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Improving the Frequency Response of a Circular Dual-Mode Resonator with a Reconfigurable Bandwidth

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***Abstract*—**In this paper, a method for reconfiguring bandwidth in a circular dual-mode resonator is presented. The method concerns the optimized geometry of a structure that may be used to host the tuning elements, which are typically RF (Radio Frequency) switches. The tuning elements themselves, and their performance during tuning, are not the focus of this paper. The designed resonator is able to reconfigure its fractional bandwidth by adjusting the inter-coupling level between the degenerate modes, while at the same time improving its response by adjusting the external-coupling level and keeping the center frequency fixed. The inter-coupling level has been adjusted by changing the dimensions of the perturbation element, while the external-coupling level has been adjusted by changing one of the feeder dimensions. The design was arrived at via optimization. Agreeing simulation and measurement results of the designed and implemented filters showed good improvements in return loss values and the stability of the center frequency.

***Keywords*—**Dual-mode resonators, perturbation element, perturbation theory, reconfigurable filters, software defined radio (SDR), cognitine radio.

I. INTRODUCTION

MODERN reconfigurable filters offer multifunctional frequency behavior which can enable advanced radio paradigms, such as Software Defined Radio (SDR), and Cognitive Radio (CR) [1]-[3].

Reconfigurable filters are usually classified by their functionality. The most common filters reconfigure their center frequency to achieve multi-band selection, while others reconfigure their bandwidth (to eliminate out-of-band noise and interference), their skirt roll-off profile, or their group-delay response (e.g. for equalization) [4].

Dual-mode microstrip resonators have been increasingly used for designing reconfigurable-bandwidth microwave filters [5].

Because of the symmetrical structure of a dual-mode resonator, it supports two mutually-orthogonal degenerate modes of resonance, which have the same resonant frequency f_0 and propagation constant β_{mnp}. The two degenerate modes are coupled and tuned synchronously when the two malki modes are symmetrically perturbed by inserting a cut or by adding a stub. The resonant frequency of each mode will change to f_1 and f_2. The location of the final resonant frequencies f_1 and f_2 is determined by the coupling strength that exists between the two resonances. The coupling coefficient $k$for synchronously tuned resonators [6] is generally given by

$$k = \frac{{f_2}^2 - {f_1}^2}{{f_2}^2 + {f_1}^2}$$

where k is directly related to the spectrum range $f_2^2 - f_1^2$. The |S11| dips at these two frequencies usually indicate excellent matching. The rest of the range between the two frequencies also has good matching, if they are relatively close to each other. As they grow apart, when coupling is increased, the matching worsens in the middle of the frequency range. However, this changing frequency range (pole pair positions) is the basis of bandwidth tuning in coupled-resonator filters [2], [7]. Since resonators form the building blocks of such filters, inter-coupling tuning gives pole-pairs that coalesce to produce bandwidth tuning in the overall filter, which often involved multiple pole pairs [2], [7].

The coupling coefficient of inter-coupled resonators is defined as k, while the coupling coefficient of input/output ports and resonator is defined as k_{ext}, and for critical coupling k_{ext} =1. Inter-coupling is related to the perturbation element dimensions, while the input/output coupling is related to input/output port dimensions.

This paper demonstrates a proposed structure as a solution to some design challenges when designing a tunable-bandwidth filter using dual-mode resonator, which are the center frequency deviation and the matching degradation. The proper solution has been analyzed and implemented.

II. PRIMARY STRUCTURE DEFINITION AND SIMULATION

A filter with reconfigurable bandwidth (BW) based on a circular dual-mode microstrip resonator at 2.47 GHz was designed to illustrate how BW can be tuned as in [8]. The layout circuit pattern of the designed filter is shown in Fig 1.

The filter is designed using Arlon 25N substrate from [9]. The filter circuit was packaged in an aluminum enclosure.

The resonator is excited using the gap-coupling method. The filter bandwidth has been tuned by changing the dimensions of the cut at the outer edge of the resonator, as shown in Fig 1. This structure was analyzed using electromagnetic simulator based on Finite Element Method (FEM), and the simulation results are shown in Fig. 2; they

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represent the insertion loss ($|S_{21}|$) for three values of the cut depth (cut_x) and fixed value of cut width (cut_y) of 3.3 mm. We observe that the inter-coupling level has been changed from under to critical, and then to over for three cases ofcut_x. At the critical-coupling case, as shown in Fig. 2, the Fractional Bandwidth (FBW) is about 3.23%; while for the strong-coupling case, the FBW is increased to 6.55%.

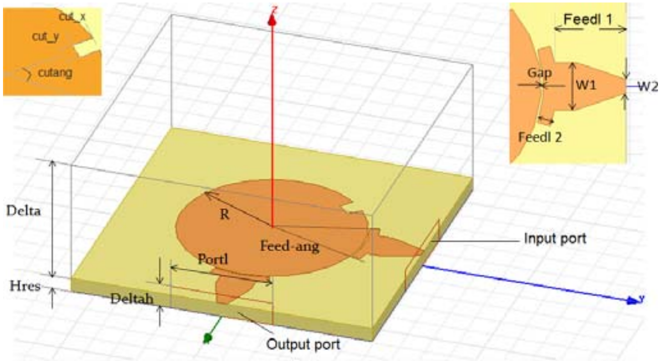


Fig. 1 Layout of the designed filter: Dimensions are in (mm) Gap = 0.25, R =18.24, Feedl1= 1.8, Feedl2 = 10.1, w1 = 7, w2 = 2, Feed-ang = 17°, cutang = 40°. Aluminum enclosure dimensions are 58.72 × 58.72 × 29.36, and substrate specifications are: Hres = 3.06, $\boldsymbol{\varepsilon_r}$ = 3.38, and $\boldsymbol{tan\delta}$ = 0.0024

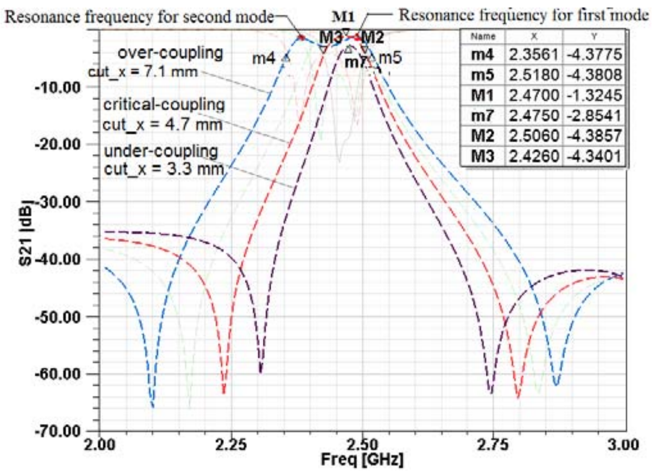


Fig. 2 Insertion loss of the simulated filter for three values of cut depth

III. Design Challenges

Initial study shows that two technical challenges are faced when BW is increased. Keeping a fixed center frequency is one of the major obstacles as shown in Fig. 3. This problem can be solved, as in [5], by choosing a suitable cut shape, and varying one cut dimension for a specific value of the other dimension. The second challenge is the mismatch problem. At critical coupling, as shown in Fig. 3, $|S_{11}|$ is about 23 dB (point m2), that's denotes to good matching in the circuit. While in over-coupling case, $|S_{11}|$ will be degraded to about 4.5 dB (point m1), and the response of insertion loss $|S_{21}|$ will not be flat in the passband. This results in higher insertion loss and important mismatch, so the filter performance is degraded. This problem will be studied in this section, and a proper solution will be suggested in the next section.

When changing the cut dimensions, the impedance of the resonator will be changed, this results in bad matching between feeders and resonators [10]. It follows that $k_{out} \neq 1$. Thus, to achieve an acceptable response for all different configurations, the input/output coupling level must be readjusted for every value of cut dimensions.

Varying the gap to adjust adjust the coupling level has been studied in [6], and a huge number of switches was needed, which complicated the structure. So, more flexible and simpler way to adjust the coupling level is proposed.

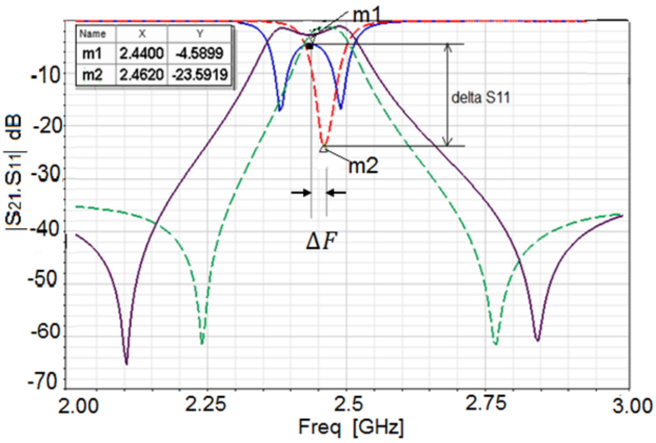


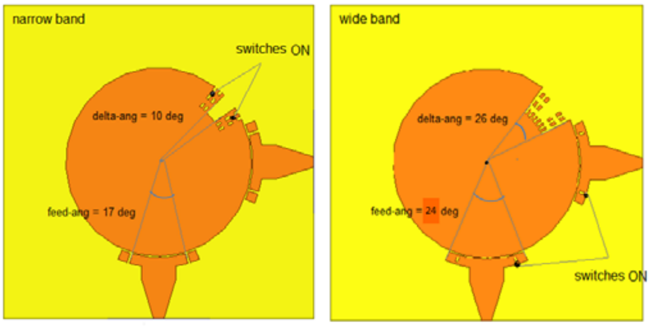
Fig. 3 Degradation of $|\mathbf{S_{21}}|$ and $|\mathbf{S_{11}}|$ when the BW of the filter is increased

IV. Practical Solution of Mismatch Problem

The input/output coupling level can be adjusted by varying the feeder dimensions as defined in Fig. 1. The width of the rectangular part "W1" has been determined to obtain a port with characteristic impedance Z_0; so it is not suitable to change it. On the other hand, it's not possible to change "Feedl1, and Feedl2", because the substrate dimensions are fixed. While the angle of the arc part of the feeder "feed-ang" is suitable to be changed, and it will affect the matching and the coupling level between the feeder and the resonator. To prove this idea, a reconfigurable bandwidth filter based on dual-mode circular-shaped microstrip resonator has been designed, analyzed and implemented at 2.47 GHz. Fig. 4 shows the layout of the designed filter.

The perturbation element dimensions and shape have been selected as in [8] to keep the center frequency fixed. Tuning the perturbation element dimensions and the angle of the cut "Delta-ang" has been achieved by simulating the use of MEMS switches; two filters samples have been implemented, the samples simulate the on/off cases of the switches.

All switches in the cut must be ON to obtain a narrow BW (Fig. 4 (a)), where the "Delta-ang" is equal to 10°, while a wider BW has been obtained for " Delta-ang " equal to 26°, where all switches are OFF (Fig. 4 (b)). The "FBW" is increased from about 2.85 % to about 8 %. Also these two cases representing the use of MEMS switches show that the feeder angle "feed-ang" can be changed from 17°(Fig. 4 (a)) to 24°(Fig. 4 (b)) in order to improve the filter response in the wideband case. Simulation results are shown in Fig. 5.



(a) (b)

Fig. 4 Layout of the designed filter at 2.47 GHz: (a) narrowband case simulating the state ON of switches in the cut. (b) wideband case simulating the state ON of switches in the arc of the feeder

We notice that, in wideband case, $|S_{11}|$ is about 4.4 dB, this value refers to high reflection and then bad matching.

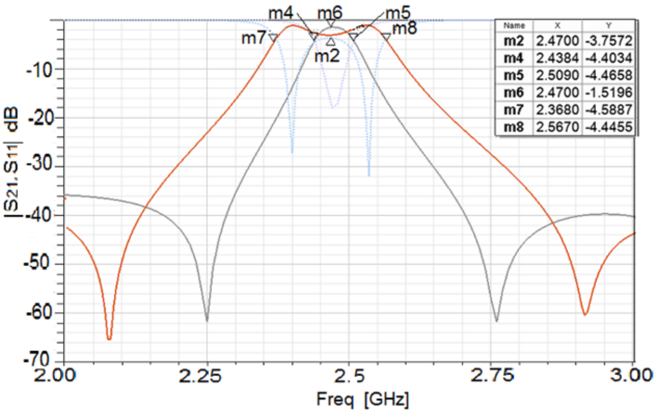


Fig. 5 Simulation results showing the insertion loss |S21| and return loss |S11| of the filter for narrow band and wide band cases

To improve the matching of the filter as we mentioned above, the feeder angle has been increased from 17 °(Fig. 4 (a)), to 24°(Fig. 4 (b)) by simulating the use of switches to connect a small piece to the arc of the feeder.

Simulation results in Fig. 6, demonstrate that, in the wide BW case, when the feeder angle is increased, the reflection coefficient $|S_{11}|$ has been improved by about 3.6 dB when compared to the previous case (from point m2 to m1), and the filter insertion loss$|S_{21}|$ has been become flat in the passband.

Finally, further improvement of the insertion loss is possible by changing the feeder angle, which is equal to 1.43 dB, also the obtained stopband attenuation is more than 30 dB.

V. Implementation and Measurement Results

Two filters have been implemented to represent the variation of feeder angle in wide BW case because we didn't use MEMS switches; the implemented filters are shown in Fig. 7. Note that the cut angle is the same.

Figs. 8 (a) and (b) show the frequency response measurements of the two implemented filters, using R&S FSH8 spectrum analyzer in scalar network mode. The measurement results show that $|S_{11}|$ is improved by about 6 dB (from 9 to 15 dB) when the feeder angle is increased from 17° to 24° as shown in Fig. 8 (a); and the insertion loss become flat in the passband. These measurement results of the two implemented filters of the wideband case demonstrate that the design challenges have been overcome. The matching of the implemented filter has been improved by tuning the arc of the feeder as shown in Fig. 8 (a), and the insertion loss in the passband has been decreased.

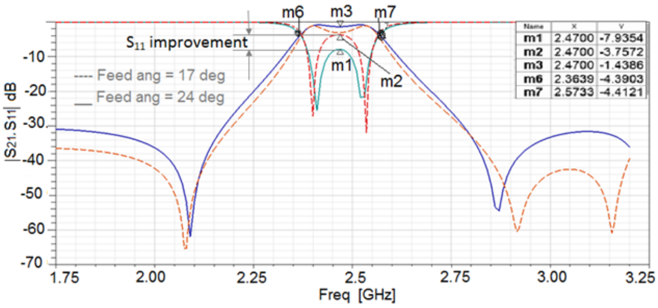


Fig. 6 Simulation results showing the insertion loss |S21| and return loss |S11| of the filter (Fig. 4 (b)) versus feeder angle

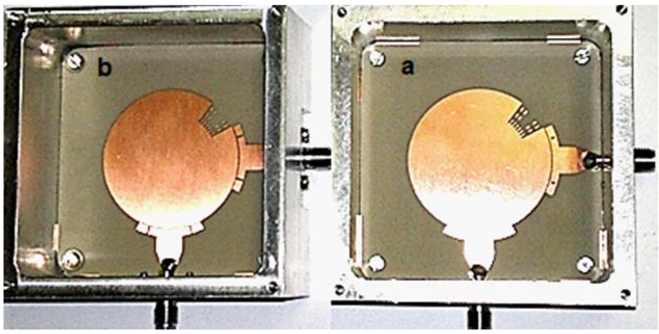
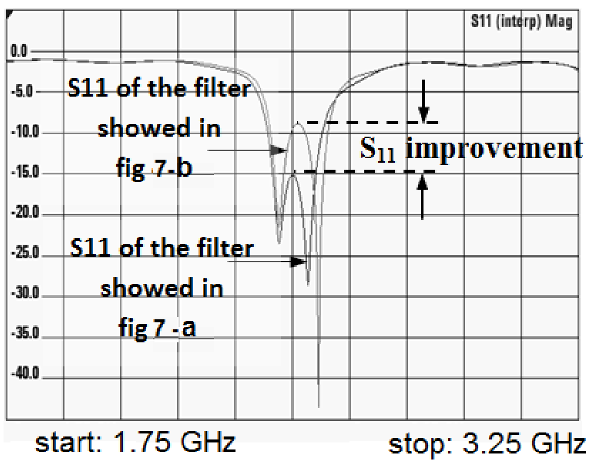
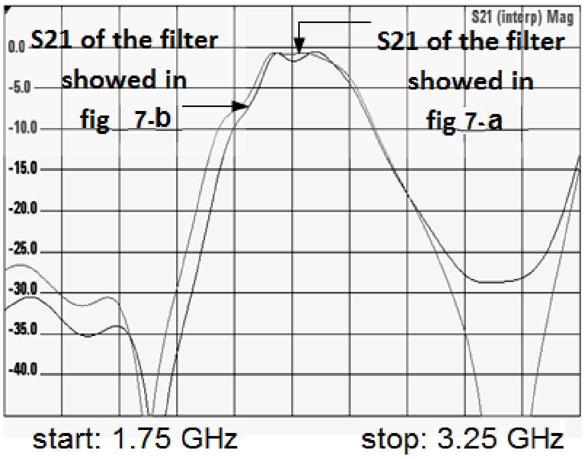


Fig. 7 The two implemented filters of the wideband case. (a) simulating the state ON of switches in the arc of the feeder. (b) simulating the state OFF of switches in the arc of the feeder



(a) $|S_{11}|$



(b) $|S_{21}|$

Fig. 8 Measured frequency responses of the two implemented filters

VI. Conclusion

Tunable bandwidth filters using circular dual-mode resonator have been analyzed, designed, and implemented.

A geometry of the resonator structure has been optimized to host the tuning elements. The BW of the filter is tuned by changing the perturbation element dimensions. A suitable cut shape and dimensions have been selected to keep center frequency fixed. The feeder dimensions have been changed to keep a good matching between the feeder and the resonator, the angle of the arc part of the feeder is more suitable to be tuned; it followed from that a good improvement in the return loss and the insertion loss of the filter in the passband.

The "FBW" of the designed filter has increased by a ratio of about 3:1, and the matching, measured by $|S_{11}|$ in dB, between the feeder and the resonator has been improved by about 3.6 dB when the feeder angle has been increased from 17° to 24°. Two filters representing the case of narrow band and wide band have been implemented, and a good agreement between simulation and implementation has been obtained. This result can be expanded to adjust the matching between the feeder and resonator for several values of "FBW".

References

[1] Christian Schuster ; Alex Wiens ; Florian Schmidt ; Matthias Nickel ; Martin Schüßler ; Rolf Jakoby ; Holger maune" Performance Analysis Of Reconfigurable Bandpass Filters With Continuously Tunable Center Frequency And Bandwidth", IEEE Transactions on Microwave Theory and Techniques ,Vol: 65 , Issue: 11, pp.4572-4583 , Nov. 2017.
[2] Pingyue Song; Hossein Hashemi A 13th-order CMOS reconfigurable RF BPF with adjustable transmission zeros for SAW-less SDR receivers" IEEE International Solid - State Circuits Conference - (ISSCC) March 2018.
[3] Adham Naji, Paul Warr, Mark Beach and Kevin Morris, "A Fundamental Limit on the Performance of Geometrically-Tuned Planar Resonators", IEEE Transactions of Microwave Theory and Techniques, Vol. 59, Iss. 6, pp. 1491-1499,2011.
[4] Ali Kursad Gorur, Pinar Ozturk Ozdemir, Elif Gunturkun Sahin, Ceyhun Karpuz2 "A novel microstrip diplexer design with tunable bandwidths and switchable channels for 4.5G applications," Turkish Journal of Electrical Engineering & Computer Science, vol. 25, pp 4445- 4456,Aug 2017.
[5] Cesar A. Lugo Jr., "Design and synthesis techniques for reconfigurable microwave filters using single and dual mode resonators",PhD dissertation, Georgia Institute of Technology, December 2006.
[6] J.-S. Hong,"Coupling of asynchronously tuned coupled microwave resonators", IEE Proc. Microw. Antennas Propag., Vol. 147, pp. 354-358, 2000.
[7] Jia-Sheng Hong, "Microstrip Filters for RF/Microwave Applications", 2nd edition, Wiley, 2011
[8] Adham Naji; and Mina H. Soliman "Center Frequency Stabilization in Planar Dual-Mode Resonators during Mode-Splitting Control", Scientific Reports, pp 1-14 Vol 7, March 2017.
[9] https://imageserv11.team-logic.com/mediaLibrary/303/25N25FR.pdf
[10] Adham Naji and Paul Warr, "Independence of the unloaded Q of a Planar Electromagnetic Resonator from its Shape", IEEE Transactions on Microwave Theory and Techniques, Vol. 60, Iss. 8, pp. 2370-2377.2012