INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2019, VOL. 65, NO. 4, PP. 731-737
Manuscript received December 9, 2018; revised September, 2019. DOI: 10.24425/ijet.2019.130256

Perturbation Element Effect on Frequency Stability in Dual Mode Reconfigurable Filters Based on Circular Microstrip Ring Resonators

Muhammad Haitham Albahnassi, Adnan Malki, and Shokri Almekdad

***Abstract*—A detailed study about the suitable perturbation element shape and location for tunable BW dual mode microstrip filter which has circular ring resonator is presented. BW tuning is achieved by resonator geometry modification. The study explains the effect of a perturbation element on the stability of the center frequency during BW tuning. Different cases have been studied for two shapes of perturbation element; which one is a rectangular and the other is a radial. The treated cases discuss whether the perturbation element is located in the inner or in the outer circumference of the ring, and whether it is a patch or a notch. BW tuning simulation treated the case of FBW_{3dB} increase for two and three times. The best case of perturbation element which has the best center frequency stability has been modeled, simulated, and fabricated at 2.4 GHz. Geometry modification of the filter took into account the RF MEMS modeling. The filter has an elliptic frequency response, and its FBW has been increased in five steps from 1.7% to 5%. The designed filters were evaluated experimentally and by simulation with very good agreement.**

***Keywords*—Dual mode ring resonators, dual-mode filters, perturbation element arrangement, BW reconfigurability**

I. INTRODUCTION

A RING resonator structure is applied in many different microwave and radio frequency circuits as filters, oscillators, mixers, and antennas [1]. It is favored because its advantages of compact size, easy fabrication, narrow passband bandwidth, and low radiation loss.

Dual-mode microstrip resonators, which firstly proposed by Wolff using a ring resonator [2], have been increasingly used for designing reconfigurable microwave filters, it became an urgent demand for advanced wireless communication systems, such as software defined radio (SDR), cognitive radio (CR), and green radio.

Reconfigurable filters can be realized using reactive elements, including micro electromechanical system (MEMS) [3,4], ferroelectric materials such as Barium Strontium Titanate (BST) [5, 6], piezoelectric transducers (PETs) [7, 8], p-i-n diodes [9, 10], varactor diodes [11, 12], etc.

These tuning elements allow the variation of many parameters of microstrip dual mode filters such as BW and center frequency. Filter BW can be tuned by changing the coupling level between exited modes within resonator by variation of perturbation element area, while center frequency can be tuned by changing resonators dimensions.

For tunable band applications using the dual-mode resonator, as band pass filter, one of the most important issues is to keep the center frequency fixed while varying the bandwidth of the filter; this issue was mentioned in many papers talking about tunable BW filters as in [13, 14].

The first article [13] illustrated microstrip diplexer with tunable bandwidth and switchable channels for 4.5G applications. First channel is at 1.8 GHz and has a bandwidth tuning range between 60 and 160 MHz, while the bandwidth of the second passband is at 2.6 GHz and can be tuned from 150 to 350 MHz. It is noticed that; the center the frequency for the first channel has been shifted about 40 MHz when its bandwidth was tuned from 60 to 160 MHz. while the center frequency shift of the second channel is about 90 MHz. In [14] a tunable dual-mode square loop resonator with patch reference elements has been illustrated, its fractional bandwidths was tuned from 1.12 % to 3.82 % at 1.64 GHz, while its center frequency has been shifted about 40 MHz. It is noticed that; these values of center frequency shift may cause bad effects in reconfigurable structures.

In this paper, a circular ring structure has been chosen as a dual mode BPF with adjustable fractional bandwidth, because it is considered as a suitable structure for magnetic-wall model, which explains the dual-mode behavior very well. This structure has been designed and simulated for several cases of the perturbation element to explain the relation between BW tuning and stability of the center frequency, and determine the best solutions to keep center frequency fixed.

II. BANDWIDTH TUNABILITY IN DUAL MODE RING MICROSTRIP FILTERS

Many modes can be supported by ring resonators. Ring resonator can be treated as a waveguide cavity with magnetic walls on the sides, so by using the magnetic-wall model, it could be shown that, the symmetrical microstrip ring resonator actually supports two degenerate modes. These modes can be excited when the boundary conditions are satisfied. The

The authors are with the Telecommunication Department, Higher Institute for Applied Sciences and Technology (HIAST), Damascus, Syria (e-mail: {haitham.bahnassi, adnan.malki, shokri.almekdad@hiast.edu.sy).

excitation is related with the perturbation and with coupling methods [3].

If circular symmetrical ring resonators has been distorted either by skewing one of the feed lines with respect to the other, or by introducing a perturbation element, then, the two degenerate modes will be coupled and their frequencies will shift.

The common practice of implementing a perturbation element in the dual mode ring resonator is by introducing a small patch at the corner of the annular ring resonator or by etching a notch at the corner. The suitable location of the patch or the notch for good coupling between the two degenerate modes is at azimuthal angles of 45°, 135°, 225°, or 315° as shown in Fig.1.

The response shape of the filter, based on dual mode ring resonators, is related to the location angle and the shape of the perturbation element [15, 16]. At azimuthal angles of 45°and 225°, frequency response type is a Butterworth for patch cases, and an elliptic for notch cases. While it is vice versa for a perturbation element located at azimuthal angles of 135 and 315°.

Usually, patch or notch is implemented in several shapes such as rectangular or radial. These shapes have many cases. Fig. 1 shows three cases of perturbation elements.

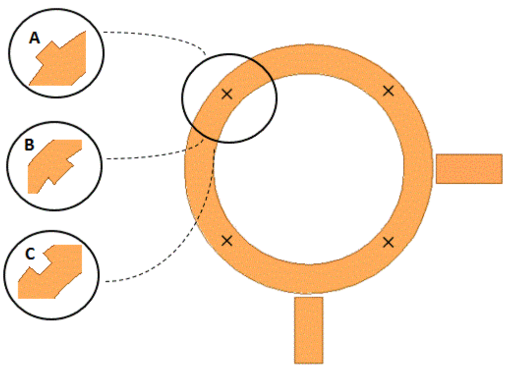

Fig. 1. Locations and shapes layout of perturbation element samples in circular ring dual mode BPF (× denotes suitable location, A: outer rectangular patch, B: inner radial patch, C: outer radial notch)

By controlling the severity of the disturbance; i.e. by changing the area of the patch or the notch, the coupling level between the two degenerate modes will change, and the frequency separation between these modes varies accordingly, so the bandwidth of the resonator will change. At critical coupling level (minimum bandwidth), the two degenerate modes have the same frequency.

Mathematically the relation between frequency separation and coupling level is represented by [17]:

$$k = \frac{{f_2}^2 - {f_1}^2}{{f_2}^2 + {f_1}^2} \qquad [1]$$

Where f_1, f_2 represents the resonance frequencies for the first and the second mode respectively, and k represents the coupling coefficient which indicates the coupling level.

In general, when coupling coefficient increases, the frequency decrease of the first mode is not equal to the frequency increase of the other, so center frequency deviation will occur.

So, stability of center frequency can be achieved when frequency decrease of the first mode is equal to the frequency increase of the other. This paper explains perturbation element location shape, and dimensions effect on center frequency stability, applied on dual mode annular ring resonators in planar circuits.

III. Filter Design And Analysis

Analysis methodology in this paper starts with the design and analysis of an initial non-tunable circular ring filter at critical coupling level, and determining the main parameters values. The next step is the simulation of the designed filter, for observing the effect of BW tuning on the center frequency deviation with respect to perturbation element dimension changes. Then several cases of perturbation element shapes and location are simulated to observe the effect of perturbation element type on the stability of the center frequency and determine the best case. Finally, a practical method for perturbation element size modification is employed, modeled, simulated and implemented.

A. Primary Structure Analysis

The initial design was based on a dual-mode microstrip circular ring resonator at 2.4 GHz. The layout circuit pattern of the designed filter is depicted in Fig. 2.

The perturbation element has been chosen as a radial shape notch located on the outer circumference at azimuthal angles of 45°.

The filter was designed using Rexolite substrate type 2200 with thickness of 1.57 mm and $\varepsilon_r = 2.62$.

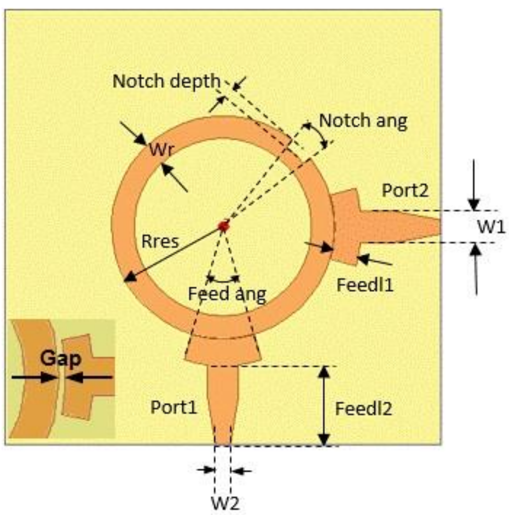

Fig. 2. Initially designed filter. .Dimensions are in (mm): R_{res} =15.3, Gap = 0.2, Feedl1= 2.4, Feedl2 = 11.8, w1 = 3.5, wr = 3.21, w2 = 2, Notch-depth = 1.28, Notch-ang = 12° , Feed ang = 40°

The resonator is excited by two feed lines connected with the input and output ports, where port 1 is the input port and port 2 is the output. The coupling between the feed lines and the ring resonator was designed as a loose coupling; which produces negligible effects to the resonance frequencies.

The filter structure was analyzed using modern electromagnetic simulation tools (which is based on the finite element method). So many of suitable dimensions, as the distance between the ring and the feeder; which is denoted as "gap", has been determined from simulation results.

The simulation results are shown in Fig. 3; it represents the insertion loss $|S_{21}|$ and the return loss $|S_{11}|$ for the critical-coupling case, the value of the insertion loss is 2.27 dB and the return loss value equal to 26.75 dB at f_o, while the $FBW_{3\ dB}$ is about 2.1%. Frequency response has an elliptic shape, attenuation at upper transmission zero (TZ) is equal to -61.7 dB at 2.637 GHz, while attenuation at lower TZ is equal to -56.337 dB at 2.2556 GHz.

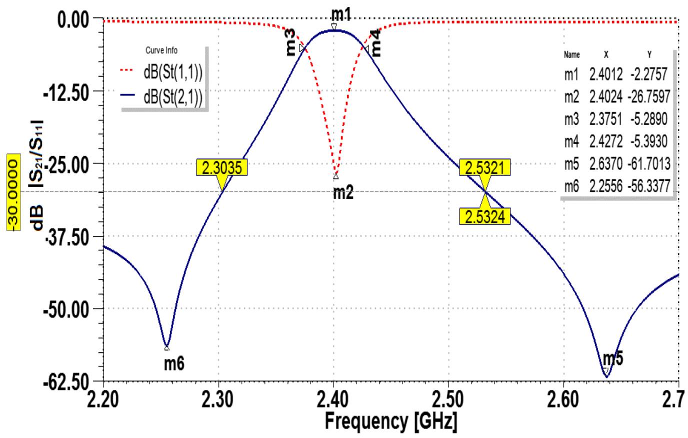

Fig. 3. Frequency responses ($|\mathbf{S_{21}}|$), ($|\mathbf{S_{11}}|$) of the filter circuit model with circuit parameters as given in Fig 2

B. *Tunable Bandwidth Filter Simulation*

By changing the area of the ring notch, the designed filter has been simulated to show the effect of the perturbation element dimensions on the bandwidth changes.

Figure. 4 shows simulation results, which represent the insertion loss ($|S_{21}|$) for various notch-depth values at notch angle equals to 12°.

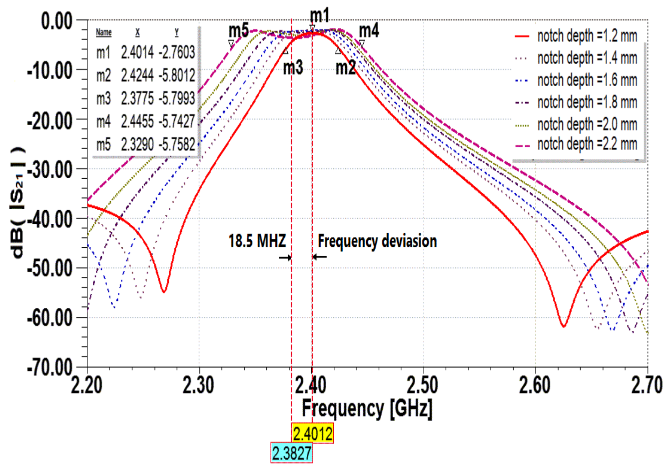

Fig. 4. Frequency responses ($|\mathbf{S_{21}}|$) of the filter for several notch-depth values at notch angle equal to 12°

The result showed that; when the BW of the filter is changed, the center frequency will drift. The deviation value in this case was 18.5 MHz when $FBW_{3\ dB}$ has increased about 2.5:1, same results were noticed for notch depth changes at other values of notch angles, but the frequency deviation showed different values.

Figure. 5 summarizes simulation results for several values of notch angle for three times increase of $FBW_{3\ dB}$. It has been noticed that, center frequency deviation value is related with notch-angle value, more accurately, it is inversely proportional to the notch angle value, and the deviation value is more than 25 MHz when notch depth is changed at notch angle less than 9 °, while it becomes too small for notch angle values bigger than 18°.

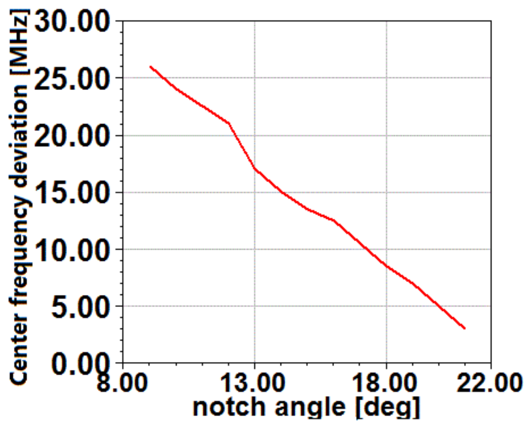

Fig. 5. Center frequency deviation for several values of notch angle for FBW increase equal to [3:1]

Similarly, the other case of notch angle variation for a certain value of notch depth has been simulated, Fig. 6 shows simulation results, representing the insertion loss ($|S_{21}|$) for several notch-angle values at notch depth equal to 1.2 $mm°$. Frequency deviation in this case was less than 2 MHz for three times increase of $FBW_{3\ dB}$, other values of notch depth have been simulated too, simulation results shows that; the frequency deviation for all notch depth values is ranging between 6 to 10 MHz, so we can conclude that; tuning filter BW by changing notch angle is a better choice than notch depth changing.

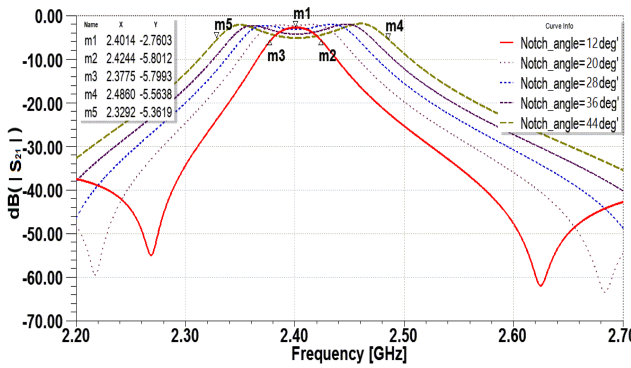

Fig. 6. Frequency responses ($|\mathbf{S_{21}}|$) of the filter for several notch-angle values at notch notch- depth to 1.2 mm

C. *The effect of perturbation element shape and location on frequency deviation*

The designed filter has been redesigned for several cases of perturbation elements shapes and dimensions. Two famous shapes used as a perturbation element in planner circuits has been chosen as shown in Fig. 7, which are radial (cases A,B,C,D), and rectangular shapes (cases E,F,G,H) as shown in Fig. 8. The two shapes have been studied as patch and notch, and when located in the inner and the outer circumference of the ring.

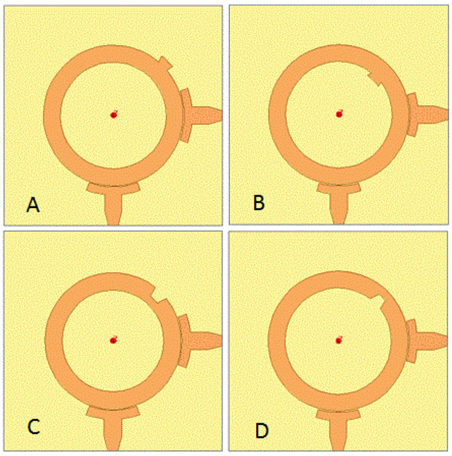

Fig. 7. Dual mode circular ring BPFs, perturbed by different cases of radial perturbation elements at azimuthal angles of 45°

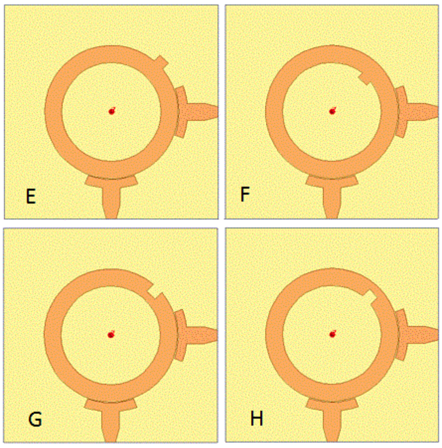

Fig. 8. Dual mode circular ring BPFs, perturbed by different cases of rectangular perturbation elements at azimuthal angles of 45°

For all cases, the perturbation elements are located at azimuthal angle of 45°. All the designed filters have been simulated for several areas of the patch and the notch, by changing its two dimensions. Changing notch area for radial shapes has been achieved either by changing the depth and/or the arc length, while for rectangular shape the change has been achieved by changing the depth and/or the width, same can be said for changing patch area but by replacing height change for depth change. The simulation results have been studied to observe the relation between notch or patch dimension's changing and the deviation of the center frequency during filter's BW tuning; the tuning has been achieved for two times increase of $FBW_{3\ dB}$, and began from critical coupling case.

Table I summarizes the simulation results for radial cases of perturbation element shapes; it shows the absolute frequency deviation ranges for all the cases.

TABLE I
FREQUENCY DEVIATION (ΔF) RANGES FOR RADIAL CASES OF PERTURBATION ELEMENT SHAPES

Perturbation element	type	Patch		Notch	
	location	Out	In	Out	In
	figure	(A)	(B)	(C)	(D)
ΔF [MHz] by changing the arc-length		4-6	0-2	3-5	4-6
ΔF [MHz]by changing the height /depth		10-12	5-7	2-12	10-11

Table I summarizes the simulation results for rectangular cases of perturbation element shapes, it shows the absolute frequency deviation ranges for all the cases.

Simulation results of the cases which has big values of frequency deviation (cases of changing height/depth), has explained in Fig. 9, and Fig.10.

TABLE II
FREQUENCY DEVIATION (**ΔF**) RANGES FOR RECTANGULAR CASES OF PERTURBATION ELEMENT SHAPES.

Perturbation element	type	Patch		Notch	
	location	Out	In	Out	In
	figure	(E)	(F)	(G)	(H)
ΔF [MHz] by changing the width		4-6	2-3	5-7	4-6
ΔF [MHz] by changing the height /depth		8-9	11-12	11-12	9-17

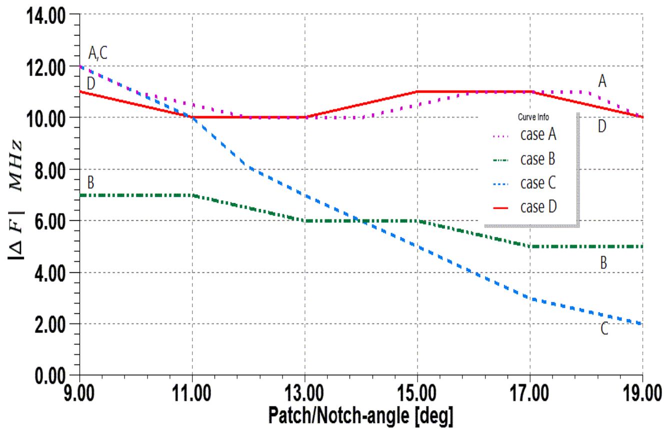

Fig. 9. Dual mode circular ring BPFs, perturbed by different cases of rectangular perturbation elements at azimuthal angles of 45°

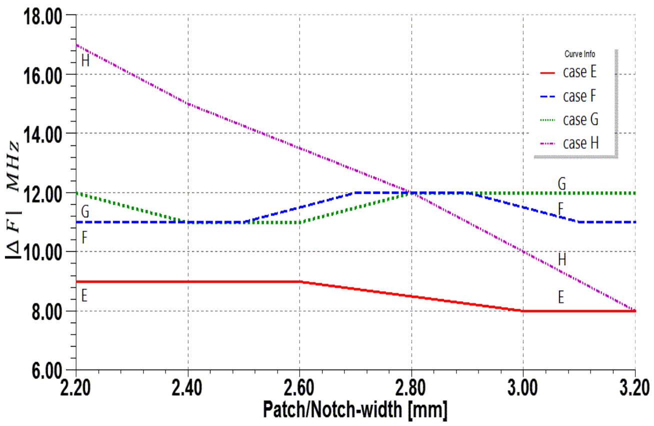

Fig. 10. Dual mode circular ring BPFs, perturbed by different cases of rectangular perturbation elements at azimuthal angles of 45°

From the illustrated results in Tables I, II, and Figs. (9, 10) it can be noticed that; bandwidth tuning of dual mode circular ring filter by changing the patch or notch depth is not preferred, because it will cause big deviation in center frequency. While the deviation value by varying the other dimension (arc length for radial shape or the width for rectangular one) has acceptable values. In addition, it can be concluded that; inner radial patch (case B) causes better stability of the filter center frequency, especially when the bandwidth is tuned by varying the arc length. In this case, high stability of the center frequency can be achieved, and the filter in this case has Butterworth response shape.

For other cases of perturbation element, as shown from the results in Tables (I&II), it is clear that; inner patch rectangular shape (case F) causes good stability but less than inner radial patch case.

Other note can be mentioned for outer radial notch (case G), which is; small deviation of the center frequency can be obtained for arc length values which correspond to big notch angle as shown in Fig. 6.

All the previous results treated the cases of perturbation elements which were located at azimuthal angles of 45°.

To confirm our results, the designed filter for the case of an inner radial patch (case F) was repeated at azimuthal angles of 135°. Fig. 11 shows the designed filer layout, where R1 represent the radius of radial patch.

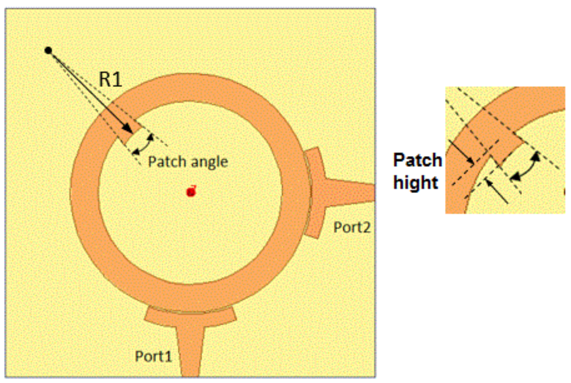

Fig. 11. Dual mode circular ring BPFs, perturbed by inner radial patch at azimuthal angle of **135°**. Main Dimensions are in (mm): $\mathbf{R_{res}}$ =15.33, R1 = 14.65, wr = 3.33, Notch-height = 1.28

The center of the patch annular sector was chosen as shown in Fig.11. This design is the preferable choice to increase the arc length of the patch by increasing the patch angle or by increasing the sector radius without changing patch angle. In our design we chose increasing the sector radius as the preferred choice to model MEMS switches.

Simulation results as appear in Fig. 12, showed that; when the patch angle is changed from 10 deg to 28 deg, the $FBW_{3\,dB}$ will change from 2.0% to 5.8%, which is equal to about [2.9:1]. In the same time, the center frequency has excellent stability, as the shift of the center frequency is less than 4 MHz. In the other hand the simulation results showed that; the center frequency will shifted about 15 MHz by varying the patch height.

According to the previous discussions we can conclude that; the best method to tune the BW of this type of filters, and to keep the center frequency fixed, is by changing the curve length of the perturbation element.

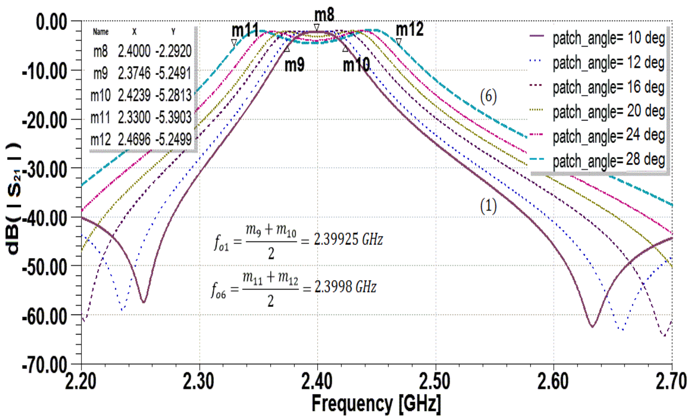

Fig. 12. Frequency responses ($|\mathbf{S_{21}}|$) of the filter for several patch-angle values at notch depth equal to 1.25 mm

D. *Experimental structure*

A key factor in arriving to an improved reconfigurable filter performance is the utilization of advanced technology. So, RF MEMS switches can be considered as a suitable choice to achieve reconfigurable filter, which needs a modifications in its geometry. Also, they are a suitable choice because of their small size, simple circuit model, zero power consumption and low insertion loss [18].

These switches can be used to control the area of the perturbation element, which is here a patch; therefore, the last designed filter has been redesigned taking in the account the utilization of RF MEMS switches, for adjusting the patch area; exactly adjusting the curve length as the last results showed.

Figure. 13 shows five cases of the designed patch (A,B,C,D,E), which explain the switches' role in changing the patch area linking the different metallization.

The designed filter was constructed using Rrexolite substrate type 2200 with thickness of 1.57 mm and a relative dielectric constant of 2.62. It has a center frequency of 2.4 GHz. Filter dimensions are illustrated in Table III.

Perturbation element dimensions of case A has determined to achieve a critical coupling level. Arc length in this case was 4 mm, and patch height was equal to 1.2 mm, the arc length increases 1.3 mm when the first group of switches is closed to change from case (A) to case (B), so at the fifth step (case E), the final length of the arc is equal to 9.2mm.

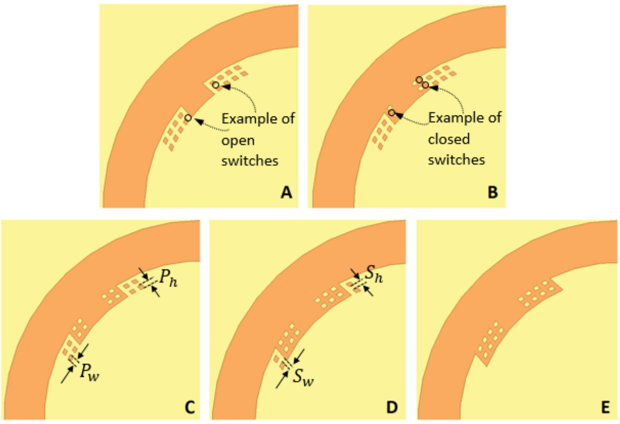

Fig. 13. Five cases of the designed patch (A,B,C,D,E) has different area, which modified by linking the different metallization by the switches

TABLE-III
THE PRACTICAL DIMENSIONS OF THE FILTER (PARAMETERS ARE ILLUSTRATED IN FIG. 2, FIG. 11, AND FIG 13)

Rres mm	Wr mm	W1 mm	W2 mm	Feedl1 mm	Feedl2 mm	Feed ang deg	Patch ang deg
15.3	3.25	3.5	2	2.4	11.8	20	7

Gap mm	R1 mm	Patch height mm	P_h mm	P_w mm	S_h mm	S_w mm
0.2	14.7	1.2	0.3	0.325	0.3	0.325

The designed filter was fabricated and the circuit was packaged in an aluminum enclosure as shown in Fig. 14.

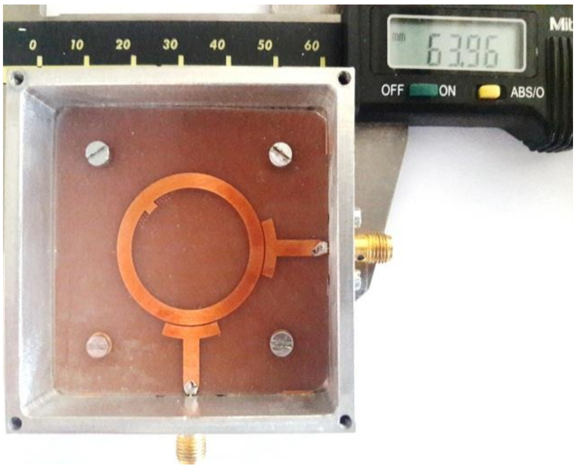

Fig. 14. Photograph of the fabricated filter for the case A of perturbation element

Fig. 15 shows the fabricated samples for the five cases of the perturbation element.

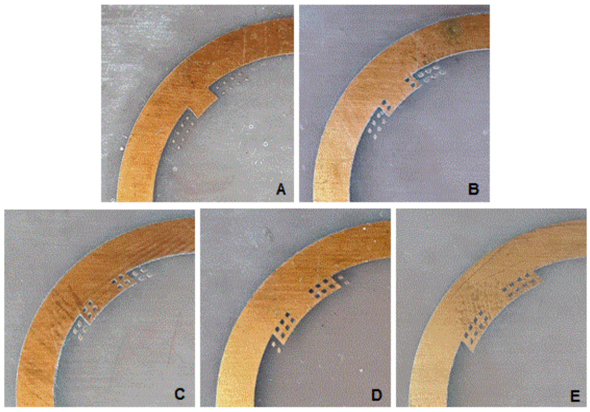

Fig. 15. Fabricated samples for the five cases of the perturbation element

Simulation results of $|S_{21}|$ responses are shown in Fig. 16; it appears that, high stability of the center frequency has been achieved. By changing the arc length from 4 mm to 9.2 mm the FBW has increased from 1.7 % to 5.1% or [3:1], this increase does not cause any deviation of the center frequency.

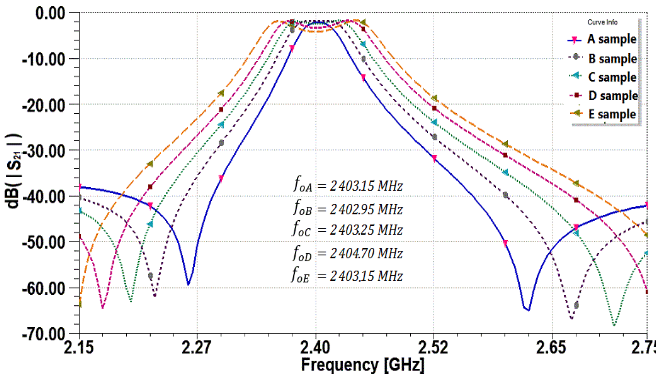

Fig. 16. Frequency responses ($|\mathbf{S_{21}}|$) of the designed filter for five samples of patch size

Figure. 17. Shows the frequency response of the fabricated filters using IFR 6823A scaler analyzer. Results of the fabricated filters show good stability of center frequency (deviation is not more than 2.8 MHz).

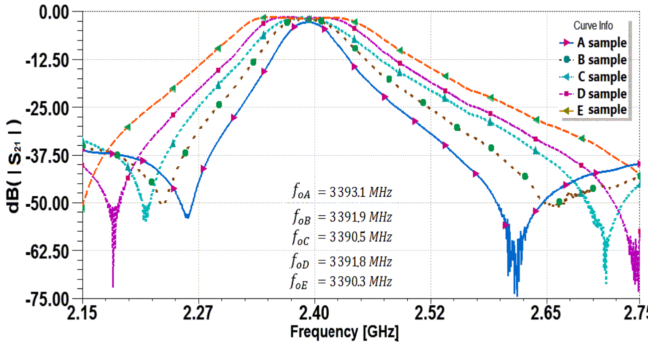

Fig. 17. Measured frequency responses ($|\mathbf{S_{21}}|$) of the implemented filters

IV. CONCLUSIONS

Perturbation element effect on center frequency stability during BW tuning of dual mode circular ring microstrip BPF filter has been presented. It is found that; a suitable choice of perturbation element shape, location, and type is very important for center frequency stability, while unsuitable perturbation element will cause big variation of center frequency during BW tuning, also the deviation of the center frequency has a big value when the BW of the filter is tuned by varying the patch height or notch depth.

Simulation results of eight cases of perturbation element of circular ring dual mode filter showed that; inner radial patch is the most suitable perturbation element for BW tuning when it is tuned by changing the arc length of the patch. Simulation results showed, for all cases of perturbation element, that; a big variation of center frequency would occur when perturbation element depth or height is changed.

A practical tunable BW sample of an inner radial patch has been designed, simulated, and then implemented. Patch geometry changing by using RF MEMS switches has been simulated. BW of the designed sample can be changed with five steps from 42 MHz to 120 MHz, without any notable variation in center frequency, good agreement between simulation and implementation has been noticed.

REFERENCES

[1] K. Chang, Microwave Ring Circuits and Antennas, New York: Wiley, 1996.

[2] I.Wolff, “Microstrip bandpass filter using degenerate modes of a microstrip ring resonator,” Electron Lett.,vol. 8, no. 12, pp. 302–303, June 15, 1972.

[3] W.-D. Yan and R. R. Mansour, “Tunable dielectric resonator bandpass filter with embedded MEMS tuning elements,” IEEE Trans. Microw.Theory Techn., Vol. 55, no. 1, pp. 154–160, Jan. 2007.

[4] S. Yonghyun, W. Zhengzheng, and M. Rais-Zadeh, “A high-performance continuously tunable mems bandpass filter at 1 GHz,” IEEE Trans. Microw. Theory Techn., vol. 60, no. 8, pp. 2439–2447, Aug. 2012.

[5] J. Nath, D. Ghosh, J. P. Maria, A. I. Kingon, W. Fathelbab, P. D.Franzon, and M. B. Steer, “An electronically tunable microstrip bandpass filter Using Thin-Film Barium–Strontium–Titante (BST) varactors,” IEEE Trans. Microw. Theory Techn., vol. 53, no. 9, pp. 2707–2712, Sep. 2005.

[6] H. Jiang, B. Lacroix, K. Choi, Y. Wang, A. T. Hunt, and J. Papapolymerou, “ Ka -and – U Band tunable bandpass filters using ferroelectric capacitors,” IEEE Trans. Microw. Theory Techn., vol. 59, no. 12, pp. 3068–3074, Dec. 2011.

[7] L. H. Hsieh and K. Chang, “Tunable microstrip bandpass filters with two transmission zeros,” IEEE Trans. Microw. Theory Techn., vol. 51 no. 2, pp. 520–525, Feb. 2003.

[8] T.-Y. Yun and K. Chang, “Piezoelectric-transducer-controlled tunable microwave circuits,” IEEE Trans. Microw. Theory Techn., vol. 50, no. 5, pp. 1303–1310, May 2002.

[9] P. W. Wong and I. C. Hunter, “Electronically tunable filters,” IEEE Microw. Mag., vol. 10, no. 6, pp. 46–54, Oct. 2009.

[10] W.-H. Tu, “Compact low-loss reconfigurable bandpass filter with switchable bandwidth,” IEEE Microw. Wireless Compon. Lett., vol. 20, no. 4, pp. 208–210, Apr. 2010.

[11] T. S. Beukman and R. H. Geschke, “A tune-all wideband filter based on perturbed ring-resonators,” IEEE Microw. Wireless Compon. Lett.,vol. 23, no. 3, pp. 131–133, Mar. 2013.

[12] W. Tang and J.-S. Hong, “Varactor-tuned dual-mode bandpass filters,” IEEE Trans. Microw. Theory Techn., vol. 58, no. 8, pp. 2213–2219, Aug. 2010.

[13] 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.

[14] Ceyhun Karpuz1, Ali Kursad Gorur2, Ayse Nihan Basmaci3 "Design of tunable microstrip dual-mode bandpass filter having reconfigurable filtering characteristics for mobile applications," Proceedings of the 46th European Microwave Conference 4–6 Oct 2016, pp. 484–493, London, UK.

[15] Ji-Chyun Liu, Chin-Shen Cheng, And Leo Yao,"Dual-mode double-ring resonator for microstrip band-pass filter design," Microwave And Optical Technology Letters, Vol. 36, no. 4, pp. 310–314, February 2003.

[16] Hesham. A. Mohamed, Heba B. El-Shaarawy, Esmat. A.F. Abdallah1, and Hadia El-Hennawy "Reconfigurable compact dual mode resonators uwb-bpf using DGS and RF pin diodes," International Journal of Engineering & Technology IJET-IJENS vol:14 no.01, pp. 19–23, February 2014.

[17] J. S. Hong and M. J. Lancaster, “Microstrip filters for RF/Microwave applications,” John Wiley & Sons, Inc., New York, 2001.

[18] G. M. Rebeiz and J. B. Muldavin, “Rf MEMS Switches And Switch Circuits,” IEEE Microwave Magazine, vol. 2, no. 4, pp. 59–71, 2001.