.

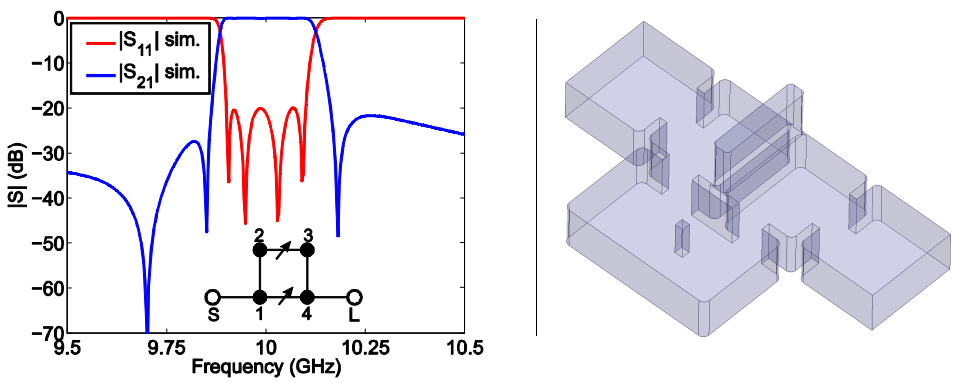


(a) (b)

Figure. 3 (a) Comparison between simulated and measured results of a quadruplet filter with dispersive cross couplings, (b) photograph of the fabricated circuit [8]

The positions of transmission zeros are nearly as designed except for the first one placed at the lower part of the stopband. It was shifted down by 15 MHz. The filter insertion loss equals to approximately 1.25 dB.

The second example is also a pseudoelliptic filter centered at 9.9 GHz with a fractional bandwidth equal to 0.02 and 20 dB return loss level. In this case, two frequency-dependent couplings were used. The first one is placed between the second and the third resonator while the second one is placed between the first and the fourth resonator (see the topology shown in the inset in Fig. 4 (a)). In this case also three transmission zeros were obtained, however in contrast to the previous example, the locations of these transmission zeros (at f_1 = 9.7 GHz, f_2 = 9.85 GHz and f_3 = 10.18 GHz) were chosen in such a way that frequency-dependent couplings with both positive and negative slope parameters have to be used. The coupling matrix, consisting of the constant and frequency-dependent part was obtained using the methodology proposed in [4]. Similarly to the previous case, constant couplings were implemented in the form of inductive windows. Dispersive coupling with positive slope (between the second and the third resonator) was implemented in a form of partial height post while the coupling with negative slope (between the first and the fourth resonator) is realized in a form of a series stub with an additional septum [12]. The filter was designed with our in-house 3D FEM solver and the results obtained were validated in the full-wave electromagnetic simulator Ansoft HFSS. Simulated results are presented in Fig. 4(a) while 3D model of the filter is presented in Fig. 4(b).



(a) (b)

Figure. 4 (a) Simulated scattering parameters of a quadruplet filter with two dispersive couplings, (b) HFSS model

4. Conclusion

In this paper a comparison between the properties of a quadruplet topology with and without frequency-dependent couplings was presented. The paper briefly discusses benefits of using dispersive couplings in terms of a possible number of transmission zeros. Moreover, the scattering parameters sensitivity of a quartet section with and without dispersive couplings was analyzed. To validate the theoretical number of transmission zeros achievable in practice, two examples were presented. These two examples clearly prove that dispersive couplings bring about three transmission zeros thereby making a quadruplet more selective.

5. Acknowledgments

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