A Novel Approach to Dual and Triple-Mode Pseudo-Elliptic Filter Design

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ABSTRACT **— A novel approach to dual and triple-mode pseudo-elliptic filter design is introduced. Instead of using the degenerate modes of a physical resonator, non-degenerate ones are used instead. All the coupling coefficients are positive (their signs are inconsequential). All intra-cavity couplings are eliminated. Each transmission zero is generated and controlled by a dedicated mode whose resonance frequency coincides with the frequency of the transmission zero. The design is ideal for situations where real transmission zeros are required in the immediate vicinity of the passband. A triple-mode rectangular cavity filter with two transmission zeros is designed, fabricated and measured to demonstrate the validity of the approach.**

Index Terms**—resonator filters, elliptic filters, band-pass filters, synthesis, design, dual-mode filters, triple-mode filters.**

I. INTRODUCTION

DUAL and multi-mode filters have been the subject of extensive research efforts due to their importance in applications where size and weight are a serious consideration. The first working multi-mode cavity microwave filter seems to have been introduced by Li in 1951 [1]. A triple-mode filter in a spherical cavity was reported by Currie in 1953 [2]. Elliptic dual-mode filters for space applications were reported by Atia and Williams in 1970 [3]. Designs involving dielectric-loaded cylindrical cavities were introduced in [4]. Designs in other technologies were reported by many authors [5]-[9].

A first basic premise behind the state-of-the-art design of dual and multi-mode filters is the existence of two or more ***degenerate*** modes in a physical resonator such as a waveguide cavity or a dielectric block. In empty cylindrical cavities, the most commonly used modes are the two degenerate and orthogonally polarized TE_{11} modes. In rectangular waveguides, triple-mode Chebychev filters based on the $TE_{101}/TE_{011}/TM_{110}$-mode combinations were reported [10]. The rectangular cavity is initially dimensioned to guarantee the degeneracy of the required number of modes [10].

A second important condition for the realization of dual-mode elliptic filters with real transmission zeros is the ability to implement both negative and positive coupling coefficients. This requirement may turn out to be a serious challenge whose solution needs both ingenuity and experience. In certain structures its realization may be even impossible.

A third point with dual mode filters is the need to couple the degenerate modes of the same physical cavity or resonator. Early developments used coupling screws which are adjusted experimentally until the desired response is achieved. Simpler coupling elements in both circular and rectangular waveguide dual and triple-mode filters were later introduced [10]-[14]. These solutions made it possible to use modern CAD tools to simulate and design the entire filter before fabrication. More recent solutions simply avoid the intra-cavity couplings altogether [15]-[17].

The work reported in this paper was undertaken to re-examine the three important points listed above. More specifically, the following questions are addressed:

1. Can dual and triple-mode pseudo-elliptic filters be designed without insisting on the degeneracy of the resonances?
2. Can dual and triple-mode pseudo-elliptic filters with real transmission zeros be designed without both negative and positive coupling coefficients?
3. Can dual and triple-mode pseudo-elliptic filters be designed with transmission zeros which are generated and controlled by specified resonances?
4. Can dual and triple-mode pseudo-elliptic filters be designed while maintaining the total decoupling of the modes of the physical cavities, i.e, without intra-cavity couplings?

This paper reveals that the answers are in the affirmative to each one of these four questions.

II. STRUCTURE AND MODELING

Obviously, such a radical departure from the state-of-the-art may necessitate the introduction of new microwave elements or at least the use of certain elements in new ways. It will be seen that Non-Resonating Nodes (NRN), which have been recently introduced by the authors, are sufficient to achieve the four goals listed above [18].

The example of a triple-mode pseudo-elliptic filter with two transmission zeros at real frequencies is used to introduce the new approach. The passband is centered at

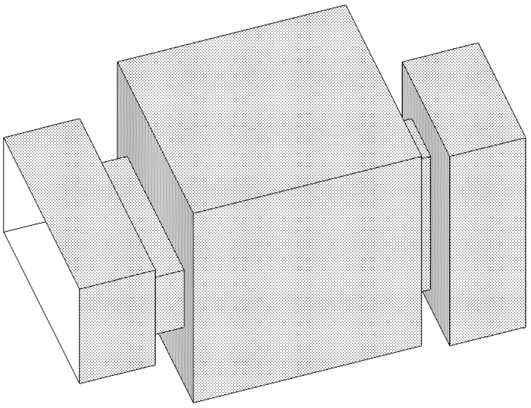

Fig. 1. Waveguide structure used to design a triple-mode pseudo-elliptic filter with two transmission zeros at real frequencies.

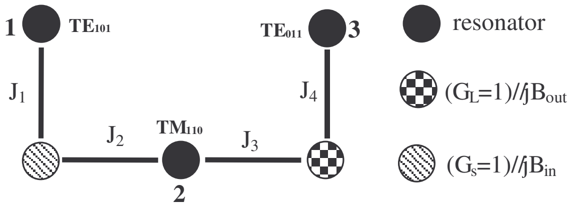

Fig. 2. Third order filter model to generate two transmission zeros at finite frequencies

f_0 and the transmission zeros are located at frequencies f_1 and f_2. The transmission zeros should be individually generated and controlled by dedicated resonances. Fig. 1 shows a sketch of the used rectangular cavity structure. The filter is based on the $TE_{101}/TE_{011}/TM_{110}$–mode combination. Input and output waveguides exhibit orthogonal alignment, i.e., the input waveguide supports the TE_{10} mode while the TE_{01} mode is propagating at the output. The feeding waveguides are coupled to the dedicated cavity modes by irises. Note that the sole excitation of the TE_{101} and TE_{011} resonances in the cavity would not allow any signal transmission in the frequency range of interest, due to the orthogonality of the polarizations in the feeding waveguides and the absence of any discontinuity inside the cavity. These conditions are achieved by centering the input and output irises with respect to the cross section of the cavity such that the TM_{110} resonance is not excited.

To generate a passband at f_0, the input and output irises are offset from the centers of the cross section of the cavity such that the TM_{110} resonance is excited both at the input and the output. With such a configuration, a reflection zero is obtained due to the TM_{110} mode, which resonates at (in the vicinity of) f_0, and two attenuation poles at the respective resonant frequencies f_1 and f_2, which are determined by the TE_{101} and TE_{011} modes. To generate the two remaining reflection zeros of a third order filter, special matching reactive elements may be needed at the input and the output. The coupling scheme, which models the behavior of this structure, is shown in Fig. 2. The dark circles are resonators which are modeled as unit capacitors in parallel with frequency independent reactances jb_i to account for the frequency shifts in the resonant frequencies of the resonators. The source and the load are normalized to unity ($G_s=G_L=1$). The different nodes in the model are connected by admittance inverters J_i. Note the presence of the frequency independent reactive elements at the input (jB_{in}) and the output (jB_{out}). The nodes at the input and output are Non-Resonating Nodes (NRNs). Sophisticated filters can be designed by using this type of nodes (Non-Resonating Nodes) as internal nodes instead of only at the input and the output [18].

A pertinent question is whether this coupling scheme can indeed generate a third order pseudo-elliptic filter with two transmission zeros. The synthesis proving this point analytically will be given during the presentation.

III. RESULTS

A third order pseudo-elliptic filter with a passband centered at f_0=12.8 GHz and two transmission zeros at f_1=13.32 and f_2=13.38 GHz has been designed. The equiripple bandwidth is 200MHz (return loss of 22 dB). The normalized coupling matrix

$$M = \begin{bmatrix} -3.8285 & 4.3559 & 0.9735 & 0.0000 & 0.0000 \\ 4.3559 & -5.200 & 0.0000 & 0.0000 & 0.0000 \\ 0.9735 & 0.0000 & 0.0285 & 0.0000 & 0.9752 \\ 0.0000 & 0.0000 & 0.0000 & -5.800 & 4.8643 \\ 0.0000 & 0.0000 & 0.9752 & 4.8643 & -4.2845 \end{bmatrix}$$

satisfies the requirements for the desired filter structure and coupling configuration (Figs. 1 and 2, respectively).

The simulated results of the designed filter are shown in Fig.3 as the dashed lines. These results were obtained from the Coupled Integral Equations Technique (CIET) [20]. For comparison, the results obtained from the lowpass prototype synthesis (solid lines) are also included. The two results exhibit good agreement in the vicinity of the passband and the transmission zeros. The differences at frequencies with increasing distance from the passband can be attributed to dispersion effects and higher order modes.

This filter was manufactured and tested to experimentally validate the approach. Fig. 4 depicts a photograph of the

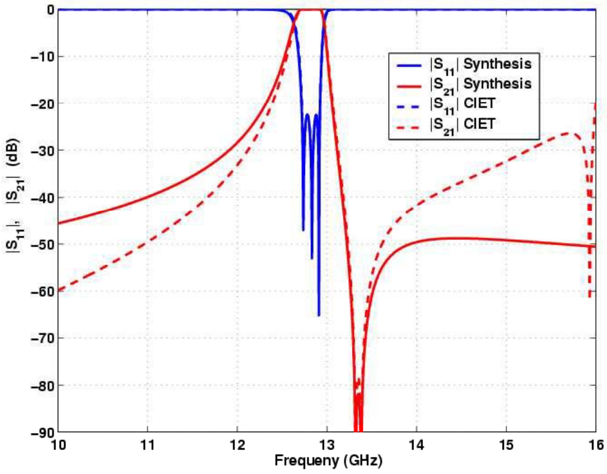

Fig. 3. Simulated results (CIET) of third order pseudo-elliptic filter with two transmission zeros. For comparison, the results of the synthesis (solid lines) are also shown

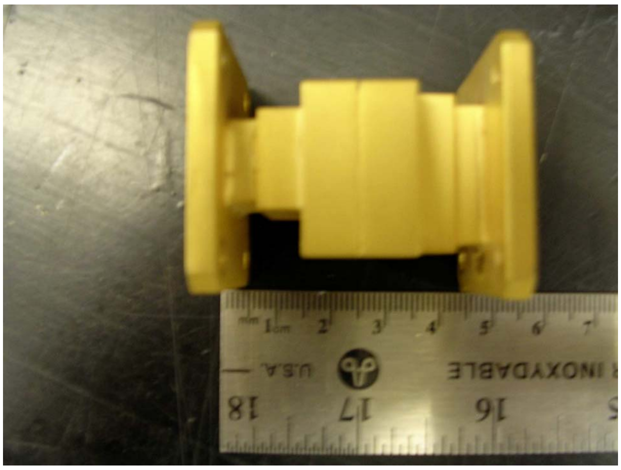

Fig. 4. Photograph of the designed filter. Without the input and output feeding waveguides (15mm each), the filter is less than 18mm long

realized filter. The measured responses, obtained without any tuning, are shown in Fig. 5 together with the simulated results.

The agreement between the two amply validates the introduced principle and its application to dual and multi-mode cavity filters. Due to the used fabrication process, the dimensions of the cavity were slightly larger than specified. The parts of the filter were machined separately and subsequently combined by soldering. To account for this, a frequency shift of 50 MHz was used in the simulated results.

Although dual-mode filters were not discussed here, they may be designed according to similar steps.

The investigation of such a filter design with a complementary characteristic (i.e., transmission zeros at the same distance on the other side of the passband) yields an interesting result. The coupling scheme in Fig. 2

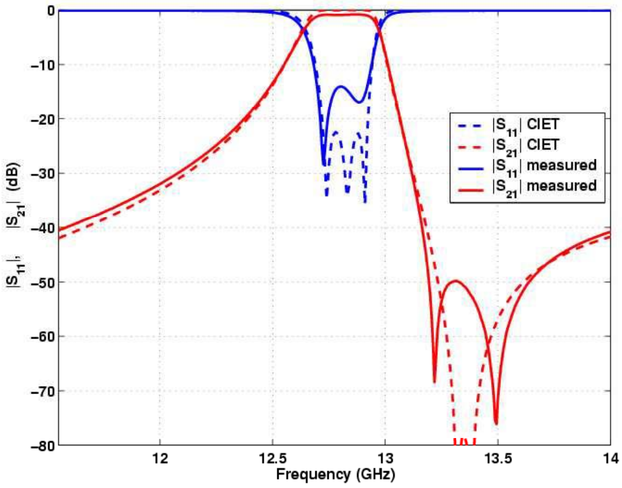

Fig. 5. Measured (solid lines) and simulated response (dashed lines) of the designed filter over frequency

exhibits the same transmission zero shifting properties as observed for the structures in [16]. This is, the transmission zeros are transferred to the other side of the passband by only changing the signs of the diagonal entries (M_{nn}) of the coupling matrix.

Finally, it should be noted that the direct calculation of the input admittance of the low-pass network (cf. Fig. 2) proves the fact that the signs of the coupling coefficients are inconsequential (except for their loading effects). It is readily found that this quantity involves only the squares of the coupling coefficients.

VI. CONCLUSION

A novel approach to the design of dual- and triple-mode filters is introduced. The approach eliminates some of the basic requirements of the state-of-the-art design technique of this class of components. In particular, the modes used are not required to be degenerate – for the introduced design, they must not be degenerate. For transmission zeros at real frequencies, all the coupling coefficients are positive (their sign is inconsequential). There are no intra-cavity couplings since there is no coupling between the resonances inside the physical cavity. Each transmission zero is generated and controlled by a dedicated resonance in the dual- or the triple-mode cavity. A third-order pseudo-elliptic filter with two transmission zeros in the upper stopband was designed, fabricated and measured. The measured results validate this novel approach. It can be used also in combination with state-of-the-art filter sections and thus will significantly enhance the overall design possibilities of these filter types.

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