Design of a Dual Band-Pass Filter Using Modified Folded Stepped-Impedance Resonators

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***Abstract*— A folded stepped impedance resonator (SIR) modified by adding an inner quasi-lumped SIR stub is used as the basic block of a new configuration of dual band-pass filter. The main advantage of the proposed filter is to allow independent control of the features of the first and the second pass bands. Additional design flexibility can be achieved by allowing the stub to be located at an arbitrary position along the high impedance line section of the main SIR. The positions of the tapped lines have been optimized in order to match the filter at the central frequencies of both pass bands. Some designs are reported to illustrate the possibilities of the structure.**

***Index Terms*— Dual bandpass filter, stepped impedance resonator (SIR)**

I. INTRODUCTION

Modern dual band operation devices require the development of efficient and compact dual band filters. Several design techniques can be found in the literature: composition of two simple band pass filters [1], designs based on cascade connection of simple bandpass filters with large bandwidth and one stop band filter [2], and filters built making use of two different types of resonators [3]. The main disadvantage of such designs is their large size when compared with a simpler implementation. Nowadays the trend is the design of filters whose individual components present a double bandpass response *per se*. Some of the distributed filters investigated during the last few years are made up of lines loaded with stubs [4]-[6]. More compact layouts are based on coupled resonators (of different types) designed in such a way that the two first resonance frequencies of the resonators coincide with the central frequencies of the two pass bands [7]-[11]. In this paper, we propose a new resonator whose resonance frequencies can be separately selected. This resonator is a modification of the conventional stepped impedance resonator (SIR) consisting in the introduction of a quasi-lumped stub SIR type. In this structure, assuming the inner stub is electrically short, the first resonance frequency only depends on the dimensions of the external SIR whereas both the external SIR and the quasi-lumped stub determine the second resonance frequency. This effect allows for the tuning of the frequencies independently, unlike the conventional SIR for which a change in its dimensions has an impact on both frequencies. A similar concept has recently been applied in [12], [13]: an open loop resonator is loaded with an internal stub to provide frequency tuning of the second pass band. However, since open loops work under $\lambda/2$ operation, the size of the designs are appreciably bigger than those proposed in the present work.

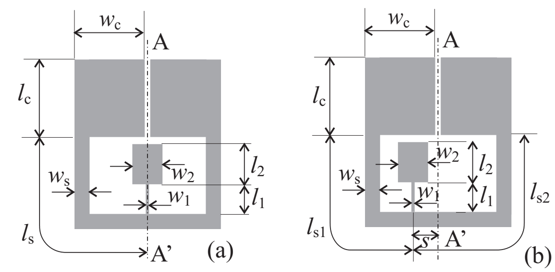

Fig. 1. Symmetric (a) and asymmetric (b) modified SIR used as basic resonators.

II. CHARACTERIZATION OF THE RESONATOR

A. Symmetrical structure

Fig. 1(a) shows the layout of a modified symmetrical SIR with a quasi-lumped stub connected to the central position of the high impedance line. This configuration admits an analysis in terms of even and odd excitations (the AA' plane behaves as an electric/magnetic wall for odd/even excitation). Voltage (current) vanishes in the inner stub [12], leading to the approximate transmission line circuit models represented in Fig. 2. Referring to Fig. 1(a), Z_s and θ_s denote the impedance and electrical length of the microstrip line (length l_s and width w_s); $Z_{o,e}$ and $\theta_{o,e}$ the modal impedances and electrical lengths of the two coupled lines (length l_c and width w_c; the separation used is the minimum slot size allowed by the used technology); and Z_i and θ_i the characteristic impedances and electrical lengths of the sections of length l_i and width w_i $(i = 1, 2)$ of the inner stub. From the condition $Y_{in} = 0$, the resonance frequencies of the odd and even excitations can be separately extracted:

$$\tan\theta_s \tan\theta_o = R_o \quad \text{(odd resonances)} \tag{1}$$

$$\frac{1}{2R_1}\left(1+\frac{\tan\theta_e\tan\theta_1}{R_e}\right)\left(\frac{\tan\theta_1}{R_1}+\frac{\tan\theta_2}{R_2}\right)+ \\ +\left(\tan\theta_s+\frac{\tan\theta_e}{R_e}\right)\left(\frac{1}{R_1}+\frac{\tan\theta_1\tan\theta_2}{R_2}\right)=0 \\ \text{(even resonances)} \tag{2}$$

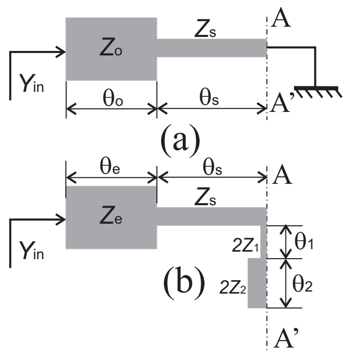

Fig. 2. Transmission line circuit model of the proposed symmetrical SIR. (a) odd excitation, and (b) even excitation.

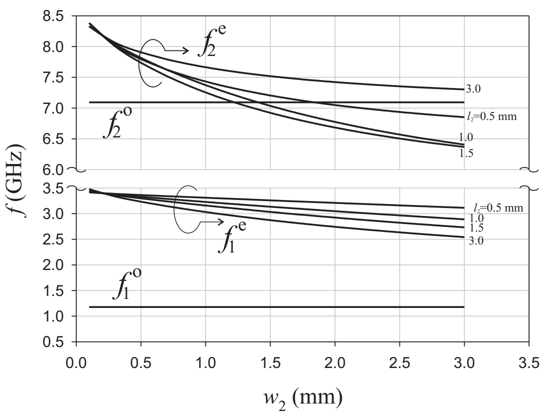

Fig. 3. Behavior of the first four resonance frequencies of a symmetric resonator versus w_2 (l_2 is used as a parameter). Dimensions: l_s =8.35 mm, w_s =0.37 mm, l_c =4.3 mm, w_c =4.3 mm, w_1 =0.2 mm, $l_1 + l_2$ =3 mm. The resonator is printed on a substrate with permittivity ε_r =9.9 and thickness h =0.635 mm.

where $R_{o,e} = Z_{o,e}/Z_s$ and $R_i = Z_i/Z_s$ $(i = 1, 2)$. As expected from Fig. 2 and eqs. (2) and (3), the resonance frequencies of odd excitations exclusively depend on the external SIR whereas those of even excitations depend on both the external SIR and the inner stub. This fact makes it possible to design a dual passband filter by tuning the central frequency of the first band varying the dimensions of the external resonator, and the central frequency of the second band varying the dimensions of the internal stub. As an example, we have obtained the four first resonances of a symmetrical resonator like that of Fig. 1(a). In Fig. 3, these frequencies have been represented versus the width w_2 using l_2 as parameter, keeping the same total length of the stub: l_1+l_2. We have distinguished between those resonance frequencies corresponding to odd excitation, f_1^o and f_2^o (they do not depend on the stub dimensions), and those corresponding to even excitation, f_1^e and f_2^e (they are sensitive to the presence of the stub). When designing the corresponding dual pass band filter, from Fig. 3 we can extract the range of values in which we can tune the central frequency of the second band (f_1^e). The third resonance frequency (f_2^o or f_2^e) gives information about the behavior of the filter beyond the second band.

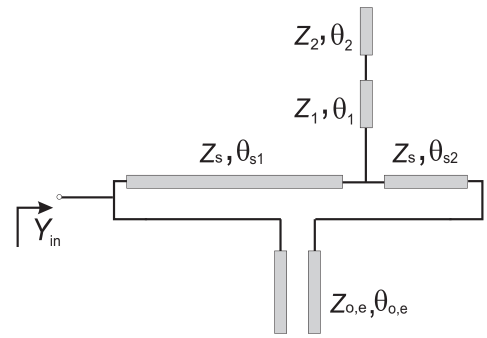

Fig. 4. Transmission line model of the asymmetrical resonator

TABLE I
VALUES OF THE FOUR FIRST RESONANCE FREQUENCIES (IN GHZ) OF AN ASYMMETRIC RESONATOR FOR DIFFERENT VALUES OF s.

s(mm)	f_1	f_2	f_3	f_4
0	1.218	2.686	6.742	7.053
0.5	1.217	2.691	6.556	7.257
1	1.216	2.704	6.314	7.591
1.5	1.214	2.727	6.073	7.965
2	1.212	2.760	5.850	8.369
2.5	1.209	2.804	5.644	8.782

B. Asymmetrical structure

Higher flexibility is achieved by allowing the stub to shift along the high impedance line section (see Fig. 2(b)). When this happens, the structure is no longer symmetrical and the analysis in terms of even/odd excitations cannot be applied (see the new equivalent circuit in Fig. 4). This circuit can be analyzed as a parallel connection of the open-ended coupled lines (modal impedances Z_e and Z_o) and the T-circuit composed of two transmission lines of impedance Z_s and an open SIR stub (impedances Z_1 and Z_2). The resonance frequencies can be obtained following the rationale in [15]. It will be shown later that the distance s between the middle of the inner stub and the axis AA' plays an essential role to determine the coupling between resonators at the second resonance. Our aim is to use s to control that coupling, for which it would be desirable that the two first resonance frequencies keep almost constant as s varies. This is approximately satisfied provided that the electrical length of the stub is small up to the second resonance frequency. The first four resonance frequencies of an example case have been tabulated in Table I. Referring to Fig. 1(b), the resonator dimensions are: $l_{s1} + s = 8.35$ mm, $w_0 = 0.37$ mm, $l_c = w_c = 4.3$ mm, $w_1 = 0.2$ mm, $l_1 = 0.6$ mm, $w_2 = 2.55$ mm, and $l_2 = 2.55$ mm. The substrate is the same as in Fig. 3. Since the electrical length of the stub increases with frequency, the higher the resonance frequency order, the stronger its dependence with s. But for the first two resonances (electrically small stub), the dependence of f_1 with s is negligible whereas f_2 changes around 4%. In order to compensate for this change, the stub has been adjusted so that both the first and the second resonance frequencies remain the same for all the stub positions (we have slightly modified

TABLE II
VALUES OF THE RESONANCE FREQUENCIES OF THE STRUCTURE (IN GHZ) OF TABLE I AFTER ADJUSTING w_2

s(mm)	w_2(mm)	f_1	f_2	f_3	f_4
0	2.55	1.218	2.686	6.742	7.053
0.5	2.57	1.217	2.687	6.563	7.256
1	2.64	1.216	2.687	6.302	7.585
1.5	2.75	1.215	2.688	6.048	7.951
2	2.93	1.211	2.688	5.807	8.344
2.5	3.20	1.209	2.685	5.575	8.740

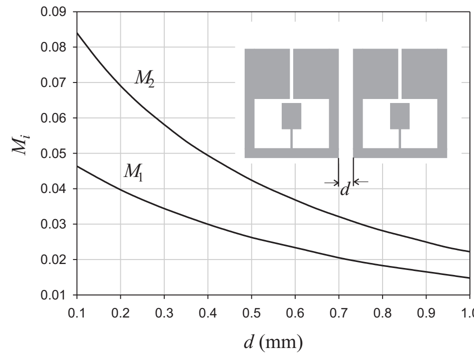

Fig. 5. Coupling coefficients, M_1 and M_2, as a function of the distance between symmetrical resonators.

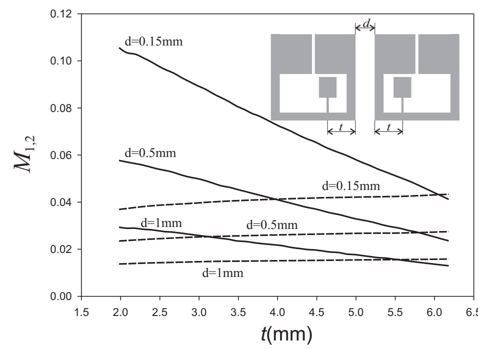

Fig. 6. Coupling coefficients M_1 (dashed lines) and M_2 (solid lines), as a function of the internal displacement of the stub using the distance d as parameter.

the value of w_2 for each value of s). After this process, the frequency values of Table I have been recalculated and shown in Table II.

III. DESIGN METHODOLOGY FOR FILTERS BASED ON MODIFIED SIR

A. Symmetric configuration

The design methodology for dual-band filters based on the proposed resonators is close to the procedure in [16] for filters with a single pass band and direct coupling. If the resonator of Fig. 1(a) is used, the first step is to adjust the dimension of the external SIR so that its first resonance frequency is the central frequency of the first passband, f_1. Then, the inner stub must be designed so that the second resonance fits f_2 (the second band). The dimensions of the outer SIR and those of the inner stub have been obtained from the model in Fig. 2 (note that there are several geometries for which the two first resonance frequencies are f_1 and f_2). The next step is to obtain the coupling coefficients, M_i at f_i $(i = 1, 2)$ from the specs of the pass bands (fractional bandwidth, Δ_i, and ripple, r_{pi} $(i = 1, 2)$) as a function of the coupling distance, d. This task has been carried out by using the commercial electromagnetic solver *Ensemble*. The coupling coefficients of a pair of symmetric resonators as a function of d are shown in Fig. 5. The substrate and the dimensions of the resonator are the same as those in Fig. 3 ($w_2 = 2.55$ mm). For this resonator, $M_2 > M_1$, thus the fractional bandwidth of the first band will be higher than that of the second band. Note that changing both the dimensions of the outer-SIR and the inner stub makes it possible to achieve values of M_1 and M_2 different from those extracted from Fig. 5.

B. Asymmetric configuration

When using the asymmetric resonator in Fig. 1(b) to design a dual band filter, the procedure is very similar to that described for the symmetric case, but with an interesting advantage. In Fig. 6 we have represented the coupling coefficients M_1 and M_2 as a function of the parameter t (which stands for the position of the inner stub) using the distance between resonators d as parameter. It should be noted that, for each value of t, the inner stub has been adjusted in order to keep invariable the two first resonance frequencies of the resonator. The dimensions and substrate are the same as in the symmetric case. As it can be seen in Fig. 6, the coupling factor in the first band, M_1, does not meaningfully depend on the position of the stub whereas the coupling factor of the second band, M_2, strongly depends on that position. In other words, by means of a simple stub shifting, we can control the coupling factor of the second band *without modifying the coupling factor of the first band*. Therefore, the range of the M_1 and M_2 values (and the possibilities for the fractional bandwidths Δ_1 and Δ_2) is much greater without changing the outer SIR dimensions in the asymmetric configuration than in the symmetric one.

In both configurations, the last step of the design consists of matching the two pass bands simultaneously. Although it is possible to follow a method similar to that described in [8] to achieve this goal, in order to avoid dual frequency transforms (which can enlarge the size of the filter) we have used the electromagnetic simulator to find the optimal dimensions and position of tapped lines, considering in all cases $50\,\Omega$ load impedances.

IV. EXAMPLES OF DESIGN

To check the design method explained above, we have designed two dual passband filters of order $N = 2$ with the bands centered at $f_1 = 1.21$ GHz and $f_2 = 2.65$ GHz using symmetric and asymmetric resonators. The dimensions of the resonators are exactly the same as those employed in the theoretical study. The specifications of filter *A*, (symmetric resonators) for the first band are $r_{p1} = 0.1$ dB, $\Delta_1 = 3.3\%$. From

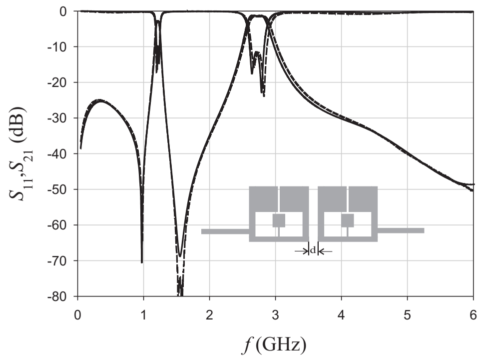

Fig. 7. Simulated (dashed lines) and measured (solid lines) response of filter *A* designed using symmetrical resonators.

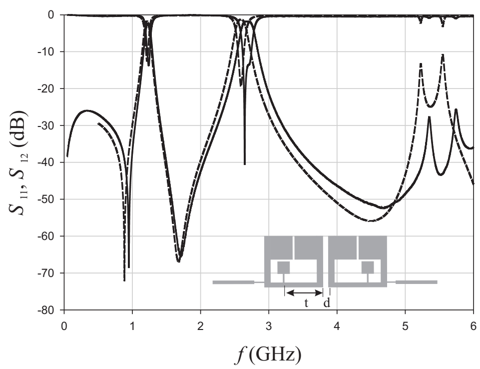

Fig. 8. Simulated (dashed lines) and measured (solid lines) response of filter *B* designed using asymmetrical resonators.

these values, in Fig. 5 we extracted the distance $d = 0.15\,\text{mm}$, which imposes the second band specifications: $r_{p2} = 0.15\,\text{dB}$ and $\Delta_2 = 10\%$. The simulated and measured filter responses of the designed filter are shown in Fig. 7. A good agreement has been found between both results. Please note that in the optimization process of the dimensions and position of the tapped lines we have achieved a transmission zero between the two pass bands, thus improving the filter selectivity. In the case of filter *B* (designed employing asymmetric resonators), we can separately establish the specs of the two pass bands: for the first band, $r_{p1} = 0.1\,\text{dB}$ and $\Delta_1 = 3.5\%$; for the second band, $r_{p2} = 0.1\,\text{dB}$ and $\Delta_2 = 4\%$. For these values, we can obtain from Fig. 6 the distances $d = 0.15\,\text{mm}$ and $t = 6.45\,\text{mm}$. In Fig. 8 it is shown the simulated and measured responses of the designed filter. Again reasonable agreement has been found between both results (discrepancies are due to dimensional tolerances).

V. Conclusion

This paper has presented a new resonator based on a modification of the conventional folded SIR. The modification consists of adding an inner SIR type stub connected to the high impedance line of the main resonator. The possibility of using symmetric and asymmetric versions of the new resonators to design dual pass band filters has been investigated. We have found that, in the case of the asymmetric resonator, the filter design is much more flexible because we can separately design the specifications of the two bands without modifying the geometry of the external SIR: we can control the fractional bandwidth of the first band by means of the distance between resonators and the fractional bandwidth of the second band with the inner stub position. Two filters have been designed, built and measured, finding in both designs a very good agreement between simulated and measured filter responses. The designs carried out in this paper are of order 2. Higher order filters are under development.

VI. Acknowledgement

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References

[1] H. Myyake, S. Kitazawa, T. Ishizaki, T. Yamada, and Y. Nagatomi, "A miniaturized monolhitic dual band filter using ceramic lamination technique for dual mode portable telephones," *IEEE-MTT-S International Microw. SYmp. Dig.*, vol. 2, pp. 789-792, 1997

[2] L.C. Tsai and C. W. Huse, "Dual-band bandpass filters using equal length coupled-serial-shunted lines and Z-transform techniques," *IEEE Trans. Microw. Theory and Tech.*, vol. 52, no.4, pp. 1111-1117, April 2004.

[3] C. Y. Chen and C. Y. Hsu, "A simple and effective method for microstrip dual band design," *IEEE Microw. Wireless Compon. Letter*, vol. 16, no.3, pp. 246-258, May 2006.

[4] C. Quendo, E. Rius, and C. Person, "An original topology of dual-band filter with transmission zeros," *IEEE-MTT-S International Microw. SYmp. Dig.*, vol. 2, pp. 1093-1096, 2003.

[5] C. M. Tsai, H. M. Lee, and C. C. Tsai, "Planar filter design with fully controllable second passband," *IEEE Trans. Microw. Theory and Tech.*, vol. 53, no. 11, pp. 3429-3439, November 2005.

[6] K. S. Chin, J. H. Yeh, and S. H. Chao, "Compact Dual-Band Bandstop Filters Using Stepped-Impedance Resonators," *IEEE Microw. Wireless Compon. Letter*, vol. 17, no. 12, pp. 849-851, December 2007.

[7] J. T. Kuo and H. S. Cheng, "Design of quasi-elliptic function filters with a dual-passband response," *IEEE Microw. Wireless Compon. Letter*, vol. 14, no. 10, pp. 472-475, October 2004.

[8] J. T. Kuo, T. H. Yeh, and C. C. Yeh, "Design of microstrip bandpass filters with a dual-passband responds," *IEEE Trans. Microw. Theory and Tech.*, vol. 53, no. 4, pp. 1331-1337, April 2005.

[9] M. H. Weng, H. W. Wu, and Y. K. Su, "Compact and Low Loss Dual-Band Bandpass Filter Using Pseudo-Interdigital Stepped Impedance Resonators for WLANs," *IEEE Microw. Wireless Compon. Letter*, vol. 17, no. 3, pp. 187-189, March 2007.

[10] S. Sun and L. Zhu, "Compact dualband microstrip bandpass filter without external feed," *IEEE Microw. Wireless Compon. Letter*, vol. 15, no. 10, pp. 644-646, October 2005.

[11] Y.P. Zhang and M. Sun, "Dual-band microstrip passband filter using stepped-impedance resonators with new coupling scheme," *IEEE Trans. Microw. Theory and Tech.*, vol. 54, no. 10, pp. 3779-3785, October 2006.

[12] X.Y. Zhang, J.-X. Chen, Q. Xue, and S. M. Li, "Dual-band bandpass filters using stub-loaded resonators," *IEEE Microw. Wireless Compon. Letter*, vol. 17, no. 8, pp. 583-585, August 2007.

[13] P. Mondal and M. K. Mandal, "Design of dual-band passband filters using stub-loaded open-loop resonators," *IEEE Trans. Microw. Theory and Tech.*, vol. 56, no. 1, pp. 150-155, January 2008.

[14] M. Sagawa, M. Makimoto, and S. Yamashita, "Geometrical structures and fundamental characteristics of microwave stepped-impedance resonators," *IEEE Trans. Microw. Theory and Tech.*, vol. 45, no. 7, pp. 1078-1085, July 1997.

[15] M. Makimoto and S. Yamashita, *Microwave Resonators and Filters for Wireless Communications*, *Springer Series in Advanced Microelectronics*, Berlin, 2001

[16] J. S. Hong and M. J. Lancaster, *Microstrip Filters for RF/Microwave Applications*, *Wiley Inter-Science*, New York, 2001.