

# Compact bandpass filter with reconfigurable X-band using stepped impedance resonator and folded structure

Molimoli Hajamohideen Masood<sup>1</sup>, Sreeja Balakrishnapillai Suseela<sup>2</sup>

<sup>1</sup>Department of Information and Communication Engineering, Anna University, Chennai, India

<sup>2</sup>Department of Electronics and Communication Engineering, SSN College of Engineering, Chennai, India  
E-mail: masoodsahib@hotmail.com

Published in *The Journal of Engineering*; Received on 18th October 2017; Accepted on 26th December 2017

**Abstract:** A reconfigurable X-band microstrip bandpass filter based on the stepped impedance resonator topology with two folded stubs is proposed. Reconfiguration is enabled in the microstrip filter using positive–intrinsic–negative (PIN) diode and the proposed filter performs frequency switching between uplink and downlink X-band services. The prototype filter is realised ideally using open-circuit and short-circuit conditions that are designed in a way similar to the design using PIN diodes that provide the same results. From the simulation and measured results, it is inferred that by altering the ON/OFF states, the filter can work from downlink frequency range of 7.25–7.9 GHz to the uplink frequency range of 8.00–8.4 GHz. Comprehensive studies are conducted on a fabricated prototype to assess its performance from which encouraging results are obtained.

## 1 Introduction

Recent development in wireless communication systems has led to increasing demand for reconfigurable components. Bandpass filters with centre frequency and bandwidth reconfigurable have been a significant research topic. Reconfigurable filters can be applied in commercial and military fields such as satellite and cellular communication, wireless, radar etc. The satellite communication industry created a demand for low-mass, low-loss, narrowband, high linearity and wide tuning range filters [1]. Reconfigurable and miniaturised radio-frequency (RF) filters indeed will be key elements in future satellite telecommunication systems which will require low size and weight as well as flexibility. In this paper, a compact microstrip Band Pass Filter (BPF) with two transmission zeroes near both passband edges of lower and higher frequency is developed. The satellite communication industry created the demand for low-loss, low-mass, highly tunable filters [2]. To improve the filter performances, the cross-coupling technique was employed with open-loop resonators [3]. The microstrip filter consists of three different patches on the top side of three different frequency band applications and two different pairs of capacitor chips incorporated into the patches [4]. The transmission zeroes become tunable when varactors are loaded at the open ends of the stubs [5]. The reconfigurable filters with fractional bandwidth control were presented [6–9].

The organisation of this paper is as follows. Section 2 presents the design of reconfigurable filter. Section 3 demonstrates the reconfigurable filter with positive–intrinsic–negative (PIN) diode. Filters are then simulated in Section 4 while Section 5 shows result analysis to evaluate the performance of the ideally implemented reconfigurable filter with the measured results.

## 2 Design of reconfigurable bandpass filters

A design consideration is very important as communication devices are getting smaller day by day and due to rough use. Robustness and compact size of the filter are other important factors to be considered in filter design. In this paper, at first we simulate regular cross-dumbbell-shaped resonator (CDSR) structure and then develop to respond at high frequency such as the X-band. The design procedure for the proposed filter includes connecting cross-coupled structure by the PIN diode with a vertical resonator as shown in Fig. 1 and simulated to the X-band. The PIN diodes

loaded of model MA4P789-287T [10] is used for reconfiguration of the proposed filter.

### 2.1 PIN diode

The PIN diode is used in many applications ranging from ultrahigh frequency to microwave frequencies. It works like a variable resistor in RF and microwave frequency being controlled by its bias current direct [11]. The microwave PIN diode's small physical size compared with a wavelength, high switching speed and low package parasitic reactance make it an ideal component for use in miniature, broadband RF signal control circuits. In addition, the PIN diode has the ability to control large RF signal power while using much smaller levels of control power [12]. The PIN diode has the power of controlling large RF signal with smaller power control.

### 2.2 Stepped impedance resonator

The typical half-wavelength stepped impedance resonator (SIR) is depicted in Fig. 2 with  $Z_1$  and  $Z_2$  being the characteristic impedances of the transmission-line sections of electrical lengths  $\theta_1$  and  $\theta_2$ , respectively. Following the standard transmission-line theory, the resonance conditions for the fundamental and harmonic resonances are found as:

$$\frac{z_2}{z_1} = \tan \frac{\theta_1}{2} \tan(\theta_2) \quad (1)$$

and

$$\frac{z_2}{z_1} = \tan \frac{\theta_1}{2} = -\tan(\theta_2) \quad (2)$$

respectively

The characteristic impedances of SIR in the transmission line are  $Z_1$  and  $Z_2$  and are the characteristic impedances within the loop resonator,  $\beta$  is the propagation constant,  $\theta_a$  is the electrical length of transmission line,  $\theta_b$  is the electrical length, and  $l$  is the length of transmission line. The parameter  $\theta_a$  is  $2(\theta_1 + \theta_2)$ . Assuming  $\theta_1 = \theta_2 = \theta$ , the characteristic impedance ( $Z_0$ ) can be determined from (17), while the impedance relation ratio ( $K$ ) is the characteristic impedance ratio between  $Z_1$  and  $Z_2$

$$Y_a = \frac{1}{Z_a} = jY_2 \frac{2(1 + K)(k - \tan A^2 \theta) \tan \theta}{k - 2(1 + K + KK^2) \tan^2 \theta + K \tan^4 \theta} \quad (3)$$

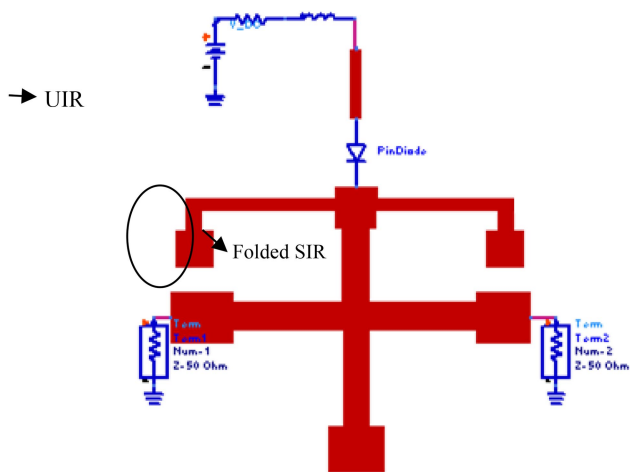


Fig. 1 Layout of the proposed reconfigurable filter with PIN diode

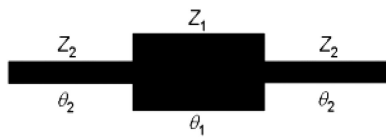


Fig. 2 Half-wavelength SIR

### 3 Basic filter structures and its operation

#### 3.1 CDSR structure with open stub

The design evolved with the main CDR for resonating at high frequency such as the X-band (8–12 GHz). Then, SIR concept is used in the design of CDR with open and shorted stubs at either side transforms a lowpass filter to bandpass filter, thereby increasing the order of the filter to achieve wideband attenuation with good return loss (Fig. 3).

### 4 Design of reconfigurable filter with PIN diode

The CDS structure consists of a vertical and a horizontal patch terminated with the stubs on each side. Fig. 4 shows the proposed filter structure with two resonating structure uniform IR (UIR) and folded SIR. The layout responsible for the X-band frequency which takes the combination of CDS structure and UIR. The CDS structure with resonator stubs placed on the input and output ports which are used for high-quality bandstop performance and perfect impedance matching. The gap between the CDSR and standing resonator UIR acts as the capacitance hence the bandpass

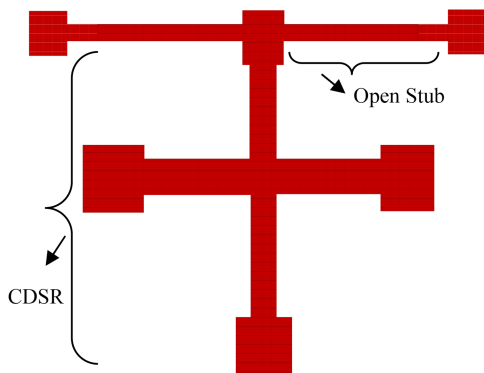


Fig. 3 CDS structure with open stub

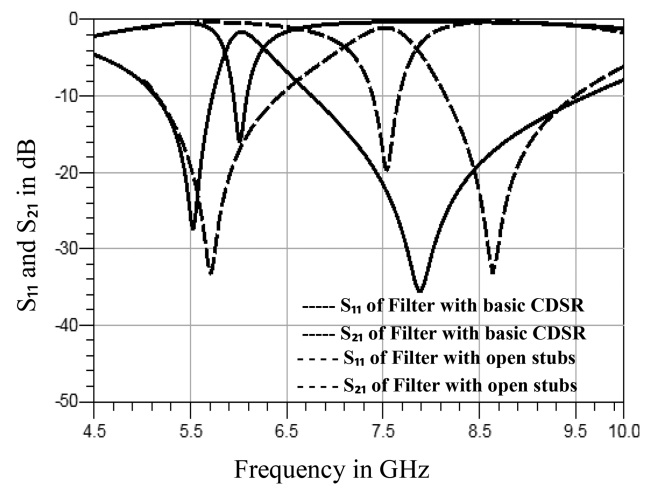


Fig. 4 Simulated results of CDSR and CDSR with open stubs

behaviour is achieved with good attenuation in the lower and higher bands.

The design of the proposed filter with open-ended stubs for the connection of PIN diode is shown in Fig. 4. The filter is shown with the biasing circuit and PIN diode between the UIR stub and CDSR with two termination sources is applied at the input and output ports.

#### 4.1 Folded SIR structure

The folded SIR stubs on either side are used to shift the transmission zero in the upper passband with the centre frequency as shown in Fig. 3. It is also used to control the filter response by controlling the bandwidth. The compact and optimised design with folded SIR is shown in Fig. 4.

#### 4.2 Uniform IR

The UIR is the standing resonator placed vertically above the whole structure for biasing the PIN diode. It is used to match PIN diode with the main resonator for reconfiguration.

The comparison of the simulation result with and without the folded SIR in the proposed design at switch ON and switch OFF states is shown in Figs. 5 and 6. When PIN diode is OFF, a desired lower frequency passband at 7.60 GHz is achieved with

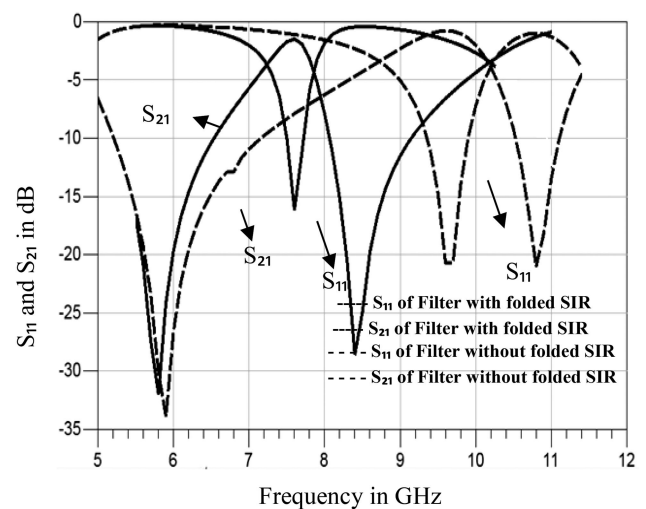
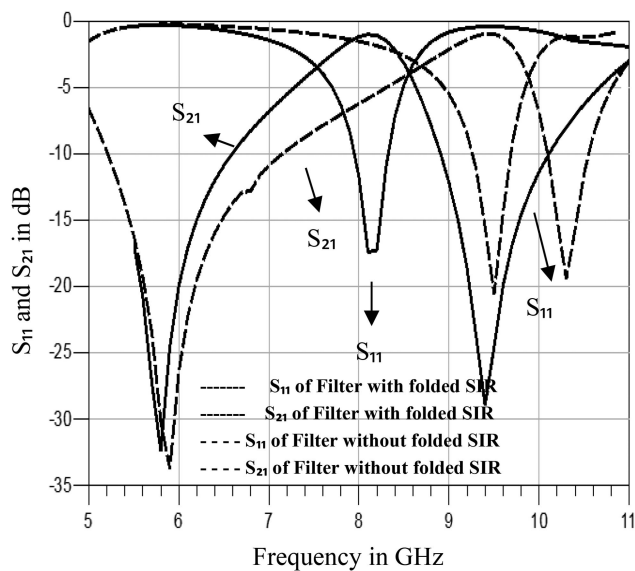


Fig. 5 Comparison of simulated filter S-parameter in switch OFF state with folded SIR and without folded SIR



**Fig. 6** Comparison of simulated filter  $S$ -parameter in switch ON state with folded SIR and without folded SIR

an insertion loss of  $-2.017$  dB and return loss of above 15 dB for the design with folded SIR and the design without folded SIR is obtained at 9.6 GHz out of the band. Similarly, when the PIN diode is ON, the filter is switched to the higher frequency band at 8.3 GHz with insertion loss of  $-1.122$  dB and return loss of above 15 dB for the design with folded SIR. Hence, the simulation results show that the folded SIR structure has influence in controlling passband's bandwidth centred at the desired frequency with high attenuation in passband.

## 5 Design methodology of ideally reconfigurable X-band bandpass filter without PIN diode

The proposed filter with PIN diode is experimented ideally by an open-circuit and short-circuited reconfigurable bandpass filters and fabricated. The design includes coupled resonator stubs at one side of the CDSR structure as shown in Fig. 4 and is excited via ports 1 and 2, where  $Z_0 = 50 \Omega$ . As illustrated in Fig. 4, the complete structure of the proposed reconfigurable filter is designed on a 0.8 mm thick Flame Retardant 4 (FR4) substrate. The final design has the size of 14 mm $\times$ 16 mm with three different resonators for frequency shifting from uplink to downlink. Consequently, a reconfigurable circuit must be carefully designed such that it is sensitive enough to small variations in its tunable capacitors.

### 5.1 Open-circuit and short-circuited stubs

For the SIR filter, the positions of the transmission zeros can be adjusted by properly tuning the structure; hence, the reconfiguration can be achieved by the same concept. In this paper, open-ended stubs for the coverage of uplink frequency (8.0–8.4 GHz) and shorted stubs for the downlink frequency of the X-band (7.25–7.9 GHz) is designed. In general, bandwidth control is accomplished by the creation of a variable coupling scheme. The centre frequency is simply controlled by the resonator's effective length. Here, both the bandwidth and centre frequency reconfiguration are achieved by shifting the uplink and downlink frequencies by opening and shorting the structure with the stubs. This is achieved by varying the effective coupling section allowing the interaction between resonators as shorted and open-ended stubs to change the centre frequency and bandwidth.

## 6 Design of open-circuit X-band bandpass filter

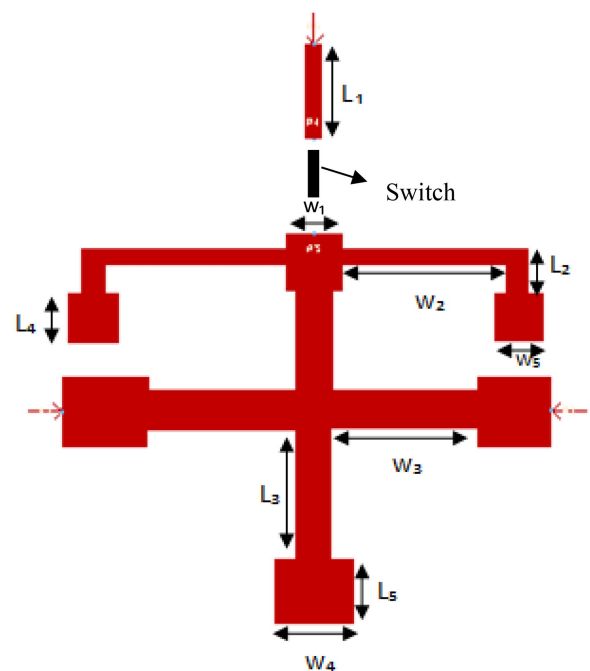
The filter design with an open-end resonator reduces the size of the whole filter. The middle section involves SIR. The advantage of using is that its structural parameters can be varied to obtain the desired response. The CDSR has a total length of 12 mm with a width of 14 mm. The various dimensional parameters of the structure include  $w_0 = 3.2$  mm,  $w_1 = 1.8$  mm,  $w_2 = 3$  mm,  $l_0 = 3$  mm, and  $l_2 = 4$  mm. The approach of placing resonator stubs on both ends of horizontal plane reduces the overall size of the filter and enhances the high stop band performance without the need of adding more sections. The reason for the choice of this resonator-coupled configuration is that it provides a wideband with tight coupling, which is important to achieve the required filter's characteristics, for switching from lower to higher frequency of the X-band. The gap between CDSR and the standing line resonator, i.e. UIR acts as the capacitance, hence the bandpass behaviour is achieved and the CDSR which is also used for steep attenuation.

## 7 Design of short-circuited X-band bandpass filter

The filter has the same structure resembling open-circuit filter as shown in Fig. 7 with the only difference of shorted stub at the top acting ideally as switch OFF position of PIN diode. Two termination sources are applied at the input and output ports. The overall dimension of the filter is about 14 mm $\times$ 14 mm. The design shorted with the stub at the top of the structure acts as the PIN diode in OFF state position for which the passband is at downlink frequency of 7.25–7.9 GHz.

## 8 Simulation and measurement results of ideal reconfigurable filter

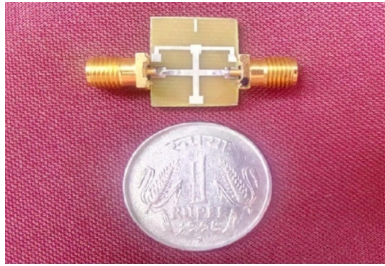
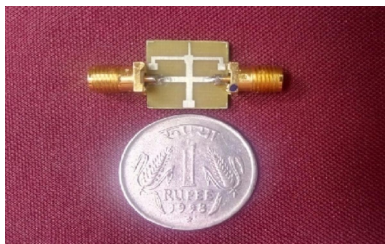
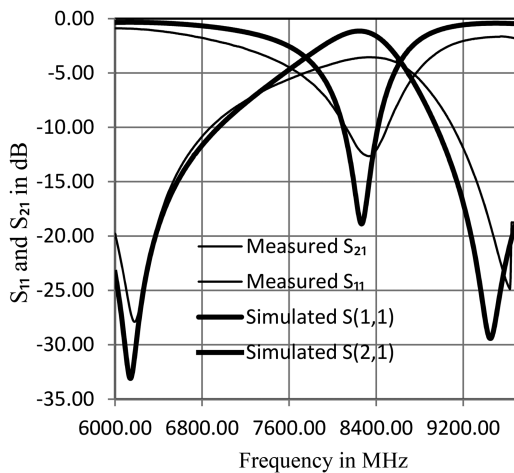
The X-band comprises uplink frequency from 8.00 to 8.40 GHz and downlink from 7.25 to 7.9 GHz. In this ideal case, the short-circuited filter provides switch ON state of the PIN diode, i.e. uplink frequency from 8.00 to 8.4 GHz of the passband and the open-circuited filter provides switch OFF state of the PIN diode, i.e. downlink frequency of 7.25 to 7.9 GHz. The insertion loss and return loss values are given in Table 1 with two states of the switches. The centre frequency is at 7.5 GHz when the switch is



**Fig. 7** Layout of the proposed ideal reconfigurable filter with open-circuit

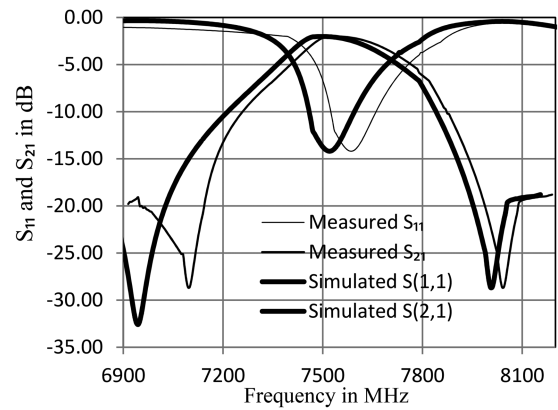
**Table 1** Simulated parameters of the design

Parameters	Values	
	Switch ON	Switch OFF
passband, GHz	8.00–8.04	7.2–7.9
insertion loss, dB	2.02	1.127
return loss, dB	15	15
bandwidth, MHz	633	403
FBW, %	54	31.15
tuning range, GHz	7.00–8.00	7.50–8.50
attenuation, dB	35	30

**Fig. 8** Fabricated layout of the open-circuited filter**Fig. 9** Fabricated layout of the short-circuited filter**Fig. 10** Comparison of simulated and measured results at switch ON position

at OFF state and 8.3 GHz when the switch is at ON state ideally (Figs. 8 and 9).

The comparison between the simulated and measured results of the ideal filter is shown in Figs. 10 and 11. It can be seen that simulation and measurement do fit very well with each other. The critical parameters are discussed in Table 1. The filter has good

**Fig. 11** Comparison of simulated and measured results at switch OFF position

insertion losses of 2.02 and 1.127 dB with a return loss of 15 dB. The bandwidth of the simulated filter is 633 MHz for uplink and 403 MHz for downlink frequency with Fractional Band Widths (FBWs) of 54 and 31.15%, respectively.

## 9 Conclusion

A reconfigurable X-band bandpass filter is designed using SIR incorporated with one PIN diode and analysed ideally in fabrication. The simulated result obtained with better insertion and return loss. Another advantage of the filter is that it operates at low bias voltage in two switch states of ON and OFF. A good agreement is seen between the measured and simulated performances of the filter. The design is simulated using Advanced Design Tools 2011 (Advanced Design System (ADS)) from Agilent technologies.

## 10 References

- [1] Doherty W.E.: 'The PIN diode circuit designer's handbook'. Microsemi cooperation, 1998, 580 Pleasant Street-Watertown
- [2] Zou X., Chen K., Zhang H., *ET AL.*: 'Design and simulation of 4 bit 10–14 GHz RF MEMS tunable filter'. IEEE Int. Conf. Nano/Micro Engineering and Molecular Systems, Shenzhen, China, January 2009, pp. 21–24
- [3] Hong J.S., Lancaster M.J.: 'Couplings of microstrip square open loop resonators for cross-coupled planar microwave filters', *IEEE Microw. Wirel. Compon. Lett.*, 2004, **15**, (3), pp. 2099–2109
- [4] Munir A., Lukius H.: 'Microstrip filter with reconfigurable frequency responses based on capacitor chips'. Radio Telecommunication and Microwave Laboratory, 2016
- [5] Zhang H., Chen K.J.: 'Bandpass filters With reconfigurable transmission zeros using varactor-tuned tapped stubs', *IEEE Microw. Wirel. Compon. Lett.*, 2006, **16**, (5), pp. 249–251
- [6] Joshi H., Sigmarsson H.H., Moon S., *ET AL.*: 'High-Q fully reconfigurable tunable bandpass filters', *IEEE Trans. Microw. Theory Tech.*, 2009, **57**, (12), pp. 3525–3533
- [7] Miller A., Hong J.-S.: 'Wideband bandpass filter with reconfigurable bandwidth', *IEEE Microw. Wirel. Compon. Lett.*, 2010, **20**, (1), pp. 28–30
- [8] MA4P789-287T SMPP series pin diodes datasheet from MACOM
- [9] Hsu H.H., Margomenos A.D., Peroulis D.: 'A monolithic RF-MEMS filter with continuously-tunable center-frequency and bandwidth'. IEEE Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems (SiRF), 17–19 January 2011, pp. 169–172
- [10] Mazri T., Riouch F., El Idrissi N.E.A.: 'Design and simulation of a SP4T switch based on the PIN diode suitable For UMTS use', *IJCSNS Int. J. Comput. Sci. Netw. Secur.*, 2011, **11**, (9), pp. 77–81
- [11] Fathelbab W.M.: 'A new class of reconfigurable microwave bandpass filters', *IEEE Trans. Circuits Syst. II, Express Briefs*, 2008, **55**, (3), pp. 264–268
- [12] Makimoto M., Yamashita S.: 'Bandpass filters using parallel-coupled stripline stepped impedance resonators', *IEEE Trans. Microw. Theory Tech.*, 1980, **MTT-28**, pp. 1413–1417