Indonesian Journal of Electrical Engineering and Computer Science
Vol. 9, No. 3, March 2018, pp. 680~684
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v9.i3.pp680-684

Bandpass filter Based on Ring Resonator at RF Frequency above 20 GHz

Norfishah Ab. Wahab[1], A. Amiruddin[2], Roskhatijah Radzuan[3], Zuhaila Mat Yasin[4], N. A. Salim[5], N. A. Rahmat[6], N. F. A. Aziz[7]
[1,2,3,4,5]Faculty of Electrical Engineering, Universiti Technologi MARA, 40450 Shah Alam, Malaysia
[6,7]Institute of Power Engineering, Electrical Power Department, College of Engineering, Universiti Tenaga Nasional, Malaysia

Article Info

Article history:

Received Sep 24, 2017
Revised Dec 27, 2017
Accepted Jan 16, 2018

Keywords:

Dual-mode bandpass filter
CMOS technology
Microstrip technology
Ring resonator

ABSTRACT

This paper presents two dual-mode rectangular ring resonators, designed at RF frequency above 20 GHz for bandpass filter applications. The first resonator is designed at 20 GHz using single layer microstrip technology, on Rogers Duroid TMM10 substrate with the following characteristics; relative dielectric constant (εr) = 9.2, substrate thickness (h) = 1.270 mm, dielectric loss tangent (tan δ) = 0. The second resonator is built using multilayer CMOS technology at 75 GHz. The resonator is simulated using fluorinated silicon glass (FSG) and silicone rich oxide (SRO) with relative dielectric constant (εr) equals to 3.7 and 4.2 respectively. Both filter designs are built using full-wave electromagnetic simulation tool. For filter design using microstrip technology, the return loss is found at 9.999 dB and the insertion loss is at 3.108 dB while for filter design using CMOS technology, the return loss is found at 11.299 dB and the insertion loss at 0.335 dB. Both results had shown good passband performance with high rejection level at the out-of band.

Corresponding Author:

Norfishah Ab. Wahab,
Faculty of Electrical Engineering,
Universiti Technologi MARA,
40450 Shah Alam, Malaysia.
Email: fishah@salam.uitm.edu.my

1. INTRODUCTION

Bandpass filter is well known as one of the essential component at the front-end system in wireless communication and RF system. Amongst the popular resonators used in RF microwave application are coaxial resonators, dielectric resonators; surface acoustic wave (SAW), yttrium iron garnet (YIG) crystal resonators and ceramic resonators. Understanding each characteristic of different resonators is a must in order to design good filters. Advancing through the digital world, there are a lot of obstacles need to be considered as the trend nowadays are towards the 5 G technology. Hence, the existing techniques and topologies may be further explored to fit into the 5 G network system [1- 3]. In terms of topologies, ring resonator can be exploited due to their low loss, compact size, high frequency selectivity and high quality (Q) factor performance which are vital in the evolution of future wireless communication system [3].

An original research proposed on dual-mode ring resonator was familiarized first by Wolff and Knoppik for microwave substrate measurement [4]. More research on dual-mode bandpass filter have been presented since then such as reported in [5-8] that allowed for various parameters to be investigated and derived, including the transmission poles, transmission zero and the resonance frequencies. In the case of coupling constant, the even/odd resonance frequency locations are utilized using lumped capacitors [9-10]. Besides this, there are several approach proposed to design a compact dual-mode bandpass filter using highpermittivity materials and variation of the rectangular ring layout [11-13]. The adaptation of coupling capacitance and frequencies filtering can also deliver varied applications in microwave circuits over alterations in electrical length by means of typical dual-mode double ring filter design whereby the filter is developed from single ring configurations to double ring structures [10], [14].

Having said these, it may be useful to also explore in the field of IC circuits, whereby cost of filter and the occupied volume can be reduced further. Complementary metal oxide semiconductor (CMOS) has a great integration proficiency towards incorporating both millimeter wave as well as digital circuits into one single chip in order to achieve low cost for the mass manufacture as well as production [14-16]. In terms of bandpass filter design, it enhanced the production of a millimeter wave which is extensively used in wireless communication systems. For instance, a millimeter-wave CMOS on-chip passive filter was discussed in [15] and millimeter-wave CMOS-based bandpass filters by means of small insertion-loss were proposed in [5], [17]. Even though designing on microstrip is much easier as the material are easily obtain while, designing on CMOS technology might be a bit hustle as few institutions has the capability on handling the material itself. However, on the bright side, CMOS can be produced in mass production at a lower cost.

The concern here is that there has yet existence of a filter design, explored and implemented both on microstrip and CMOS technology. In this paper, we present the design and analysis of a dual mode rectangular ring resonator that used the topology in [18]. In this work, the topology is explored for microstrip and CMOS technology for much higher frequency that is applicable for 5 G network system. The resonance frequencies of these filters are chosen at 20 GHz and 75 GHz. At 20 GHz, the filter is designed on single layer microstrip technology while at 75 GHz, the filter is proposed on multi layer CMOS technology. Both designs are simulated using full wave simulator and results had shown good performance in terms of return loss and insertion loss with high frequency selectivity.

2. RESEARCH METHOD

Explaining research chronological, including research design, research procedure (in the form of algorithms, Pseudocode or other), how to test and data acquisition [1], [3]. The description of the course of research should be supported references, so the explanation can be accepted scientifically [2], [4]. Various research and studies had been conducted to gain necessary insight and information specifically on the technologies used, transmission line, resonance frequency and the techniques implementation. Typically, the common parameters involved when designing bandpass filter are insertion loss, return loss, transmission zero, transmission poles, fractional bandwidth and coupling. In this work, two types of bandpass filters with different resonance frequency are proposed here.

The first design is proposed on *Rogers Duroid TMM10* using microstrip technology with relative dielectric constant (εr) = 9.2, substrate thickness (h) = 1.270 mm, dielectric loss tangent ($\tan \delta$) = 0.0023 and operating frequency at 20 GHz. The second design is performed on CMOS technology. The materials used are fluorinated silicone glass (FSG) with relative dielectric constant (εr) = 3.7 and silicone rich oxide (SRO) with relative dielectric constant (εr) = 4.2. These materials was obtained from the CMOS18 FSG standard process that offers a single poly with three layers metal (3LM), four layer metal (4LM), five layer metal (5LM) or six layer metal (6LM). Both filters are design to meet specifications as shown in Table I.

Table 1. Design Specifications for Bandpass filter

Parameter	Specification
Return Loss, S_{11}	< 10 dB
Insertion Loss, S_{12}	> 3 dB

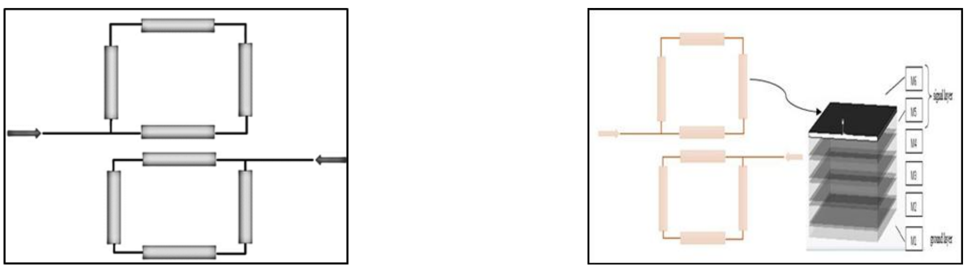

Figure 1. (a) Ideal circuit of the dual-mode rectangular ring bandpass filter topology, (b) Bandpass filter designed using multi layer CMOS Technology

Figure 1(a) shows the topology of the 2nd order bandpass filters using two rings resonator. Figure 1(b) indicates the first layer of the two rectangular rings with CMOS technology. The ground panel is formed by connecting M1 and M2 together while the top metal, M6 is where the designed structure is placed.

3. RESULTS AND ANALYSIS

Figure 2(a) displays the simulated response on dual mode bandpass filter using microstrip technology at 20 GHz. Based on the simulated response, it shown resonance frequencies are obtained at 19.34 GHz and 20.95 GHz. At 20 GHz, the center frequency of S_{11} is 9.999 dB and the insertion loss, S_{12} is 3.108 dB. There are two transmission zeroes exist at the frequencies of 18.74 GHz and 21.79 GHz. The transmission zero at 18.74 GHz is 25.546 dB while at 21.79 GHz the transmission zero is 23.603 dB. On the other hand, there also exist two resonance frequencies at 19.61 GHz and 20.50 GHz. The attenuation level of the resonance frequencies are 14.515 dB and 14.649 dB respectively. The filter design gives a fractional bandwidth of 8.05%.

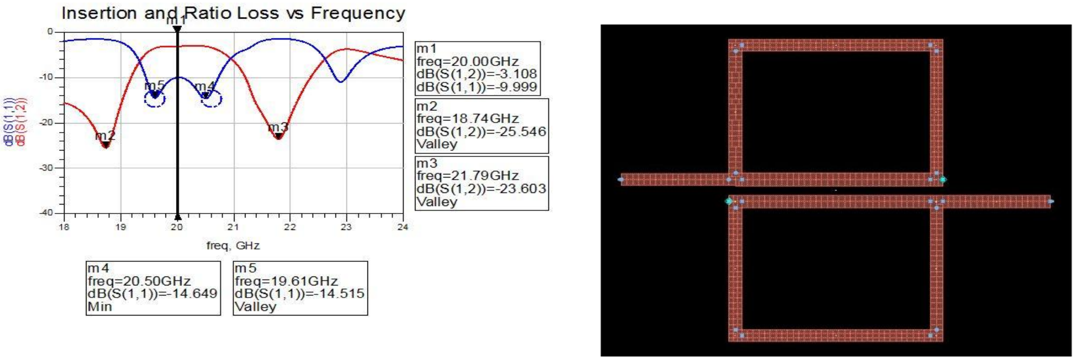

Figure 2. (a) Simulated response of 2nd order bandpass filter using two rings on microstrip technology at 20 GHz, (b) Layout design for dual mode rectangular ring at 20 GHz

The ideal topology of the ring circuit is transformed into distributed element and final layout is displayed in Figure 2(b). The layout clearly shows two rectangular rings with 50Ω transmission feed line and also coupling line. This filter design is proposed on microstrip technology, using *Rogers Duroid TMM10* substrate specifically built to be used in *RF* applications systems with the following characteristics; relative dielectric constant (ε_r) = 9.2, substrate thickness (*h)* = 1.270 mm, dielectric loss tangent (tan δ) = 0.0023 and operating frequency at 20 GHz.

Table 2. Filter's Parameters on Microstrip Technology at 20 GHz

Parameters	Dimensions (um)
W0	434
WC	467
LC	6440
S2	350
W1	436
L1	4466
L1a	6440
L0	3680
W2	436
L2	4466
L2a	6440

Based on the dimensions in Table 2, length of coupling lines, top rings as well as the bottom rings need to be the same in order for the ring to be in a symmetrical shape. ***L1a*** indicate length of the top rings, ***L2a*** indicate the bottom rings and ***LC*** indicate the coupling length which all measure as 6440um with the gap coupling, ***S2*** of 350um. Parameters ***L1*** and ***L2*** both show the length of the ring side which is 4466um respectively. The lengths of the side also need to take into account as to maintain the rectangular shape.

Widths of the rings are all designated by ***w***. The second design of bandpass filter is proposed at 75 GHz. Figure 3(a) shows the simulated response on dual mode bandpass filter using CMOS technology at 75 GHz on a wider range in which the next figure will show the enhanced response on more specific frequency range. Two resonance frequencies are found at 71 GHz and 79 GHz with 38.397 dB and 27.191 dB respectively. The attenuation level of the insertion loss at 75 GHz is found at 0.335 dB. The transmission zero frequencies are obtained at 56 GHz and 100 GHz respectively. The markers at ***m4*** and ***m5*** signify the levels of both transmission zeroes of aforementioned frequencies at 45.906 dB and 8.471 dB respectively. The fractional bandwidth of this filter is around 24% slightly higher than that of the first filter. The layouts along with the dimensions of every element of the bandpass filter are displayed on Figure 3(b) and Table 3 respectively. The lengths, widths and gap of the second filter follow the same labels with the first filter as in Figure 2(b).

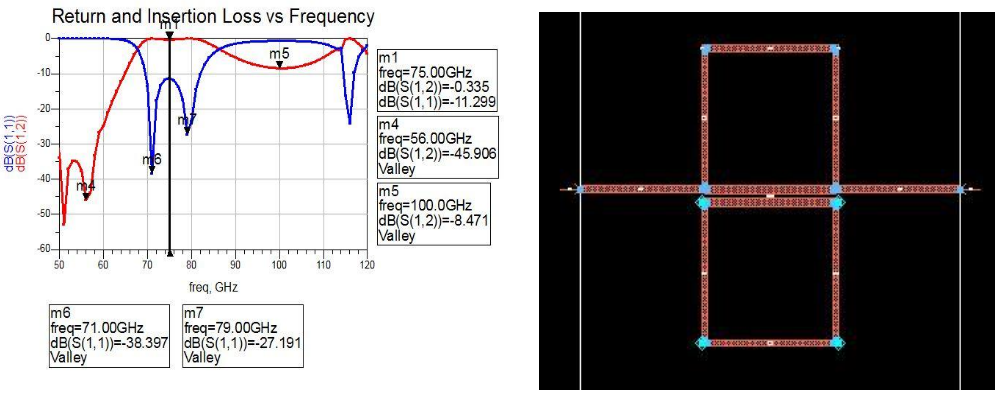

Figure 3. (a) Enhance simulated response of the 2nd order bandpass filter using two rings on CMOS technology at 75 GHz, (b) Layout design for dual mode rectangular ring at 75 GHz

Table 3. Filter's Dimensions on CMOS Technology at 75 GHz

Parameters	Dimensions (um)
W0	80
WC	80
LC	650
S2	35
W1	80
L1	730
L1a	650
L0	650
W2	80
L2	730
L2a	650

Table 4. Summarized Measured Response of the Dual Mode bandpass filter Rectangular Ring Using Microstrip and CMOS Technologies

Parameters	2-rings using microstrip technology (a)	2-rings using CMOS technology (b)
Centre Frequency ,f_o	20 GHz	75 GHz
Return loss (S_{11}) Insertion loss (S_{12})	9.999 dB 3.108 dB	11.299 dB 0.335 dB
Fractional Bandwidth (FBW) FBW= ($f_L - f_U$)/ f_0	FBW= (19.34 GHz-20.95 GHz)/20 GHz= 8.05 %	FBW= (68 GHz-86 GHz)/75GHz= 24 %
Transmission zeros (dB) Lower frequency Higher transmission frequency	 $f_{18.74GHz}$ = 25.546 $f_{21.79GHz}$ = 23.603	 f_{56GHz} = 45.906 f_{100GHz} = 8.471

Table 4 summarized the simulated responses and performances of the ring resonators using microstrip and CMOS technologies respectively. Based on the results obtained, both resonators had shown acceptable performance for bandpass filter applications. The resonators achieved good selectivity with transmission zeroes at the stopband and two transmission poles in the passband region. The rejection levels for the resonators exceeding 20 dB which indicate good rejection level. In terms of bandwidth, the resonators are suitable to be used for narrowband application since the fractional bandwidths are less than 30%.

4. CONCLUSION

In a nutshell, two bandpass filters were presented using dual-more rectangular resonator as a base cell. The first filter was designed at 20 GHz using single layer microstrip technology while the second filter was designed at 75 GHz using multilayer CMOS technology. Both filters were successfully simulated with acceptable responses in terms of insertion loss and return loss. In view of the experimental results, this arrangement scheme realized a filter not only with high selectivity and sharp skirt but also compact size, good performance and simple design and therefore is possible to be applied at high frequency above 20 GHz.

ACKNOWLEDGEMENTS

This work was supported by Faculty of Electrical Engineering, Universiti Teknologi MARA and Institute of Research Management and Innovation (IRMI) of Universiti Teknologi MARA (Grant no: 600-RMI/DANA 5/3/LESTARI (72/2015).

REFERENCES

[1] Elahe Mohammadi, Habib Ghorbaninejad, "Novel Resonant Structure to Compact Partial H-Plane Band-Pass Waveguide Filter," *International Journal of Electrical and Computer Engineering (IJECE)*, Feb 2017, vol. 7, no. 1, pp. 266-270.
[2] Zhang, Pingjuan, and Minquan Li, *"A Novel Compact Microstrip Lowpass Filter with Sharp Transition and Improved Stopband," Indonesian Journal of Electrical Engineering and Computer Science*, 13.1 (2015): pp 85-90.
[3] K. Chang and L. H. Hsieh, Microstrip Ring Circuits and Related Structures. New York: Wiley, 2004.
[4] I. Wolff and N. Knoppik, "Microstrip ring resonator and dispersion measurement on microstrip lines," *Electron. Lett*., Dec 1971, vol. 7, no. 26, pp. 779 781.
[5] A. C. Kunda and I. Awai, "Control of attenuation pole frequency of a dual-mode microstrip ring-resonator bandpass filter," *IEEE Trans. Microw. Theory Tech*., Jun 2001,ol. 49, no. 6, pp. 1113–1117.
[6] M. Matsuo, H. Yabuki, and M. Makimoto, "Dual-mode stepped impedance ring resonators for bandpass filter applications," *IEEE 2001.Trans. Microw. Theory Tech.*, Jul 2001,vol. 49, no. 7, pp. 1235–1240.
[7] B. T. Tan, S. T. Chew, M. S. Leong, and B. L. Ooi, "A dual-mode bandpass filter with enhanced capacitive perturbation," *IEEE Trans. Microw. Theory Tech*., Aug. 2003, vol. 51, no. 8, pp. 1906–1910.
[8] M.-F. Lei and H.Wang, "An analysis of miniaturized dual-mode bandpass filter structure using shunt-capacitance perturbation," *IEEE Trans. Microw. Theory Tech.,* Mar. 2005, vol. 53, no. 3, pp. 861–867.
[9] Kai Chang," Microwave Ring Circuits and Antennas", J. Wiley & Sons, 1996.
[10] L.-H. Hsieh and K. Chang, "Dual-Mode quasi-elliptic-function bandpass filters using ring resonators with enhanced-coupling tuning stubs, " *IEEE Trans. Microwave Theory Tech*., May 2002, vol. 50, pp. 1340-1345.
[11] Michiaki Matsuo, Hiroyuki Yabuki, and Mitsuo Makimoto, "Dual-mode Stepped-Impedance Ring Resonator for Bandpass filter Applications" *IEEE Transactions on Microwave Theory And Techniques*, July 2001, vol.49, no.7, pp1235-1240.
[12] Man-Long Her, Quei-Min Lin, Kun-Ying Lin, Ying-De Wu, and Yu-Lin Wang, Dual- mode and three-transmission-zero bandstop filter with closed-loop ring resonators, *Microwave and Optical Technology Letters*, 2005, vol. 44, No. 2, pp. 114-118.
[13] Si-Weng Fok, Pedro Cheong, Kam-Weng Tam, and Rui P Martins, A novel microstrip square-loop dual-mode bandpass filter with simultaneous size reduction and spurious response suppression, *IEEE Transactions on Microwave Theory and Technology*, 2006, vol. 54, No. 5, pp. 2033-2041.
[14] S. Sun, J. Shi, L. Zhu, S. Rustagi, and K. Mouthaan, "Millimeter-wave bandpass filters by standard 0.18-mm CMOS technology," *IEEE Electron Device Lett*., Mar. 2007, vol. 28, no. 3, pp. 220–222.
[15] C. H. Doan, S. Emami, A. M. Niknejad, and R. W. Brodersen, " *Design of CMOS for 60-GHz applications*," in Proc. IEEE Solid-State Circuits Conf., 2004, pp. 440–441.
[16] M. Miao and C. Nguyen, "A novel multilayer aperture-coupled cavity resonator for millimeter-wave CMOS RFICs," *IEEE Trans. Microw. Theory Tech*., Apr. 2007, vol. 55, no. 4, pp. 783–787.
[17] Tuan Anh Vu, Minoru Fujishima, A 300 GHz CMOS Transmitter Front-End for Ultrahigh-Speed Wireless Communications, *International Journal of Electrical and Computer Engineering (IJECE), Aug. 2017, v*ol. 7, No. 4, pp. 2278 – 2286.
[18] N. Ab. Wahab, N. Hidayat, Z. Ismail Khan, Z. Mat Yassin, N. A. Salim, Noriza Othman, M. K. M. Salleh, "Two Parallel-coupled Rings for Narrow Bandpass filter Application," *Journal of Telecommunication, Electronic and Computer Engineering*, 2017, vol. 8, no. 373.