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Design and development frequency reconfigurable microwave filter for wireless application

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ABSTRACT

This paper presents a novel reconfigurable bandpass filter with three reconfigurable states used for C band wireless applications. The frequency reconfigurable is achieved using the combination of a different microstrip coupled resonator structure and switching device as PIN diodes. The open-loop filter structure provides three narrow band states at 5.1, 5.2, and 5.8 GHz. The frequency reconfiguration is obtained without compromising performances. The compact size of the proposed designed along with the targeted frequency bands at lower wireless local area network (WLAN) (5.1 and 5.2 GHz), and worldwide interoperability for microwave access (WiMAX) (5.8 GHz) applications. The prototype is constructed on an RT duroid 5880 substrate and tested for validation in vector network analyzer (VNA). The designed filter provides excellent selectivity and good rejection at desired resonant frequencies.

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1. INTRODUCTION

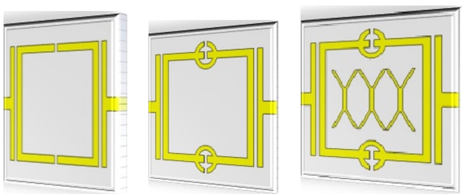
Reconfigurable filters used in many wireless applications that work at different frequency bands. Reconfigurable filters can operate in different frequencies with the same design and do the same operation as several filters without increasing overall size making them an attractive choice for portable devices [1]-[4]. There are many techniques for making a bandpass filter smaller and improving its electrical parameters. The first method is to use a stepped impedance resonator (SIR) and uniform impedance resonator (UIR) for bandpass filter to improve the selectivity and insertion loss for multi-frequency applications [5]–[9]. The major benefit of metamaterial is that it makes devices smaller. Using a meta property design for a bandpass filter, it is small, can be used for many different frequencies, and has good selectivity [10]–[18]. The defected ground structure (DGS) is a defect built into the ground plane of microwave planar circuits. It is used to make a bandpass filter. DGS is a new way to improve the different aspects of microwave circuits, such as their narrow bandwidth, cross-polarization, and low gain [19]-[22]. The filter is made smaller and reconfigurable in three main ways first: the resonator is reduced in size, second one: the structure is made smaller using the metamaterial resonator, and third is a reconfigurable component used like PIN diode or varactor diode. There are many methods for the design filter microstrip and resonator based filters [23], [24] capacitor-loaded resonators, step impedance resonators (SIR) [5]-[9], DGS based bandpass filter (BPF) [19]-[22], metamaterial based BPF [14],

[25], [26]. Liu *et al.* [4] shows a novel tunable liquid crystal (LC) based bandpass filter with tunable bandwidth using a varactor diode. There is the design of dual bandpass filters using metamaterial unit cells. In that design, no reconfigurability is possible, but they design split ring resonator based unit cells for multi-frequency operation. In proposed work designed compact reconfigurable BPF for wireless application. The reconfigurable filter design uses two-stepped impedance resonators (SIRs) and one uniform impedance resonator (UIR) [6] in which size is more compared to the proposed work. Chavda and Sarvaiya [11] shows the reconfigurable band stop filter for a single band using a novel shape hexagonal metamaterial cell but the size of the proposed filter much more compared to the proposed work. This proposed paper presents a reconfigurable novel bandpass filter design using a microstrip coupled resonator with a PIN diode. A miniature bandpass filter with excellent electrical performance is achieved based on a square split ring resonator and X shape series resonator with optimization and a specific design method. First, the metamaterial unit cell is studied to obtain a desired resonant frequency. The proposed BPF is very compact and has good rejection and insertion loss compared to previous year's literature.

2. BANDPASS FILTER

2.1. Bandpass filter design

A BPF is an essential element of wireless communication systems [1]-[3]. This paper shows a triple frequency for a single band using different microstrip coupled resonators, as shown in Figure 1, with optimized filter geometry parameters provided in Table 1. It resonates at two different frequencies, which correspond to the outer split-ring structures, and the second frequency corresponds to the inner X-shape resonator. Initially, a single frequency BPF was developed utilizing a single split ring (Figures 1(a) and 1(b)). Similarly, a second inner 'X' shape resonator to the initial design for dual frequency functioning is shown in Figure 1(c). The resonant frequency of the proposed BPF is 5.1, 5.2 and 5.8 GHz, which is useful for IEEE 802.11 wireless standards. The basic structure of the bandpass filter outer ring designed using a simple square split ring resonator (SSRR) attached to the circle shape slotted ring resonator (SRR) to the split of the main square split ring resonator with two splits. It will be resonant at the desired frequency. Figure 1(a) shows a bandpass filter design using a square split ring resonator structure. Figure 1(b) shows some modifications, like adding two circular shape ring resonators across the split of the SRR in the design of conventional SRR. Figure 1(c) shows the novel structure of the BPF coupled with X shaped resonator. Using this novel shape resonator makes the design reconfigurable. The Material used for the proposed design is RT duroid 5880 with a height of 1.57 mm, and tangent loss of 0.02.



(a) (b) (c)

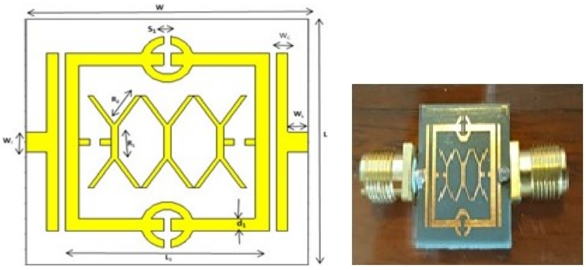
Figure 1. Different shape resonators (a) SSRR-square split ring BPF, (b) modified design of BPF, and (c) novel shape of BPF

Table 1. Dimension table for the BPF

Parameter	L	W	L1	WF	S1	d1	WL	WC	R1	R2
Size (mm)	15	15	12	1.3	0.4	0.8	1.4	0.6	2	2.2

Figure 2 shows the novel bandpass filter design operates with 5.11 GHz with a bandwidth of 176.18 MHz. In Figure 2(a) shows the simulated Figure 2(b) shows fabricated result. The lower cut-off frequency at -3 dB is 5.09 GHz, and the higher cut-off frequency at -3 dB is 5.20 GHz. The insertion loss of the proposed BPF is -0.20 dB, and the return loss is -34.39 dB. The different optimized parameter of the novel BPF shown in Table 1. The length L is 15 mm, and the width W is 15 mm, which is shown in Figure 2. The square outer ring d1 is 0.8 mm, and the width and length are 12 mm. The feeding length WL=1.4 mm, the width of the feeding line WF=1.3 mm, and split width S1=0.4 mm. The dimension of the inner three ”X” resonators R1=2 mm, R2=2.2 mm [9]. Figure 2(b) shows the fabricated model for the BPF.

Figure 3 shows the simulated result of the BPF with the center frequency of 5.11 GHz. Simulated S11 and S21 shows the pass band and insertion loss. Figure 4 shows the measured result of the BPF using vector network analyzer (VNA) (Agilent 8722ES 50 MHz-40 GHz) with its measurement setup. There is good agreement between simulated as shown in Figure 4(a) and measured results as shown in Figure 4(b).



(a) (b)

Figure 2. Novel shape BPF (a) simulation of BPF filter for C band and (b) fabricated model for the BPF

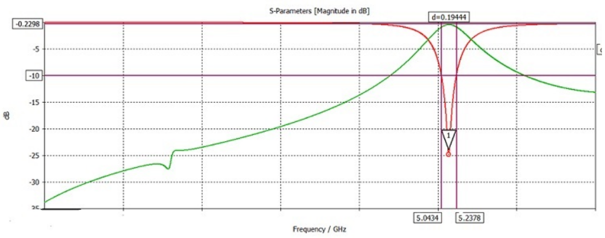
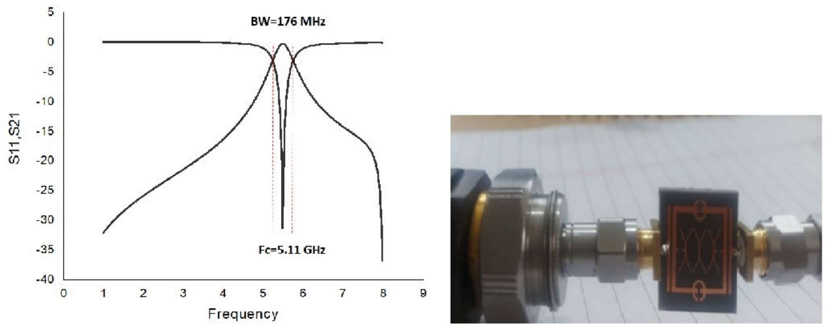


Figure 3. Simulated result of BPF



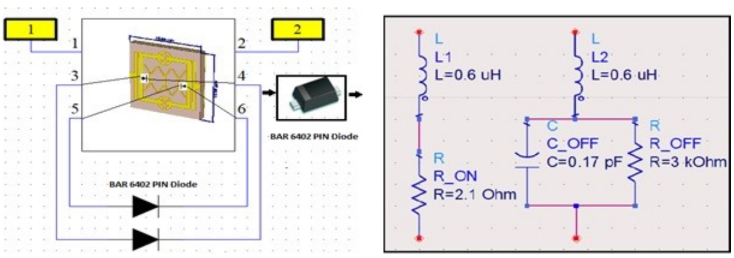
(a) (b)

Figure 4. S11 and S21 parameter of novel BPF (a) simulated S parameter and (b) measured S parameter using VNA

2.2. Reconfigurable BPF

In wireless communication, reconfigurable applications PIN diodes are used like a variable resistor switch, but a simpler biasing circuit controls their ON/OFF states. The complete reconfigurable switching function using PIN diode simulation using CST microwave studio is shown in Figure 5. In Figure 5(a) and Figure 5(b) shows an simulated and equivalent circuit diagram of the PIN diode (BAR 6402). The insertion loss in the ON state of the equivalent circuit is caused by the low resistance (Rs) (forward-biased). When a PIN diode is turned off, the equivalent circuit combines the reverse bias resistance (RP) and the total capacitance (Cp) in reverse biased. These diodes are used to make sure that frequency band reconfiguration is done with a high level of reliability. In the proposed design, BAR 6402 diode used with values for diodes in ON state are L=0.6 nH and Rs=2.1 Ω, whereas for diodes in OFF state are Rp=3 K and Cp=0.17 pF, as per the data sheet provided by the manufacturer. These PIN diodes used to achieve frequency reconfiguration, as shown in Table 2.

To design a reconfigurable multi-frequency filter, two PIN diodes (BAR64-02). By applying a proper dc bias across the PIN diode, the diode is turned 'ON,' and a direct current (DC) block capacitor and RF choke prevent damage to the diode. When the ring switch is 'ON,' the outer ring is activated directly shorted with the inner resonator (X shape resonator). When the switch is 'OFF,' there is only the outer SRRR ring resonates. The description of the different operating modes functioning reconfigurable, BPF: case-1: when both PIN diodes switches are "OFF" (see Figure 2(a)), the inner and outer rings resonate at a frequency of 5.11 GHz, as seen in Figure 3. In case-2: when one PIN diodes switch is "OFF," and the other PIN diode is "ON " it operates with 5.2 GHz which is shown in Figure 6. The outer ring is connected with the inner resonator with a single PIN diode shown in Figure 6(a), and the simulated result is shown in Figure 6(b). In case-3: both PIN diodes in the ON condition are shown in Figure 7, and the filter resonates at 5.8 GHz, as seen in Figure 7(a) and simulated result shown in Figure 7(b). Table 3 provides a summary of the different switching performances. The current distribution at 5.2 GHz confines in the outer ring when both PIN diodes are "OFF" (case-1), but at 5.8 GHz, it flows through the inner resonator. This result includes that the outer ring is responsible for the resonance at 5.2 GHz. Similar to this, the inner X shape resonator shorted with the outer SRR ring causes resonance at 5.8 GHz.

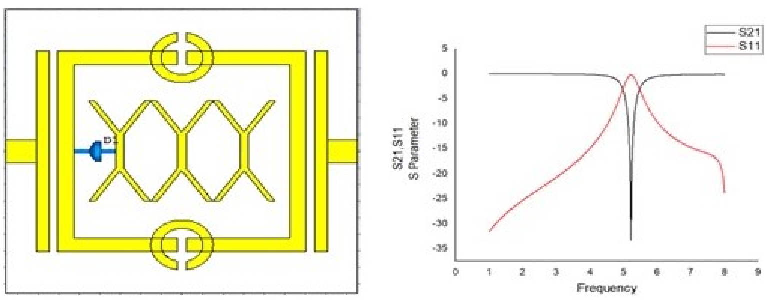


(a) (b)

Figure 5. Reconfigurable BPF (a) reconfigurable design for the BPF using CST design studio and (b) equivalent ON and OFF switching configuration for PIN diode

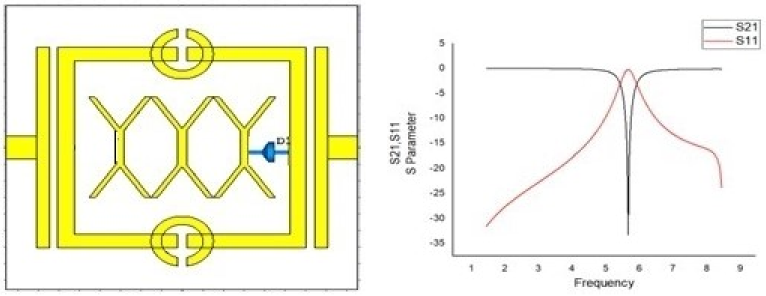
Table 2. Different operating modes for reconfigurable BPF

Operating mode	S1	S2	Operating frequency (GHz)
Case-1	OFF	OFF	5.11
Case-2	ON	OFF	5.2
Case-3	OFF	ON	5.8



(a) (b)

Figure 6. Case-2: single PIN diode ON condition for reconfigurable BPF (a) reconfigurable design for the BPF using CST design studio and (b) simulated S parameter result of BPF at 5.2 GHz



(a) (b)

Figure 7. Case-3: single PIN diode ON condition for reconfigurable BPF (a) reconfigurable design for the BPF using CST Design studio and (b) simulated S parameter result of BPF at 5.8 GHz

Table 3. Different modes of switches for BPF (PIN diode in ”ON /OFF state”)

Operating mode	S1	S2	Operating frequency (GHz)
Case-1	OFF	OFF	5.11
Case-2	ON	OFF	5.2
Case-3	OFF	ON	5.8

2.3. Design methodology of the reconfigurable BPF

According to the technical data sheet, the BAR64-02V PIN diode has a forward resistance of 1.35 Ω. To control 9 V connected RF choke is RL875S-222K-RC with a 2.2 mH inductance value and 1 k resistance connected across the circuit battery supply. The PIN diode is enabled to function in the ON state by supplying a DC voltage of +9 V. According to the millimeter measurement, the DC forward current flowing in the circuit is 90 mA. According to the ON and OFF condition of the PIN, diode BPF operate with three different operating modes shown in Figure 8 presents the coupling diagram of the proposed reconfigurable BPF in the ON and OFF states of the PIN diodes. As it is observed that the resonator does not couple the appropriate frequency to the load in the forward biased condition (ON state), whereas, in the reverse biased condition (OFF state), energy is only coupled through the resonator at the frequency for which it is characterized. In Figure 8 shows the measurement set up for the reconfigurable BPF and Figure 9 show the measured result with S paprameter.

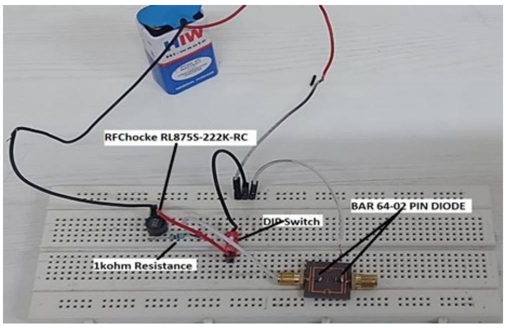


Figure 8. Measurement set up for the reconfigurable BPF

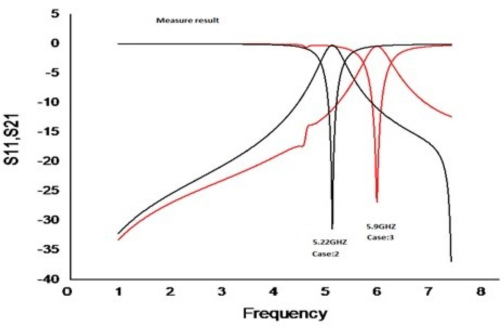


Figure 9. Measurement result of reconfigurable BPF

3. RESULTS AND DISCUSSION

The proposed reconfigurable BPF was simulated using CST software, and the difference between the simulated and measured results is shown above. The designed prototype is built and tested in real-time to make sure it works at RF Microtech Electronics, Baroda (VNA Agilent 8722ES 50 MHz-40 GHz), and at Government Engineering College (GEC), Bhavnagar. There was minor frequency shifting in fabricated and simulated results due to soldering and fabrication loss. The reconfigurable BPF's most important features are: the BPF is entirely customizable in the frequency range of 5.1 to 5.9 GHz. The reconfigurable frequency properties of the filter are completely independent of other functions. The Table 4 shows proposed reconfigurable BPF design is compact compared to the previous year's literature.

Table 4. The comparison table of proposed works with previous years' literature

Ref. No.	Year	Band	Size of filter	Frequency (GHz)	BW	Insertion loss (dB)	Rejection (dB)	Reconfigurable
[4]	2022	Single	35x20 mm^2	0.072 to 0.222	72 to 222 MHz	5.2 to 8.7	20, 16, 12, and 4	Yes varactor diodes
[5]	2020	Dual	10x12 mm^2	2.8 to 5.3	2.5 GHZ	3.81	25.0	No
[6]	2021	Dual	24x20 mm^2	2.4, 3.5, and 5.2	11.6, 4.2, and 6.7 GHZ	1.7	10	Yes PIN diode
[11]	2022	Single	40x40 cm^2	2.44 and 3.65	200 MHz	1.8, 2	26.93 and 24.06	Yes PIN diode
work		Single band (S-Band) -triple frequency	15x15x1.57 mm^3	5.11, 5.2, and 5.8	176, 182, and 182 MHz	0.2, 0.39, and 0.39	34.39, 21.52, and 26	Yes PIN diode

4. CONCLUSION

The proposed work designed for frequency-reconfigurable BPF has been done for wireless applications with a single band for three different frequencies (5.1, 5.2, and 5.8 GHz). The main advantage of this proposed BPF is reduced size with good performance. For frequency reconfigurability, proposed BPF design using inner, outer and 'X' shape resonator connected with PIN diodes with proper biasing. Compared to other scientific publications, the proposer filter has been found to perform better in size, reducing up to 35%. The proposed design improves the different electrical parameters like insertion loss and selectivity. A fabricated filter design has been made to validate the results of the simulations. In future work, the frequency-switching filter can be designed for multiband wireless applications.

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