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A Compact Reconfigurable Multi-mode Resonator-based Multi-band Band Pass Filter for Intelligent Transportation Systems Applications

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ABSTRACT

A compact wide band reconfigurable bandpass filter (BPF) which utilises a hemi-circular flower shaped multimode resonator (MMR) is presented. The proposed MMR provides three resonant modes which fall within the broad frequency spectra. Among these, two modes are even and one is odd. These modes are optimised by varying the dimensions so as to obtain the desired frequency response. The fractional bandwidth is more than 96 per cent. The filter can be operated as multi-band BPF. In OFF condition of 'Pin' diode, the centre frequencies are 2.43 GHz, 3.5 GHz, and 5.9 GHz in ON condition of 'Pin' diode centre frequencies are 2.43 GHz, 3.5 GHz, 5.9 GHz, 6.5 GHz, and 8.8 GHz which are used for vehicular, WiMAX, intelligent transportation systems and satellite communication respectively. Microstrip filter structures are integrated with 'Pin' diodes. Appropriate biasing has been provided by choosing lumped components with precise values. The insertion loss in OFF condition are 0.5 dB, 0.67 dB, and 0.8 dB and in ON condition 0.5 dB, 0.7 dB, 1.2 dB, and 1.9 dB. The measured results agree well with the full-wave simulated results.

Keywords: Bandpass filter; Hemi-circular flower shaped; ITS; Multimode resonator; Multiband

1. INTRODUCTION

Filters are used in radio frequency (RF) transceivers for proper band selection or rejection. Moreover the reconfigurable devices find application in cognitive radio (CR), software-defined radio (SDR), vehicular communication, intelligent transportation systems (ITS) and in modern wireless application. Due to its flexible response, the tunable filters are required in commercial and ITS applications. The reconfigurable filters also help in obtaining wideband coverage with minimised system size, cost and complexity. An RF transceiver supports multi-band operation with the emerging application in wireless communication and ITS.

Presently several solutions are adapted to provide multi-band operation in the reconfigurable bandpass filter (BPF). A flexible and practical tunable dual-band bandpass filter using coupled feeding lines has been reported by Ghaderi[1], *et al*. Various dual, triple and quad-band BPF has been designed with the help of open stubs loaded shorted stepped-impedance resonator (SIR)[2]. A filter with fish spear-shaped multimode resonator (MMR) provides sharp rejection and high performance as described by Jhariya[3], *et al*. Open-loop resonators have been used for filtering operations[4]. A reconfigurability induced BPF has been mentioned by Rauscher[5] and Hua[6]. Wideband BPF with excellent selectivity using complementary split ring resonator (CSRR) has been reported by Luo[7], *et al*. Tunable reconfigurable BPFs[8] and wideband tunable BPF have been presented[9]. Different miniaturised reconfigurable and switchable BPF for wireless and ITS application is reported[10-12]. A reconfigurable filtering monopole antenna design with three switchable states for UWB/WLAN applications has been presented[13,14]. Deng[15], *et al*. investigated switched reconfigurable high-isolation dual-band BPF. Design of RF receiver front-end with bandpass and hairpin resonator narrow band filter have been presented[16]. Different filter architectures with multimode resonators has been reported in the context of ITS and wireless communication[17-20].

In this study, a simple and compact microstrip reconfigurable multimode resonator based BPF for ITS applications having three modes is proposed. The presented reconfigurable wideband filter is designed using hemicircular flower shaped MMR. The filter provides sharp rejection with wide upper stopband. The reconfigurability is achieved by 'Pin' diodes. It has three resonant modes including two even and one odd mode. The stub locations control the even and odd modes. Even higher order modes can be achieved by varying the stub dimensions.

2. RECONFIGURABLE BAND PASS FILTER DESIGN

The flow chart of the computer aided design (CAD) based filter design is as shown in Fig 1. The general synthesis procedure has been discussed. The step by step procedure of designing is summarised in Fig 1. The schematic design structure of multimode resonator based reconfigurable BPF is as shown in Fig. 2 (a). The substrate has dielectric constant ϵ_r= 4.4, substrate width h= 1.524 mm and loss tangent

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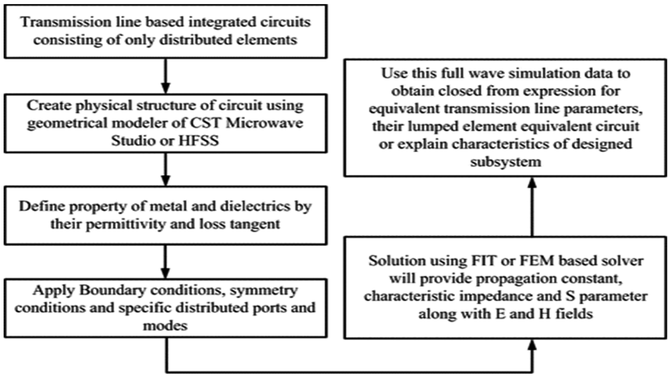


Figure 1. Flow chart of CAD-based passive RF circuit design approach.

tanδ = 0.0025 is used. The overall dimension of filter is (L×W) = (26 mm^2 × 20 mm^2). The dimension of the filter is outlined in Table 1. Figure 2 (a) shows the geometry of the compact reconfigurable filter. The filter consist of two branch MMR at left and right side and the main hemicircular resonator is connected to the microstrip feed line. Figure 2 (b) shows fabricated prototype of the top view of the filter. In the top view of the filter, two 'Pin' diodes are inserted between coupling line. Two 'Pin' diodes (D_1 and D_2) are inserted between coupling line to allow reconfigurability. Switching RF power in portable applications is challenging for electromechanical switches due to size, cost and speed considerations. Figure 2 (c) shows fabricated prototype of the ground plane of the filter. The interdigital coupled transmission lines are modelled as input/output ports and between them, a hemicircular flower shaped MMR is designed. A flower shaped resonator is designed as a branch of main MMR for achieving desired resonance frequency by dividing the induced current in the branch. Due to strong coupling in lines and MMR, higher order modes are produced. The filter achieved low loss, compact size, sharp selectivity, wide bandwidth and good out of band rejection. Its dimension is optimised and simulated using high-frequency structure simulator (HFSS) v16. In filter design process the dimensions should be optimised so that |S11| lie below -10 dB and |S21| close to 0 dB over the existing frequency band.

The filter contains a couple of inter digital input/output coupled lines and a hemicircular shaped with two flower shaped branch MMR for high selectivity and miniaturise the size. A multimode resonance frequency is achieved by adjusting flower shaped MMR. A metallic plane etched down the substrate as a ground plane. In Fig. 3 ON state 'Pin' diode behaves like a series combination of L and R and in OFF state 'Pin' diode behaves like the series combination of L with the parallel combination of R&C.

Two-'Pin' diode RF switch over the coupling line as shown in the Fig. 3. By modelling we can turn in ON-OFF state and incorporate the 'Pin' diode in BPF the operating frequency can be shifted.

Table 1. Dimensions of MMR based reconfigurable BPF (mm)

Parameter	L	W	G	r_1	r_2	h	r_3	l	l_1	$lx1$
Value	26	20	1.2	5	3.5	1.6	2.5	10	4.8	5.25
Parameter	$lx2$	l_2	ly	w_2	w					
Value	7.75	7	7.1	0.5	3					

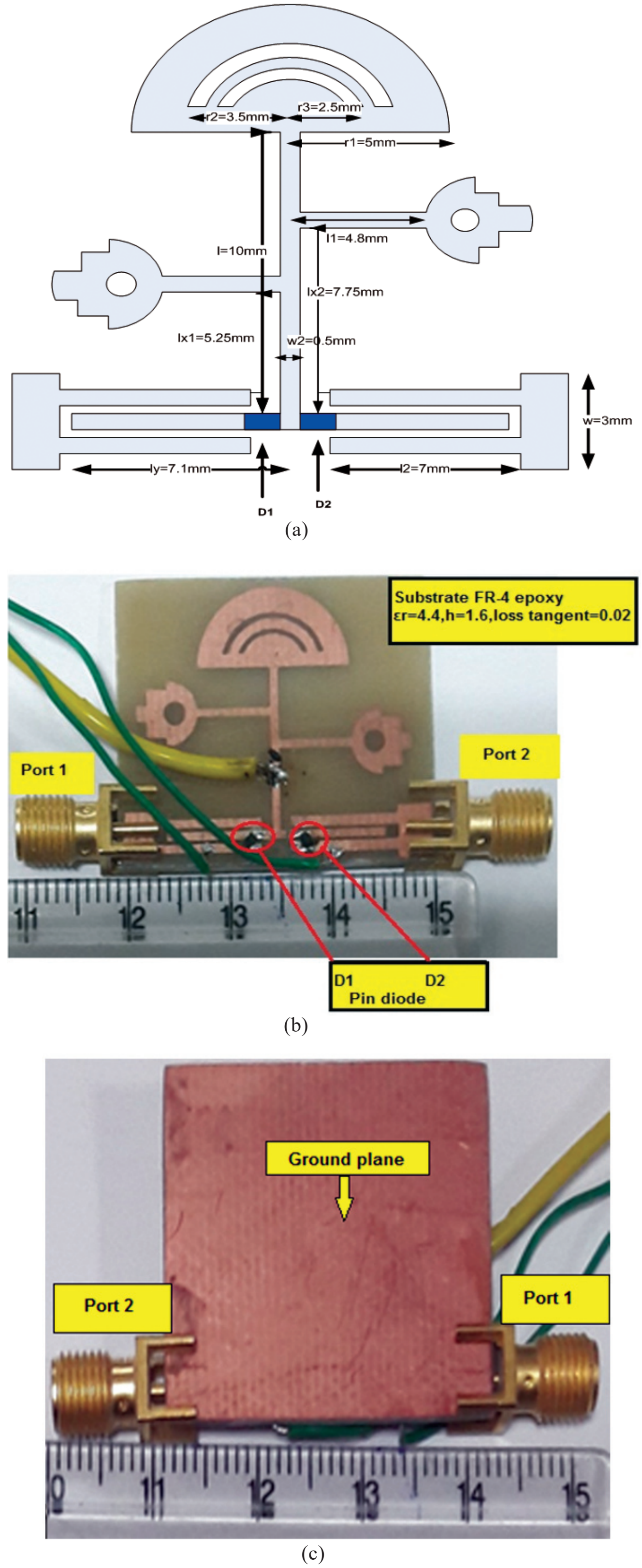


Figure 2. Reconfigurable BPF : (a) Hemicircular two flower shaped MMR based, (b) Fabricated prototype of the top side, and (C) Fabricated prototype of the bottom side.

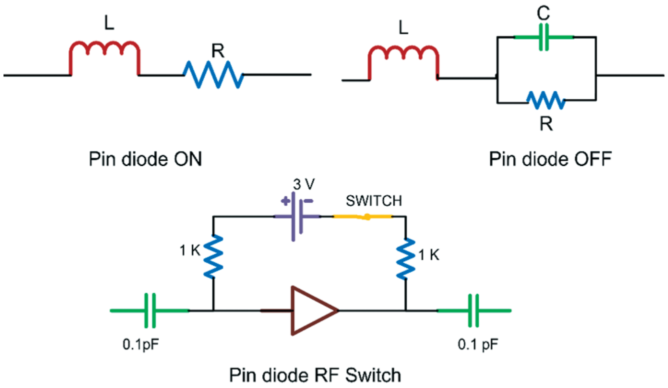


Figure 3. Equivalent circuit of RF 'Pin' diode.

3. CHARACTERISTICS OF RECONFIGURABLE BPF

Physical structure of MMR is symmetrical so even and odd mode analysis is used for resonance

$$Y_{ieven} = Y_{iodd} = 0 \tag{1}$$

where Y_{even} is the admittance of even mode structure and Y_{odd} is the admittance of odd mode structure. The simulated resonant peaks correlate with the analytical solutions for both even and odd modes. The approximate transmission line circuit models for odd and even mode excitation are represented in Fig. 4 (a). Here θ_m and θ_2 refer to electrical lengths and Y_m, Y_2, and Y_3 refer to characteristic admittance of the width.

The input admittances Y_{ieven} and Y_{iodd} for the odd and even modes are as follows:

$$Y_{ieven} = Y_m \frac{Y_2 + jY_3 \tan(\theta_2/2)}{1 - jY_3Y_2 \tan(\theta_2/2)} \tag{2}$$

$$Y_{iodd} = -jY_m \cot\theta_m \tag{3}$$

In Fig. 4 (b) even mode frequencies are varied but odd mode frequencies are fixed when changing the gap 'G' between resonators. Three transmission zeros are generated with loosely coupled two resonators.

$$Q_e = \frac{f_o}{\Delta f} \tag{4}$$

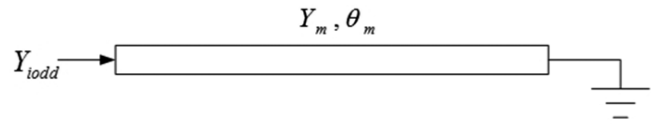
$$\Delta f = f_+ - f_- \tag{5}$$

where f_o = Centre frequency, Δf is bandwidth, f_+ and f_- are the frequencies when the phase is $\pm 90°$ with respect to f_o.

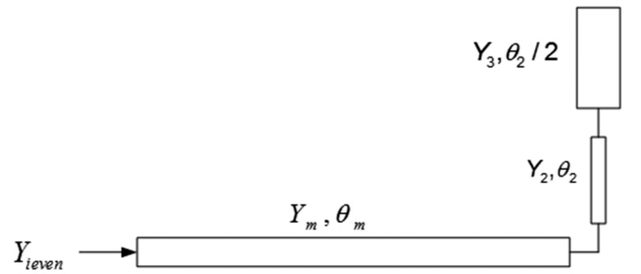
Moreover, by introducing three TZ's three bands are obtained in reconfigurable BPF. The location of two transmission zeros is calculated using a simple transmission-line model depending on the size of the perturbation element.

4. SIMULATION AND MEASUREMENT RESULTS

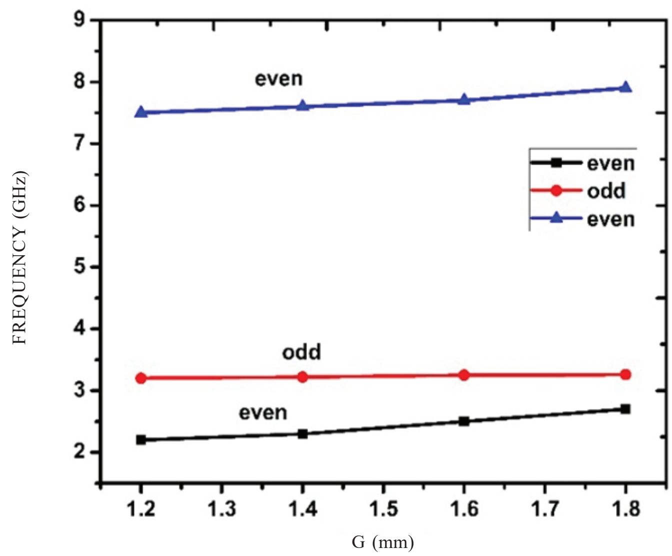
Figure 5 shows the simulated and measured S-parameters of the switchable BPF. In Fig. 5 (a) when the diode is OFF, means D_1 and D_2 both are in OFF condition, the filter is operating at 2.43 GHz (2.1 GHz - 2.45 GHz), 3.5 GHz (3 GHz - 3.5 GHz) and 5.9 (3.5 GHz – 6 GHz). Insertion losses are 0.6 dB, 0.67 dB and 0.8 dB at resonant frequencies of 2.43 GHz, 3.5 GHz and 5.9 GHz respectively. The fractional bandwidth is 13.46. In Fig. 5 (b), when diode is ON means D_1 and D_2 both are in ON condition, Three bands having resonant frequency 2.43 GHz (2.3 GHz - 2.43 GHz) with insertion loss of 1.2 dB, 3.5 GHz (3.2 GHz - 3.5 GHz) with insertion loss of 1.9 dB and 5.9 GHz (3.7 GHz - 8 GHz) with insertion loss of 0.7dB are achieved. The fractional bandwidth is 10.83. In Fig. 5 (c), when D_1 is ON and D_2 is OFF, wideband resonant frequency at 5.9 GHz (5.2 GHz - 6.5 GHz), having insertion loss 0.5 dB and return loss -35 dB are achieved. The fractional bandwidth is 10. In Fig. 5 (d) when D_1 is OFF and D_2 is ON, three resonant frequencies are achieved at 6.5 GHz (5 GHz - 7 GHz), 7.9 GHz (7.8 GHz - 8 GHz) and 8.8 GHz (8.8 GHz - 9 GHz) with insertion loss of 1.2 dB, 2.6 dB, and 3 dB, respectively The fractional bandwidth is 11.17. These bands are useful for vehicular, WiMAX, ITS and satellite communication respectively. The filter gives better selectivity between the triple bands and rejects undesired frequencies.



(a)



(a)



(b)

Figure 4. (a) Odd mode equivalent transmission line model and (b) Even mode equivalent transmission line model.

Table 2 shows the performance comparison of the filter with some earlier reported reconfigurable BPFs.

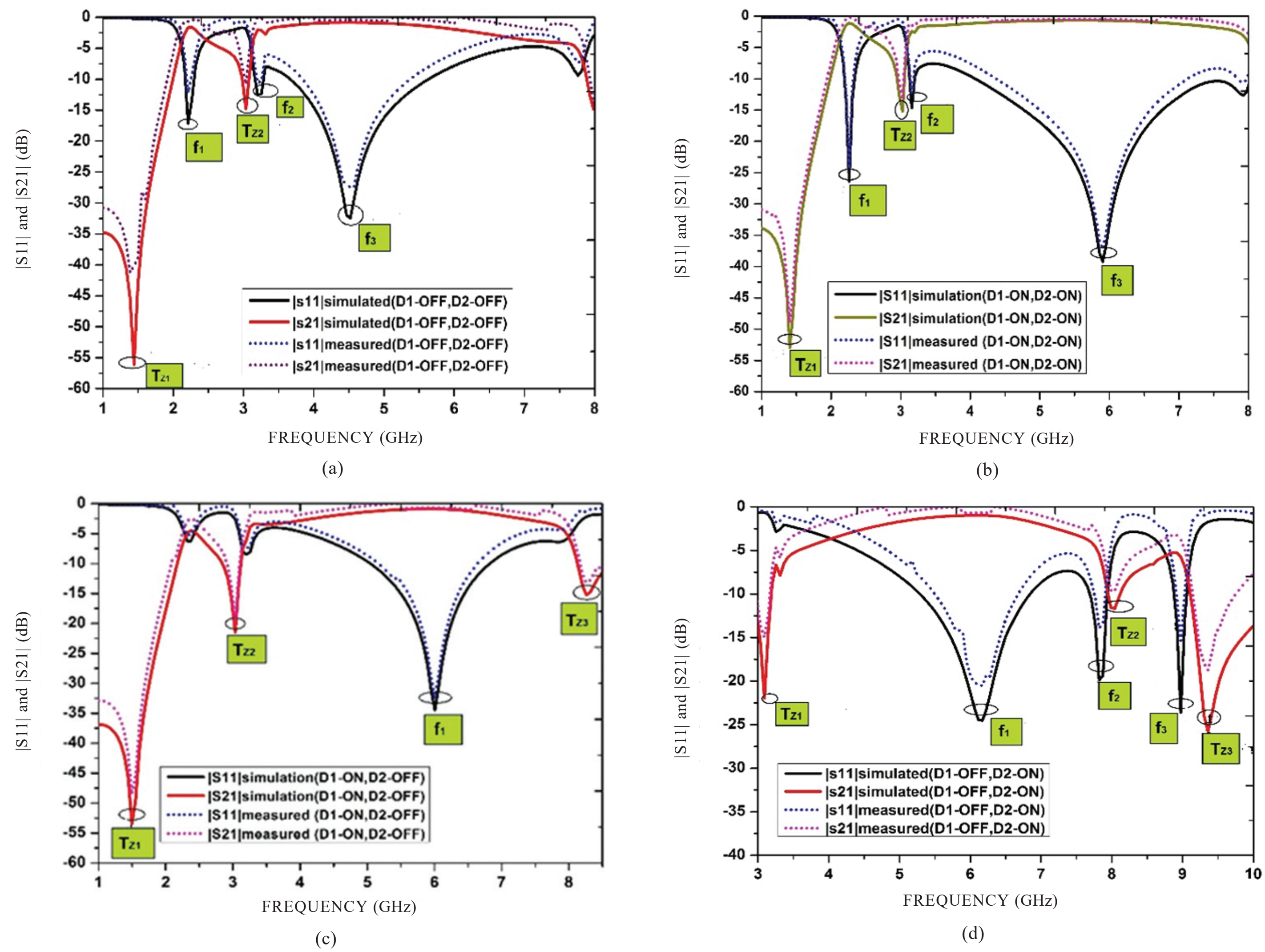


Figure 5. Simulated and measured S-parameters of the reconfigurable BPF (a) when D_1-OFF, D_2-OFF, (b) D_1-ON, D_2-ON, (c) D_1-ON, D_2-OFF, and (d) D_1-OFF, D_2-OFF.

Table 2. Performance comparison of reported reconfigurable BPFs

Reference	Centre Frequency (GHz)	Insertion loss (IL) (dB)	Returnloss (RL) (dB)	No. of transmission Zeroes (Tzs)	Size (mm)	Fractional bandwidth FBW
Ghaderi[1], *et al.*	2.1/2.63	0.68/1.08	19.3/30.7	3	16.4 × 13.4	2.15/1.48
Qin[9], *et al.*	0.6/ 1.15	1.1/2.8	21/23	2	9.5 × 9	15.2/15.9
Karim[10], *et al.*	2.2/2.4/3.6/10	0.9/1.9/2.1/3	21.3/2384/15.72	2	14 × 11.7	7.0/ 5.0/ 3.5/2.8
Elelimy[11], *et al.*	0.9/ 2.45/3.5	1.5/1.8/1.8	19/15/21	-	13.6 × 12.9	7.1/8.5/8.7
Boutejdar[18]	4.3/5.3	3/5	16.7/15	1	25 × 15	12 / 9.7
Proposed study	2.43/3.5/5.9/6.5/8.86	0.5/0.6/0.7/1.2/1.9	15/20/21/25	3	25 × 16 26 × 20	13.43/10.83/27. 98/11.17/10

5. CONCLUSIONS

A novel reconfigurable BPF designs with simple, compact size, sharp rejection, and wide passband. The BPF is constructed using hemicircular flower shaped MMR. Even and odd mode analysis is used to analyse the filter. A switchable filter is designed by using the 'Pin' diodes. To bring three resonant modes into the desired passband, filter dimensions are optimised. The resonant passband frequencies are 2.43 GHz, 3.5 GHz, 5.9 GHz, 6.5 GHz, and 8.86 GHz. The filter is designed, fabricated, and measured to validate the resent concept. The insertion loss of 0.5 dB, 0.6 dB, 0.7dB, 1.2 dB, and 1.9 dB at passband frequencies are achieved. The impedance bandwidth of 0.3 GHz, 0.5 GHz, 2.5 GHZ, and 0.2 GHz are obtained from the measured result of the filter. A good consistency is achieved between simulated and measured results. In comparison of the filter with some earlier reported reconfigurable BPFs the proposed filter results are better than earlier reported filter in terms of size, insertion loss, fractional bandwidth and transmission zeros. The filter is suitable for intelligent transportation systems.

REFERENCES

1. Ghaderi, A.; Golestanifar, A. & Shama, F. Design of a compact microstrip tunable dual-band bandpass filter. *AEU Int. J. Electron. Commun.,* 2017, **82**, 391-396. doi: 10.1016/j.aeue.2017.10.002
2. Xu, J.; Wu, W. & Miao, C. Compact microstrip dual-/tri-/quad-band bandpass filter using open stubs loaded shorted stepped-impedance resonator. *IEEE Trans. Microwave Theory Tech.,* 2013, **61**(9), 3187-3199. doi: 10.1109/TMTT.2013.2273759
3. Jhariya, D.; Azad, A.R.; Mohan, A. & Sinha, M. Compact wideband bandpass filter using fish spear-shaped multimode resonator. *Microwave Optical Technol. Lett.,* 2015, 1, **57**(12), 2833-7. doi: 10.1002/mop.29437
4. Boutejdar, A.; Ibrahim, A.A. & Ali, W.A. Design of compact size and tunable band pass filter for WLAN applications. *Electronics Letters,* 2016, **52**(24), 1996-7. doi: 10.1049/el.2016.3073
5. Rauscher, C. Reconfigurable bandpass filter with a three-to-one switchable passband width. *IEEE Trans. Microwave Theory Tech.,* 2003, **51**(2), 573-577. doi: 10.1109/TMTT.2002.807818
6. Hua, C. & Lu, Y. Compact UWB bandpass filter with a reconfigurable notched band. *Int. J. RF Microwave Comput. Aided Eng.,* 2017, **28**(4), e21212. doi: 10.1002/mmce.21212
7. Luo, X.; Qian, H.; Ma, J.G. & Li, E.P. Wideband bandpass filter with excellent selectivity using new CSRR-based resonator. *Electronics Letters*, 2010, **46**(20), 1390-1391. doi: 10.1049/el.2010.1817
8. Schuster, C.; Wiens, A.; Schmidt, F.; Nickel, M.; Schüßler, M.; Jakoby, R. & Maune, H. Performance analysis of reconfigurable bandpass filters with continuously tunable center frequency and bandwidth. *IEEE Trans. Microwave Theory Tech.*, 2017, **65**(11), 4572-83. doi: 10.1109/TMTT.2017.2742479
9. Qin, W.; Cai, J.; Li, Y.L. & Chen, J.X. Wideband tunable bandpass filter using optimized varactor-loaded SIRs. *IEEE Microwave Wireless Components Lett.*, 2017, **27**(9), 812-814. doi: 10.1109/lmwc.2017.2734848
10. Karim, M.F.; Guo, Y.X.; Chen, Z.N. & Ong, L.C. Miniaturized reconfigurable and switchable filter from UWB to 2.4 GHz WLAN using PIN diodes. *In* IEEE Microwave Symposium Digest. MTT-S International, 2009, **7**, 509-512. doi: 10.1109/mwsym.2009.5165745
11. Elelimy, A.M.; El-Tager, A.M. & Sobih, A.G. A compact size switched reconfigurable tri-band BPF for modern wireless applications. *In* the 56th International Midwest Symposium on Circuits and Systems (MWSCAS), 2013, **4**, 772-5. doi: 10.1109/MWSCAS.2013.6674763
12. Naglich, E.J.; Lee, J.; Peroulis, D. & Chappell, W.J. A tunable bandpass-to-bandstop reconfigurable filter with independent bandwidths and tunable response shape. *IEEE Trans. Microwave Theory Tech.,* 2010, **58**(12), 3770-3779. doi: 10.1109/TMTT.2010.2086533
13. Deng, J.; Hou, S.; Zhao, L. & Guo, L. A reconfigurable filtering antenna with integrated bandpass filters for UWB/WLAN Applications. *IEEE Trans. Antennas Propag.,* 2018, **66**(1), 401-404. doi: 10.1109/TAP.2017.2760363
14. Torregrosa-Penalva G.; López-Risueno G. & Alonso, J.I. A simple method to design wide-band electronically tunable combline filters. *IEEE Trans. Microwave Theory Tech.,* 2002, **50**(1),172-177. doi: 10.1109/22.981262
15. Deng, P.H. & Jheng, J.H. A switched reconfigurable high-isolation dual-band bandpass filter. *IEEE Microwave Wireless Compon. Lett.*, 2011, **21**(2), 71-73. doi: 10.1109/LMWC.2010.2098023
16. Ranjan, P.; Raj, S.; Upadhyay, G.; Tripathi, S. & Tripathi, V.S. Circularly slotted flower shaped UWB filtering antenna with high peak gain performance. *AEU-Int. J. Electron. Comm.,* 2017, **81,** 209-217. doi: 10.1016/j.aeue.2017.08.055
17. Borazjani, O.; Nosrati, M. & Daneshmand, M. A novel triple notch-bands ultra-wide-band band-pass filters using parallel multi-mode resonators and CSRRs. *Int. J. RF Microwave Comp. Aided Engg.,* 2014, **24**(3), 375-381. doi:10.1002/mmce.20770
18. Boutejdar, A. Design of 5 GHz-compact reconfigurable DGS-bandpass filter using varactor-diode device and coupling matrix technique. *Microwave Opt. Technol. Lett.*, 2016, **58**(2), 304-309. doi: 10.1002/mop.29561
19. Tripathi, S.; Pathak, N.P. & Parida, M. Microwave front-end subsystems design for ITS/GPS applications. *Eng. Sci. Technol. Int. J.*, 2016, **19**(4), 1815-1825. doi: 10.1016/j.jestch.2016.08.017
20. Hong, J.S. Microstrip filters for RF/microwave applications. Ed. 2. New York, Wiley, 2011. doi: 10.1002/9780470937297

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In the current study, he is to conceived of the presented idea its simulation and measurement

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Contribution in the current study, he provided inputs in simulation.

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In the current study, he helped in writing in paper.