Enhanced Topology for the Design of Bandpass Elliptic Filters Employing Inductive Windows and Dielectric Objects

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***Abstract*— This work presents a new topology for the design of bandpass elliptic filters employing inductive windows and dielectric objects. The proposed filtering structure combines, for the first time, the modified TE_{102} resonating mode with the modified TE_{201} mode. The TE_{201} mode is excited by placing a wide dielectric post inside a waveguide cavity. The main advantage of the new topology is that two transmission zeros can be synthesized in the insertion loss response of the filter, for a second order structure. Also there is a high flexibility on the location of the transmission zeros. They can be synthesized along the frequency axis for maximum selectivity, or as a pair of complex poles for phase equalization.**

***Index Terms*— Dielectric posts, doublet topology, inductive filters, transmission zeros, transversal filters, waveguide filters.**

I. INTRODUCTION

Microwave filters are components largely used for space and terrestrial communication systems [1]. Because of their simplicity of design and easy manufacturing processes, waveguide inductive filters are of special interest in many different applications. Specifically, elliptic responses combined with inductive topologies where investigated in [2]. In that work, inductive discontinuities in waveguide structures with asymmetric couplings were employed in order to implement second order transversal filters. The fundamental resonances of the proposed filters were the modes TE_{102} and TE_{201}. To allow for the propagation of the TE_{20} mode, the width of the resonator was properly increased. A more recent contribution on this topic can be found in [3]. In that work, an alternative method for the implementation of transversal filters with a more compact structure was presented. The structure consists of a cavity coupled with inductive windows, and with a dielectric post placed asymmetrically inside the cavity. The resonant modes employed to implement the transversal filters in this case were the TE_{102} and the modified TE_{103} mode by the dielectric post. The TE_{103} resonance was adjusted with the dielectric post placed inside the cavity, while the TE_{102} was not perturbed by this dielectric post.

This contribution is focused on the further development of the transversal filter first presented in [3]. In that work, the proposed filter was able to implement only one transmission zero (doublet topology [4]), by combining the modes TE_{102} and TE_{103}. The mode TE_{103} was resonating at the right frequency due to the presence of a dielectric post in the waveguide cavity. Also, the implemented transmission zero was placed always very close to the passband. This important limitation arose because of the fact that the couplings from the ports to the TE_{102} mode were always larger than the couplings to the modified TE_{103} mode.

In this paper, we present a technique to overcome this difficulty, using the same basic structure. The main idea consists on the use of the modified TE_{102} mode, combined with the modified TE_{201} mode. The resonant TE_{201} mode is excited by increasing the width of a dielectric post placed inside de cavity. In addition, the larger width of the dielectric post will cause some perturbation on the TE_{102} mode resonance. This will result in that the coupling from the ports to this mode will not necessarily be much larger than the coupling to the modified TE_{201} mode. In this way, the transmission zeros are not necessarily placed very close to the passband, as it was the case in the original design proposed in [3].

In addition, it is shown in this paper that the new proposal is able to implement the topology known as modified doublet (see Fig. 1), instead of the classical doublet topology obtained with the original structure proposed in [3]. In this way, the new structure is able to implement two transmission zeros for maximum selectivity. Finally, it is worth mentioning that the novel proposal achieves high flexibility in where the two transmission zeros are located. In this way maximum selectivity can be obtained either in one side or in both sides of the passband. All these are interesting advantages of the new structure over existing topologies, that can be used in space applications to reject unwanted signals with a flexible and compact structure.

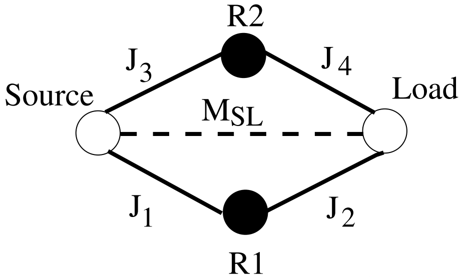

Fig. 1. Typical scheme of a Modified Doublet. J_1 to J_4 represent the couplings from the source S and the load L to the resonators R_1 and R_2.

II. THEORY

The structure under study is sketched in Fig. 2. It consists of a waveguide cavity coupled with two inductive windows, and a dielectric post touching one of the cavity walls. A similar filter configuration was introduced in [3]. However, the main difference of the new structure is that the dielectric post is now chosen with a larger width as compared to the narrow dielectric used in [3].

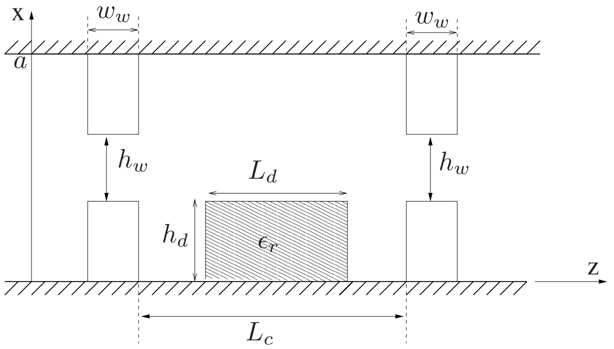

Fig. 2. Proposed topology for implementing the modified doublet scheme of Fig. 1. It consists of a single waveguide cavity with a wide dielectric post.

The new structure will now implement the topology known as Modified Doublet shown in Fig. 1 [4]. In this case the resonances used to build the filter are different from the ones used in the original work proposed in [3]. Note that the main advantage of the structure presented in [3], consisting of the reduction of the volume of the device as compared to the design presented in [2], is maintained in this new proposal, since the width of the cavity is not increased in size. In fact, only the width of the dielectric post is increased inside an otherwise not modified waveguide cavity.

For the design of the filter, first the cavity is used to adjust the TE_{102} resonance at the working frequency. In Fig. 3 we show the scattering parameters obtained for the structure shown in Fig. 2 when the dielectric is removed. We can see the TE_{101} resonance at 11.12 GHz, and the TE_{102} resonance at 16.84 GHz. This mode, that will be perturbed by the introduction of a wide dielectric post, will form the first resonator of the modified doublet, and will be the responsible for the required sign change in one of the couplings, typical of this topology [4].

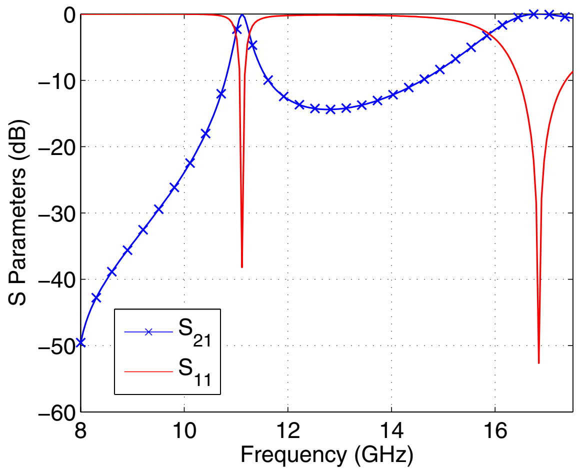

Fig. 3. S-parameters of the cavity shown in Fig. 2, without the dielectric post. Dimensions: $a = 19.05$ mm, $L_c = 14.30$ mm, $\omega_\omega = 4$ mm, $h_\omega = 10.05$ mm, $f = 16.84$ GHz.

The second resonator of the final filter will be implemented by the TE_{201} resonance. This mode can be excited if a dielectric object of sufficient width is introduced in the waveguide cavity. To show that this is indeed the case, a similar cavity as before, but including a wide dielectric post of $\varepsilon_r = 4$, has been studied. The length of the cavity has also been increased to $L_c = 16.50$ mm to slightly detune the first resonance. The scattering parameters obtained in this case are shown in Fig. 4. We can observe that a new resonance, that will be identified as the TE_{201} mode, has appeared at 13.64 GHz, due to the introduction of the wide dielectric post in the cavity. The two other resonances, that were already present in the cavity without the dielectric post, have been shifted to lower frequencies due to the larger cavity length, and due to the perturbations introduced by the wide dielectric post.

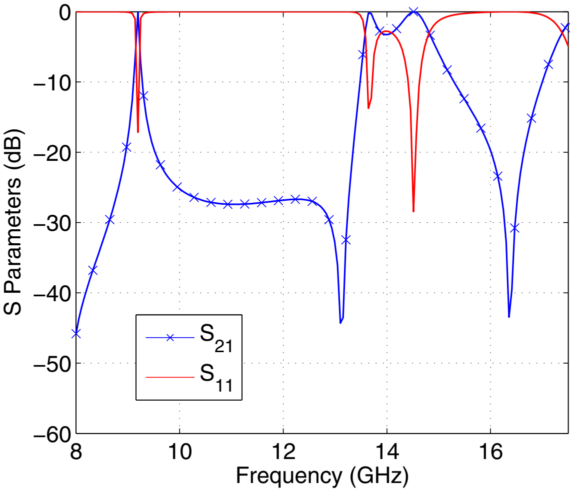

Fig. 4. Scattering parameters of a cavity loaded with a wide dielectric post. Dimensions according to Fig. 2: $a = 19.05$ mm, $L_c = 16.50$ mm, $\omega_\omega = 4$ mm, $h_\omega = 10.05$ mm, $L_d = 8.348$ mm, $h_d = 4.9$ mm, $\varepsilon_r = 4$.

In Fig. 5 the electric field pattern of the structure at 13.64 GHz is shown. We can observe the typical behavior of the TE_{201} mode, strongly perturbed by the wide dielectric post. Besides, in Fig. 6 the electric field pattern of the structure at 14.51 GHz is shown. In this case we observe the TE_{102} mode, but perturbed by the wide dielectric post. In the original structure proposed in [3], the TE_{102} mode was not perturbed by the dielectric post, since the thin post was placed at the null of the electric field at the center of the cavity. Due to this fact, the mode TE_{102} was essentially in the cavity air, while the TE_{103} was concentrated inside the dielectric post. This resulted in a much higher coupling from the ports to the TE_{102} mode than to the TE_{103}, generating a transmission zero placed very close to the passband. However, in this new structure, the larger width of the dielectric post causes a clear

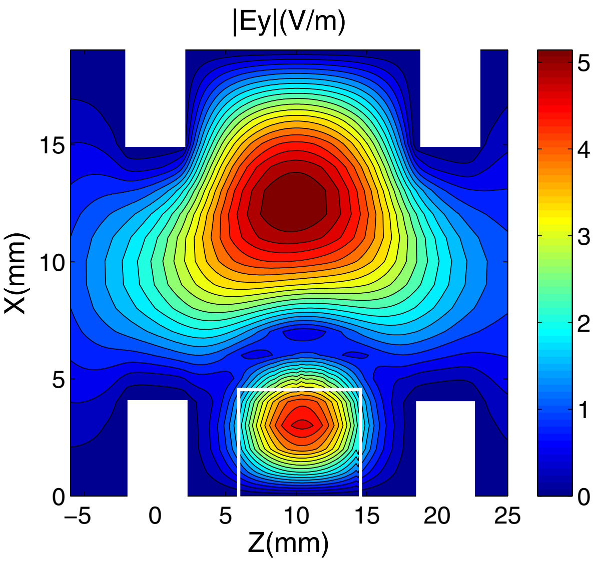

Fig. 5. Resonant TE_{201} mode perturbed by the dielectric post at the frequency of 13.64 GHz. Dimensions according to Fig. 2: $a = 19.05$ mm, $L_c = 16.50$ mm, $\omega_\omega = 4$ mm, $h_\omega = 10.05$ mm, $L_d = 8.348$ mm, $h_d = 4.9$ mm, $\varepsilon_r = 4$.

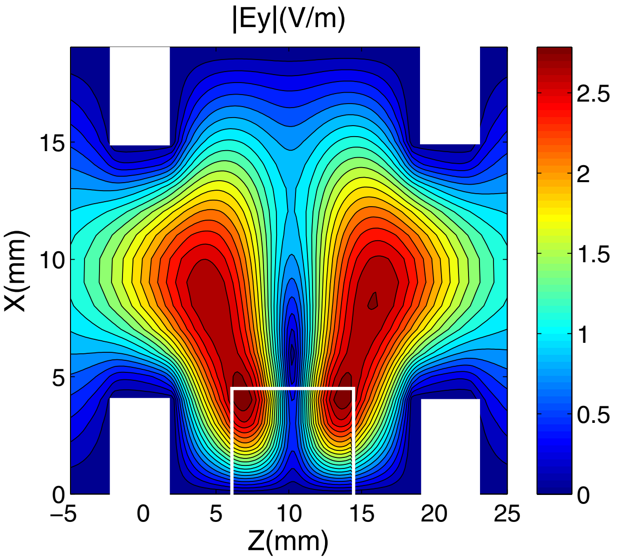

Fig. 6. Resonant TE_{102} mode perturbed by the dielectric post at the frequency of 14.51 GHz. Same dimensions as in Fig. 5.

perturbation on the TE_{102} mode. It can be seen that part of the field is concentrated inside the dielectric post, in a similar way as the second TE_{201} mode. This will avoid large differences in the coupling terms from the ports to the two resonating modes, thus allowing the transmission zeros to be placed far from the passband.

III. RESULTS

We consider here some examples in order to show the usefulness of the new filter structure proposed. The high versatility of the filter comes from the possibility to obtain both, symmetrically or asymmetrically positioned transmission zeros in the real plane, or even a complex pair of transmission zeros. The transmission zeros will be placed in the same side of the passband for a given relative position of the two main resonances, and they will be in different sides of the passband if we reverse the order.

Fig. 7 shows the responses of the filter structure, when the position of the two transmission zeros is varied by adjusting the length of the cavity L_c and the width of the dielectric post L_d. The results are obtained using an integral equation technique for the analysis of the basic structure shown in Fig. 2 [5]. In this case the two transmission zeros are located at the same side of the passband, by tuning the TE_{102} mode below the TE_{201} mode. It can be seen in the figure that a value of $L_c = 20.23$ mm leads to an optimized filtering response with two transmission zeros above the passband located along the real frequency axis. However, if the value of the cavity length is reduced and the width of the dielectric post is readjusted to maintain the same level of -15 dB return losses, the center frequency of the filter is shifted to the right. This shift comes together with a variation in the position of the transmission zeros, which now migrate to the complex plane. A larger reduction in the cavity length will cause a new shift of the passband to the right. In this way, the complex transmission zeros can be moved closer to the passband for filter equalization. If this process is repeated, the complex pair of transmission zeros will move to the left side of the passband, until they eventually come back to the real frequency axis.

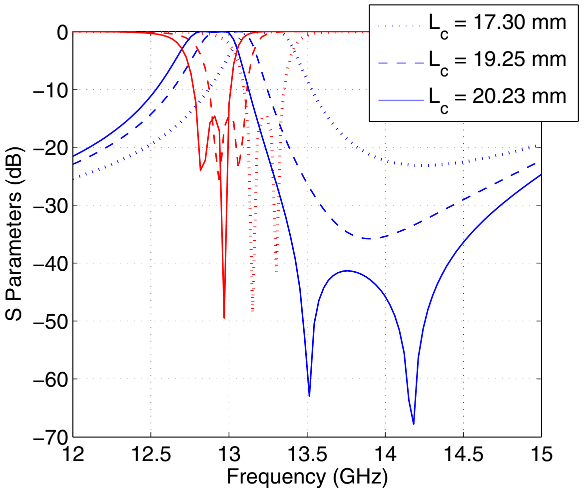

Fig. 7. Simulated responses for the proposed filter with various values for the dimensions L_c and L_d. All other dimensions are as in Fig. 5.

On the other hand, if the relative positions of the two resonances of the filter are inverted, one transmission zero will appear in each side of the passband. By following the same procedure as before, the transmission zeros can be placed asymmetrically or symmetrically around the passband. The symmetric case is shown in Fig. 8. The results obtained by analyzing the structure with HFSS© are also included in Fig. 8 for validation purposes. The coupling matrix obtained with the synthesis technique presented in [6] is also shown in Fig. 8.

It is important to highlight that, in the last example, the

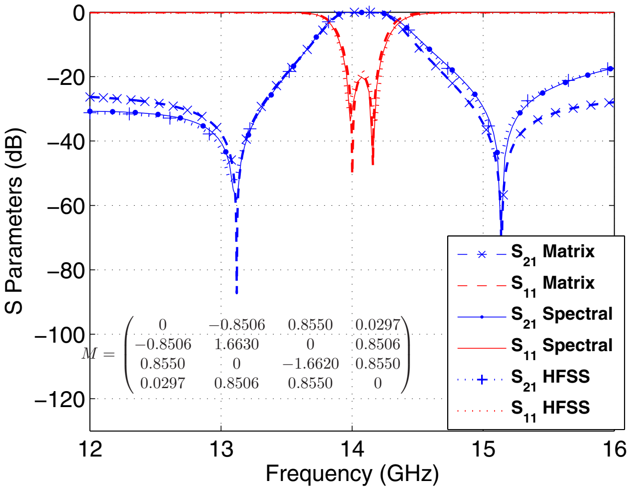

Fig. 8. Coupling matrix and scattering parameters of a symmetric bandpass filter. Dimensions according to Fig. 2: $a = 19.05$ mm, $L_c = 14.30$ mm, $\omega_\omega = 4$ mm, $h_\omega = 10.05$ mm, $L_d = 8.348$ mm, $h_d = 6.25$ mm, $\varepsilon_r = 4$.

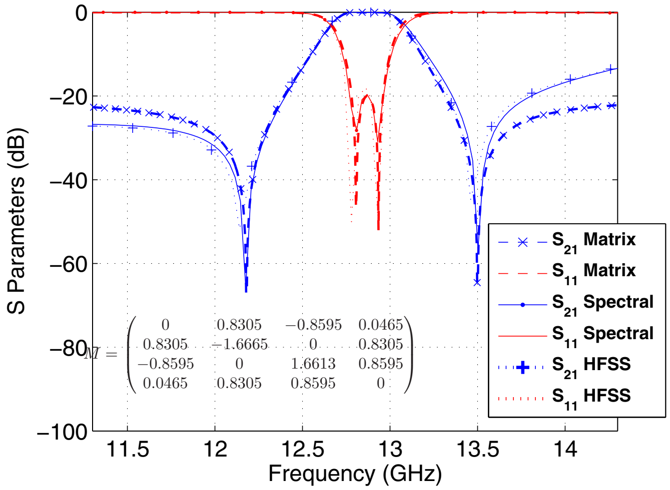

Fig. 9. Coupling matrix and scattering parameters of a symmetric bandpass filter and higher dielectric constant. Dimensions according to Fig. 2: $a = 19.05$ mm, $L_c = 17.3$ mm, $\omega_\omega = 4$ mm, $h_\omega = 10.75$ mm $L_d = 10.56$ mm, $h_d = 3.8$ mm, $\varepsilon_r = 6$.

coupling values from the ports to the two resonators are very similar, thus effectively overcoming the limitation of the original structure presented in [3], where the coupling term from the ports to one of the resonators was always much bigger than the other.

All the previous designs have been performed with a dielectric post of relative permittivity $\varepsilon_r = 4$. With a fixed dielectric post it is not possible to control independently the center frequency of the filter and the positions of the transmission zeros. However, this is not a limitation of the structure, since the value of the relative permittivity of the dielectric post can be adjusted to independently control these two factors. To show this possibility, a new symmetric filter has been designed with a relative permittivity $\varepsilon_r = 6$. Fig. 9 shows the results obtained as compared with the ideal response given by the coupling matrix (also presented in the inset of the figure). Results obtained with HFSS© are again included for validation, showing good agreement. In this case the transmission zeros are placed symmetrically for a center frequency of 12.8 GHz. It is important to note that the higher value of the relative permittivity also allows to place the transmission zeros closer to the passband. In the first example ($\epsilon_r = 4$) the transmission zeros are placed at a relative distance of 7.1% with respect to the center frequency. On the contrary, in the second example ($\epsilon_r = 6$), the transmission zeros are placed at a relative distance of only 4.7%. This feature can also be seen in the direct coupling term (M_{SL}) shown in the coupling matrices of Fig. 8 and Fig. 9. The direct coupling term of the second example is larger ($M_{SL} = 0.0465$) than in the first example ($M_{SL} = 0.0297$), clearly indicating that the transmission zeros are closer to the passband.

IV. CONCLUSIONS

In this paper, a new bandpass elliptic filter employing inductive windows and dielectric objects has been proposed and investigated. The filter combines for the first time the perturbed TE_{102} mode with the perturbed TE_{201} mode to implement the topology known as modified doublet. The TE_{201} mode is excited by placing a wide dielectric post inside a cavity resonator. The advantages over previous topologies is that two transmission zeros can be synthesized for a second order response. Also, they can be placed in a broad range of combinations, going from the real frequency axis for maximum selectivity, to the complex plane for phase equalization.

V. ACKNOWLEDGMENTS

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REFERENCES

[1] S. Amari, U. Rosenberg, and J. Bornemann, “Adaptive synthesis and design of resonator filters with sourde/load-multiresonator coupling,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 50, pp. 1969–1978, August 2002.

[2] M. Guglielmi, P. Jarry, E. Kerherve, O. Roquebrun, and D. Schmitt, “A new family of all-inductive dual-mode filters,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 49, pp. 1764–1769, October 2001.

[3] F. J. Perez-Soler, M. Martinez-Mendoza, F. D. Quesada-Pereira, D. Canete-Rebenaque, A. Alvarez-Melcon, and R. J. Cameron, “Design of bandpass elliptic filters employing inductive windows and dielectric objetcs,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 55, pp. 2392–2398, November 2007.

[4] S. Amari and U. Rosenberg, “A universal building block for advanced modular design of microwave filters,” *IEEE Microwave and Wireless Components Letters*, vol. 13, pp. 541–543, December 2003.

[5] F. Q. Pereira, V. B. Esbert, J. P. Garcia, A. V. Pantaleoni, A. A. Melcon, J. G. Tornero, and B. Gimeno, “Efficient analysis of arbitrarily shaped inductive obstacles in rectangular waveguides using a surface integral equation formulation,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 55, pp. 715–721, April 2007.

[6] R. J. Cameron, “Advanced coupling matrix synthesis techniques for microwave filters,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 51, pp. 1–10, January 2003.