A New Simple Microstrip Open-Loop Resonators Filter for High Selectivity Applications

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***Abstract*— In this paper the design of a novel planar microwave filter is presented. The structure is designed in microstrip technology, and it is formed by two loop resonators of different lengths. The length of the first resonator is adjusted *so* that a suitable odd resonance is tuned to the center frequency of the filter. The length of the second resonator is adjusted *so* that the next even resonance is tuned again to the center frequency of the filter. The change in phase introduced by the resonances of the loops produces a cancellation of energy at a given frequency, therefore implementing a transmission zero for high selectivity. In this paper a design example is provided, and results of a manufactured prototype are discussed. Measured results confirm the theoretical predictions, and validate the new structure for high selectivity applications.**

I. Introduction

Microwave filters are still very important components for mobile, wireless, and satellite applications [1]. In the design of microwave filters, of paramount relevance is the filter selectivity, which must be increased in order to better reject spurious signals [2]. A very popular technique for controlling the selectivity is the implementation of transmission zeros at precise frequencies in the insertion loss response of microwave filters [3].

With respect planar microstrip filters several previous works have been developed in order to increase de filter selectivity. For instance, in [4] a printed filter composed of square open-loop resonators is presented. In the structure, the transmission zeros are obtained by classical cross-coupling interactions between nonadjacent resonators. The work proposed in [4] is based on previous works [5], [3], in which elliptic transfer functions are also implemented by using similar square open-loop resonators combined with cross couplings between nonadjacent resonators. Another example of a printed filter which uses side cross-coupling interactions can be found in [6], where hair pin resonators are placed in a square matrix to achieve an elliptic transfer function for a second-order filter.

In addition to the classical side-coupled implementation of transmission zeros, other approaches based on broadside couplings have been implemented. A very useful example can be found in [7], where an elliptic transfer function is synthesized for a second order filter by broadside coupling two resonators through a slot open on the common ground plane of a two layers microstrip structure. Also in [8] a three pole filter is presented with a transmission zero due to a broadside cross coupling between the first and third resonator.

In this paper we present an alternative procedure for the implementation of transmission zeros in the insertion loss response of microstrip printed filters. The big difference with respect previous designs is that the transmission zero is not created by introducing cross-couplings between nonadjacent resonators. The structure is composed of two open-loop resonators of different lengths. The first length is adjusted to tune a suitable odd resonance of the resonator to the center frequency of the filter. On the contrary, the second length is adjusted to tune the next even resonance of the resonator to the center frequency. The opposite phases occurring in the signal path from the input and output in both resonators produce a cancellation of energy at a given frequency, therefore creating the desired transmission zero. The structure is based on the same design strategy as presented in [9]. In [9], however, the technique is applied to the design of dual mode filters in waveguide technology. The extension of this technique to planar printed microstrip structures shows to lead to very compact and useful microwave filters exhibiting high selectivity.

In this paper we present briefly the design strategy of the filter, together with the procedure to cascade several basic configurations to obtain higher order structures. A filter prototype is manufactured, and the results are discussed. The measured results show that the structure presented is indeed feasible, and results in a high selectivity simple microstrip filter configuration.

II. Structure Description

The basic configuration of the filter structure can be seen in Fig. 1. It consists on the input and output lines which are coupled in a shunted configuration to two open loop resonators of different lengths. One resonator is designed to work at an even resonance, while the other is designed to operate at an odd resonance. The interaction of both produces the required cancellation of energy at a given frequency, therefore leading to a transmission zero in the insertion loss response of the filter.

The main parameters to be optimized in this structure are the lengths of the resonators, which in an initial design can take the approximated values of $N\,\lambda_{eff}/2$ and $(N+1)\lambda_{eff}/2$ respectively at the center frequency of the band. In this way, the cancellation of energy, and therefore

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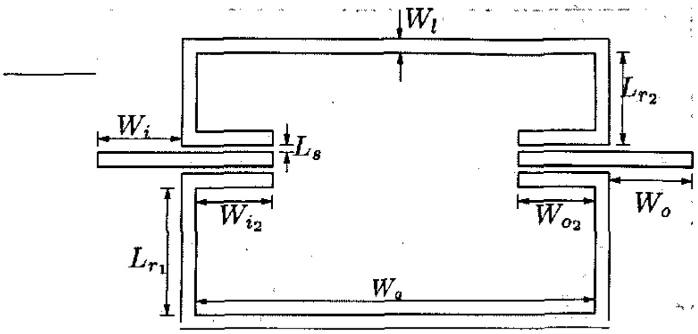

Fig. 1. Filter layout (not to scale). The Dimensions are $W_i = 8.0mm$, $W_o = 8.0mm$, $W_{i_2} = 16.0mm$, $W_{o_2} = 16.0mm$, $W_g = 42.0mm$, $W_l = 1.0mm$, $L_{r_1} = 16.8mm$, $L_{r_2} = 16.4mm$, and $L_s = h = 0.51mm$.

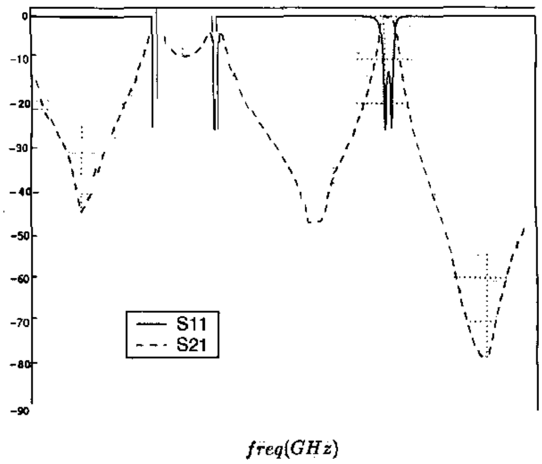

Fig. 2. Single-stage filter response simulated by ADS.

the transmission zero, is obtained in the proximity of the center frequency, leading up to a sharp transition band. Much care must be taken with the distance W_g, namely it must exist enough separation to avoid direct coupling between the input and output lines of the filter.

The lengths W_{i_2} and W_{o_2} of Fig. 1, together with the gaps L_s, control the input and output couplings of the filter, and must be carefully adjusted to achieve the required bandwidth. Since the input and output lines are side coupled to the resonators, relatively narrow baridpass filters can be obtained. In our designs we have achieved up to *2.5%* relative bandwidths.

In the bandpass filter configuration proposed, we have a trade off between the Q factor and the bandwidth achieved. If the lengths of the resonators are adjusted so that the two poles get closer together, then the Q factor increases and lower reflection coefficient is obtained, but at the expense of a lower bandwidth. On the other hand, by separating the reflection poles, a wider matching bandwidth can be obtained, but the filter becomes less selective (the transmission zero appears less deep in the insertion loss response).

In practical terms, by reducing L_s, we can obtain wider bandwidth and higher return loss. On the other hand, if L_s is slightly increased (0.1mm or 0.2mm longer for the examples in this paper), the Q factor increases, and the return loss decreases. As a side effect, changing L_s might vary the operating frequency, since it controls not only the transmission zeros, but also the position of the bandpass reflection poles. Further length increments can even cause coincidence between the reflection poles and transmission zeros, leading to undesired responses. This behavior, however, can also be used to implement filter responses with a transmission zero below the passband of the structure. This is an interesting behavior, since transmission zeros above and below the passband can easily be obtained.

In Fig. 2, a typical response of this filter with the transmission zero above the passband is simulated with the lull-wave commercial electromagnetic simulator ADS (HP - Advanced Design Simulator). In this design we have optimized the length of the resonators for an operation with an $N = 5$ higher order resonances. The whole design process is accomplished with few operations if the described previous steps are carefully followed.

Once the single filter configuration has been designed, two identical unit cells can be cascaded to obtain a higher-order response in a compact structure. Both high selectivity and bandwidth can be simultaneously obtained by cascading two of these novel filters as shown in Fig. 3.

For the design of this more complex structure two new important parameters need to be adjusted in order to control the coupling between the unit cells. The first one is the distance L_d between the two set of resonators (see Fig. 3). This distance can be changed to control the ballance between the two pair of resonances. The other important parameter is the width of the coupling line joining the two unit cells. This width can be decreased to adjust properly the inter-resonator coupling between the two set of resonators. This last step will achieve the right level of ripple throughout the whole passband. In this way, a constant-ripple elliptic-filter with both high selectivity and wider bandwidth can be achieved, as can be seen in Fig. 4. It should be noted that the structure is completely symmetric, arid that the transmission zeros of both pair of resonators lie on the same side of the passband, thus resulting into a double transmission zero on this side. The simulation results obtained with ADS software tool suggest that very high quality factor filters can be achieved in a small compact configuration.

An alternative design can be foreseen, by combining two set of resonators, one optimized to produce a transmission zero below the passband, and the other optimized to produce a transmission zero above the passband. This last alternative can be used when high rejection is to be obtained on both sides of the passband. On the contrary the complexity of the design increases, since this last concept leads to a non-symmetric structure.

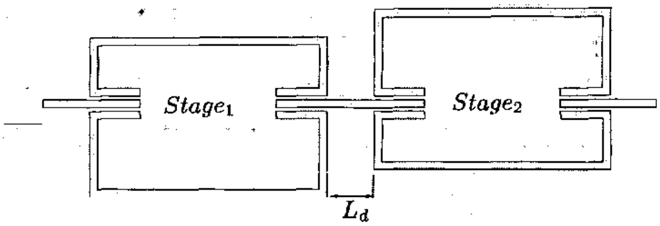

Fig. 3. Two-stages cascade filter.

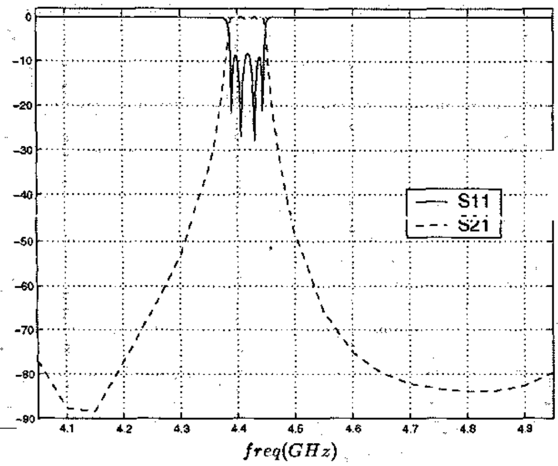

Fig. 4. S-parameters two-stages cascade filter calculated by ADS.

111. RESULTS

ADS Soltware was employed lor the design, simulation and optimization of a filter prototype with the resonators operating at $N = 5$ higher order resonances. The structure has been optimized following the basic simple steps shown in this contribution. The prototype of the single stage microstrip filter has been manufactured to check the validity of the proposed design. The layout of the prototype microstrip filter structure is shown in Fig. 5. The strip width is fixed in 1mm to get a 50Ω input/output lines, and the four gaps $(L,)$ controlling the input and output couplings have the same dimensions: 0.2mm. These gaps are usually very small to achieve the input/output coupling required for the specified bandwidth. Also the lengths W_{i_2} and W_{o_2} are optimized for suitable bandwidth.

The structure has been manufactured on a TMM-4 substrate ($\epsilon_r = 4.5$, $h = 0.51mm$). The physical dimensions are shown in Fig. 1.

The transmission and reflection responses of this structure are obtained for the manufactured prototype filter from three different sources, namely from the ADS software tool simulation (which uses the infinite size multilayered media Green's functions [10]), from experimental measured results obtained with an HP-8720-ES vector network analyzer, and from a volume/surface integral equation applied to the analysis of finite size arbitrary shape microstrip structures [11].

In Fig. 6 and Fig. 7 these three results are compared. It can be seen good agreement except for a frequency shift of about 50 MHz. Also, since higher order resonances ($N = 5$) have been used to optimize the passband of the filter, lower order resonances can be seen before the actual passband. Results show that the nearest lower order resonance occurs around 3.9 GHz. The optimization of a filter prototype with $N = 1$ will decrease further the total dimensions of the filter as compared to Fig. 5.

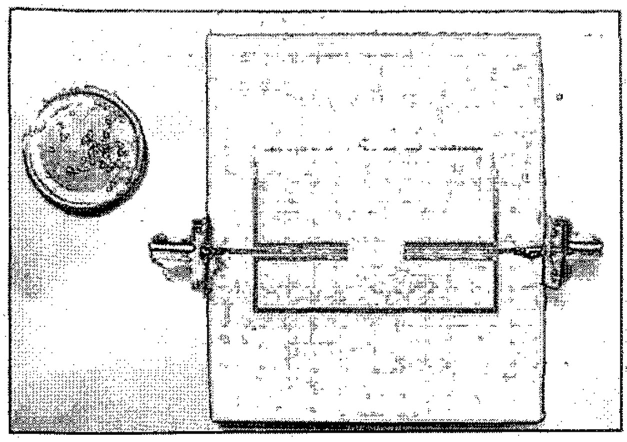

Fig. 5. Manufactured filter prototype.

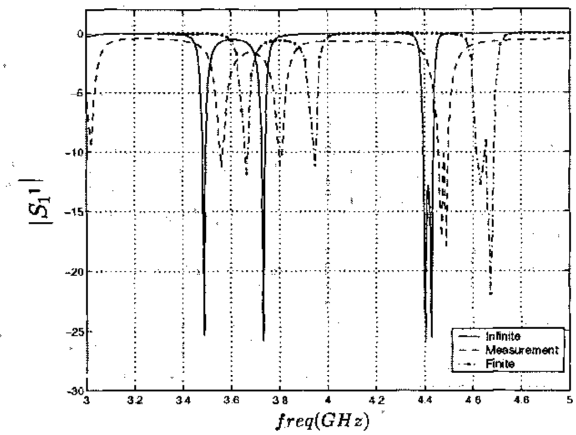

Fig. 6. S_{11} single-stage response comparison.

In addition, it must be pointed out that, while ADS simulation assumes an infinite dielectric layer, the finite IE method simulates a scenario in which the size of the dielectric substrate is adjusted to the conductor limits. This limiting case of the size of the substrate produces an additional frequency shift as shown in Fig. 6.

Measured results show that the filter has a bandwidth of 1.38% and center frequency f_0 of 4.43GHz. The passband ripple remains lower than 0.25dB. As expected, the two resonators produce a 2-pole response filter with sharp transition due to a transmission zero.

IV. CONCLUSIONS

In this paper we have presented a new microstrip filter structure exhibiting high selectivity. Unlike traditional

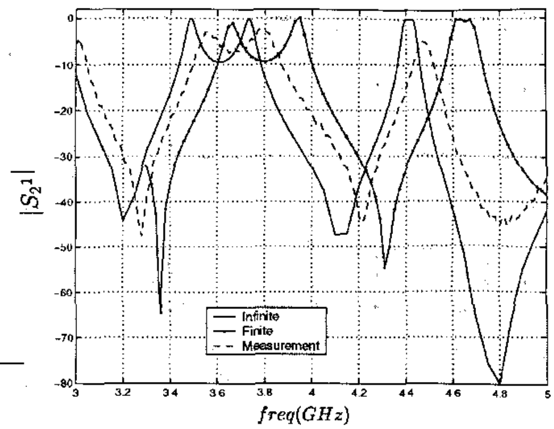

Fig. 7. S_{21} single-stage response comparison.

designs, a transmission zero is implemented without introducing cross couplings between nonadjacent resonators. The basic structure consists on a two open-loop resonators of different lengths. The lengths are adjusted to tune the N and $N+1$ resonance of each resonator respectively to the center frequency of the filter. The opposite phases of the signal in each resonator produces the cancellation of energy required for the implementation of a transmission zero. A filter prototype with $N=5$ has been designed, manufactured and tested. Measured results on the manufactured prototype confirm the validity and usefulness of the proposed structure.

References

[1] C.-Y. Chang and W.-C. Hsu, "Novel planar, square-shaped, dielectric-waveguide, single, and dual-mode filters," *IEEE Transactions on Microwave Theory and Techniques*, vol. 50, pp. 2527–2536, November 2002.

[2] J. S. Hong, M. J. Lancaster, D. Jedamzik, R. B. Greed, and J. C. Mage, "On the performance of HTS microstrip quasi-elliptic function filters for mobile communication application," *IEEE Transactions on Microwave Theory and Techniques*, vol. 48, pp. 1240–1246, 2000.

[3] C. C. Yu and K. Chang, "Novel compact elliptic-function narrow-band bandpass filters using microstrip open-loop resonators with coupled and crossing lines," *IEEE Transactions on Microwave Theory and Techniques*, vol. 46, pp. 952–958, 1998.

[4] J. S. Hong and M. J. Lancaster, "Design of highly selective microstrip bandpass filters with a single pair of attenuation poles at finite frequencies," *IEEE Transactions on, Microwave Theory and Techniques*, vol. 48, pp. 1098–1107, 2000.

[5] J. S. Hong and M. J. Lancaster, "Couplings of microstrip square open-loop resonators for cross-coupled planar microwave filters," *IEEE Transactions on Microwave Theory and Techniques*, vol. 44, pp. 2099–2109, 1996.

[6] J. S. Hong and M. J. Lancaster, "Cross-coupled microstrip hairpin-resonator filters," *IEEE Transactions on Microwave Theory and Techniques*, vol. 46, pp. 118–122, 1998.

[7] S. J. Yao, R. R. Bonetti, and A. E. Williams, "Generalized dual plane multicoupled line filters," *IEEE Transactions on Microwave Theory and Techniques*, vol. 41, pp. 2182–2189, 1993.

[8] A. A. Melcon, J. R. Mosig, and M. Guglielmi, "Efficient CAD of boxed microwave circuits based on arbitrary rectangular elements," *IEEE Transactions on Microwave Theory and Techniques*, vol. 47, pp. 1045–1058, July 1999.

[9] 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.

[10] K. A. Michalski and J. R. Mosig, "Multilayered media green's functions in integral equation formulations," *IEEE Transactions on Antennas and Propagation*, vol. 45, pp. 508–519, 1997.

[11] F. Quesada-Pereira and A. A. Melcon, "Analysis of finite microstrip structures using an efficient implementation of the integral equation technique," in *Proceedings of IEEE, MTT-Symposium*, MTT-S, 2003. Accepted.