Indonesian Journal of Electrical Engineering and Computer Science
Vol. 10, No. 3, June 2018, pp. 867~874
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v10.i3.pp867-874

A Compact Bandpass Filter Using a T-shaped Loaded Open-Ended Stub Resonator

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Article Info

Article history:

Received Jan 9, 2018
Revised Mar 2, 2018
Accepted Mar 18, 2018

Keywords:

Band reject
Bandpass filter
Open stub Resonator
Skirt selectivity
Transmission zero

ABSTRACT

This paper proposes a compact bandpass filter using a loaded open-ended T-shaped stub. The open-ended T-shaped stub is loaded with vertical resonators placed across. The key advantage of using vertical resonators in the design is the simplicity and low insertion loss it provides. The structure used is an open-ended stub attached on one end to the transmission line (λ/2) to form a T-shaped resonator (λ/4) having vertical resonators placed across. The vertical resonator position alters the position at which the transmission zero occurs. A pair of the T-shaped resonator is placed on parallel sides of the feed line. The proposed filter is designed with the aid of Computer Simulation Technology Microwave Studio Software. The proposed concept is verified by designing filters with four different vertical resonator positions. The filter possesses a good rejection and low insertion loss of < 2dB with Chebyshev response. This filter is suited for modern-day communication applications since it shows good rejection of out of band signals.

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1. INTRODUCTION

The rapid advancement of modern communication systems and the congestion of radio spectrum have made multifunctional and multiband devices a research hotspot. Bandpass filters are prime components in communication systems as they help to inhibit interference and provide the needed selection of the signal band. Bandpass filters that possess high selectivity in the passband are needed to suit modern communication applications.

Controlling the transmission zero position is very important to researchers in preventing interference with adjacent frequency bands.Various techniques have been used to make bandpass filter suit modern communication characteristics [1-14]. A fixed frequency open ended tapped stub with good selectivity is shown in [1] and [2].Bandpass filters using a tuned tapped stub with a varactor to yield reconfigurable transmission zeros and tunable frequency range is presented in [3, 4]. In [5], a stepped impedance resonator is used to control the transmission zero and produce a low insertion loss filter. A wide tuning range is presented by the use of parallel coupled lines in [6]. This technique gives a very good return loss and rejection; however the insertion loss performance is relatively high as it is close to 3dB. Centrally loaded resonators are used to propose tunable passbands [7] for dual bands. Controllable passband frequencies and bandwidths by using a multi-stub loaded resonator with compact size is demonstrated [8] however this design is complex. Multiband tunable filters having good characteristics suitable for modern communication systems are shown in [9, 10]. A varactor tuned open ring resonator is used in [15] to design a tunable bandpass filter with absolute bandwidth.

In [16], a T shaped resonator is also used but without vertical resonators. In this paper, an improved technique for designing the open-ended tapped stub (T-shaped resonator) bandpass filter with compact size and sharp selectivity is presented. As compared with other designs [2, 3], the position of the loaded vertical resonator affects the transmission zero frequency and makes the size more compact. In previous designs using the T-shaped stub, the frequency is changed by increasing the length of the stub from its end. In this design, Vertical resonators are placed across the open-ended stub to change the transmission zero frequency. The introduction of vertical resonators across the open-ended stub results in a change in the characteristics impedance of the shunt stub which thereby affects the frequency at which transmission zero occurs. One pair of T-shaped resonator of the same electrical length is coupled to both sides of the transmission line. Two pairs of vertical resonators are used in the design to show four different frequency states. This design has a very good rejection and low insertion loss of < 2dB, thereby making it a good candidate for multifunctional devices.

2. PROPOSED FILTER DESIGN STRUCTURE

The fundamental structure used in the design is shown in Figure 1. In this structure an indirectly coupled transmission line resonator (λ/2) is tapped at the center by an open-ended stub. The open-ended stub combines with the transmission line resonator to form a T-shaped resonator (λ/4). This open-ended stub forms a shunt which is equivalent to a LC resonator in series which produces a transmission zero. Therefore the transmission zero largely depends on the shunt stub characteristics. To tune the transmission zero the characteristics of the shunt stub would have to be altered.

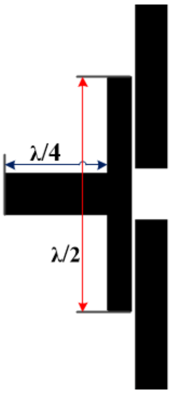


Figure 1. T-shaped bandpass filter

The generalized equation of the design (impedance transforming equation) shows the relationship between the electrical length of stub, characteristics impedance and the frequency (f) at which transmission zero occurs as in Equation (1). Z_0 represents the characteristic impedance of the stubs on both sides of the feedline, θ_0 represents the electrical length of the stub at the given transmission zero. The generalized equation used in the design shows that a change in the effective electrical length Θ_0 of the stub would affect the the frequency f_o at which transmission zero occurs.

$$f_0 = \frac{1}{2\pi z_0 \tan\theta_0} \tag{1}$$

The same dimensions of T-shaped resonator are coupled to both sides of the transmission line. This has minimal effect on the center frequency as can be seen in Figure 2. Figure 2 depicts the comparison of having either one or two T-shaped resonators coupled to the transmission line. This designed can be compared to [12].

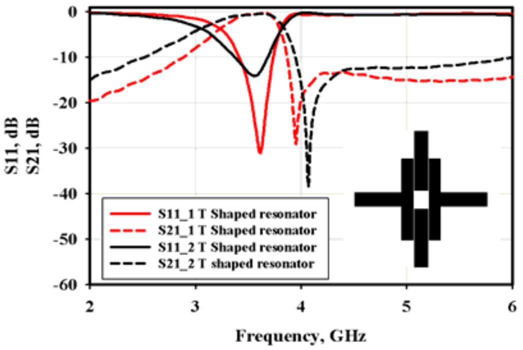
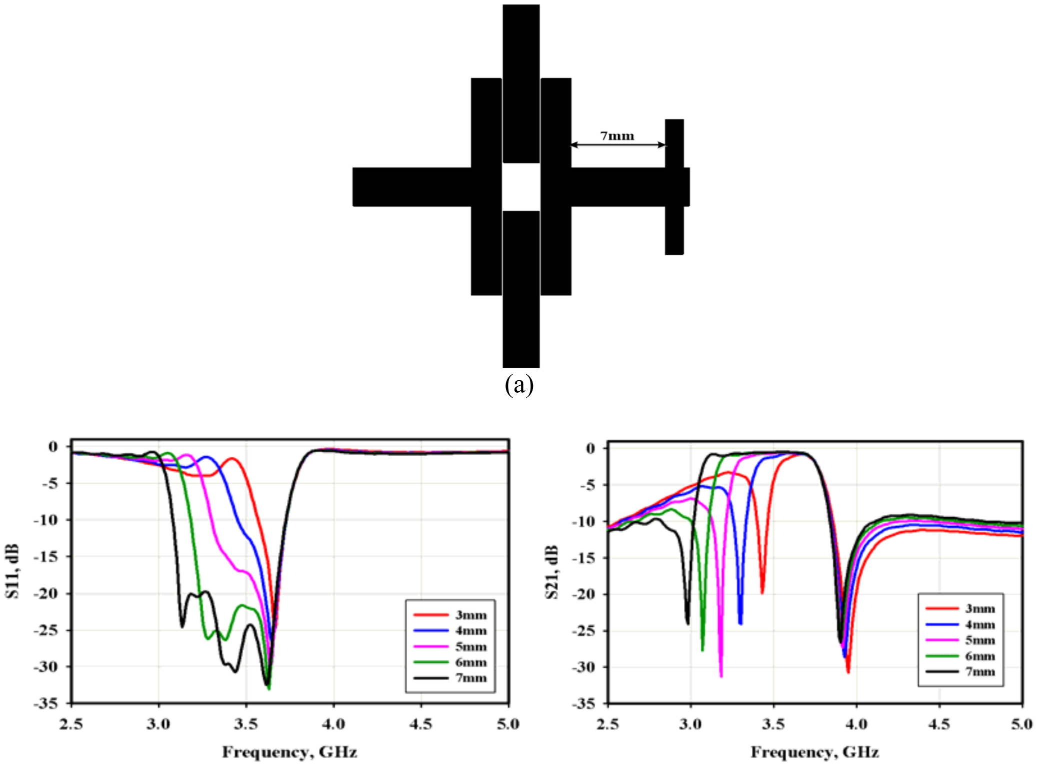


Figure 2. Comparison of one and two T-shaped resonators

By placing vertical resonator across the open-ended resonator, the characteristic impedance of the shunt stub is altered thereby affecting the frequency at which transmission zero occurs. Consequently when the vertical resonator is placed at different distance from the transmission line resonator there is a shift in the frequency at which transmission zero occurs. The shift in frequency of transmission zero is caused by the vertical resonator introducing a new effective resonant length which stops at the vertical resonator position. This is shown in Figure 3. In Figure 3, the vertical resonator is placed between 3mm and 7mm away from the transmission line. As the Stub is placed further away from the transmission line the transmission zero is moved towards the lower frequency.

The vertical resonator produces an effect on the characteristics impedance which acts as a band reject/stop, thereby producing a transmission zero at such frequency of rejection. This behavior gives a bandpass filter effect producing a sharp selectivity at both the lower and upper frequency band. As the frequency of transmission zero is moved, the passband frequency is also changed either to the higher or lower frequency.



(a)

(b) (c)

Figure 3. Parameter sweep showing the effect of Vertical resonator on the open ended stub (a) Structure (b) S11 (c) S21

3. THEORETICAL AND EXPERIMENTAL RESULTS

Figure 4 shows the final design structure after various parametric studies were carried out with vertical resonators placed on both sides of the T-shaped resonator. A pair of the vertical resonator is placed at different lengths on both sides of the indirectly fed line. Each Vertical resonator pair produces a different center frequency while maintaining a sharp rejection which is an important characteristic for filters. Since the vertical resonators affects the frequency at which transmission zero occurs, the center frequency is also affected whenever the transmission zero position changes as in the design.

The bandpass filter is designed using a low cost FR4 board with a dielectric constant of 4.3 and thickness of 1.6mm. The values of the filter dimensions are as follows*: L = 38 mm, W = 34 mm, G = 5 mm, f = 3 mm, dg = 0.2 mm, d1 = 4.8 mm, d2 = 7 mm, u = 22.5 mm, v = 14 mm, s = 4 mm, ds = 10 mm and dw = 1.5 mm*. The center frequency of the T-shaped resonator designed is 3.5 GHz without placing the vertical resonators. By placing one pair of vertical resonators on both sides of the transmission line the effective resonance length of the stub is changed. The vertical resonators are placed in four different states as shown in figure 5 to 8. From the results four (4) states of frequency are obtained. Therefore the frequency can be changed while also altering the transmission zeros.

The vertical stub on the left is labeled L while that on the right is labeled R. By placing a pair of L and R at different length along the stub a specific bandpass frequency is produced. The effective resonance length is altered on both the Left and Right side T-shaped stubs to produce different positions of transmission zeros. The vertical resonators positions are placed in the following dimensions, *State 1; d1 = 3.3 mm and d2 = 5 mm, State 2; d1 = 3.3 mm and d2 = 7 mm, State 3; d1 = 1.3mm and d2 = 5 mm, and State 4; d1 = 1.3 mm and d2 = 7 mm*. Therefore from Figure 5 to 8, it is observed that the Vertical stub position affects the bandpass frequency behavior of the filter.

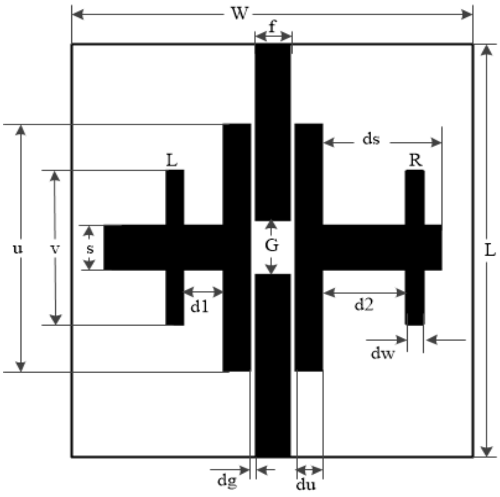


Figure 4. Filter structure

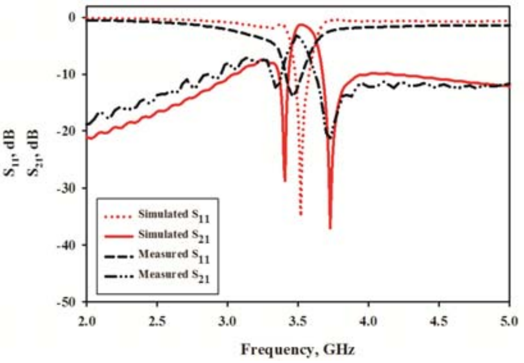


Figure 5. Simulated and Measured state 1 result

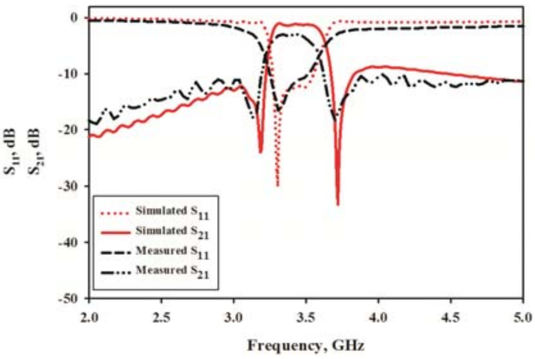


Figure 6. Simulated and Measured state 2 results

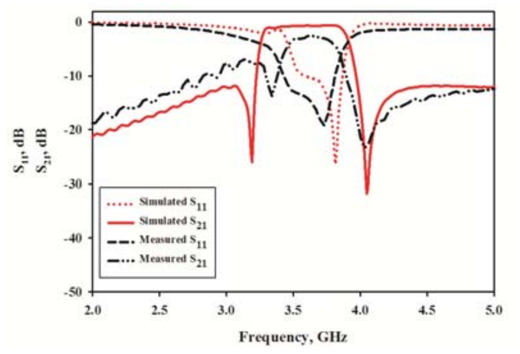


Figure 7. Simulated and Measured state 3 results

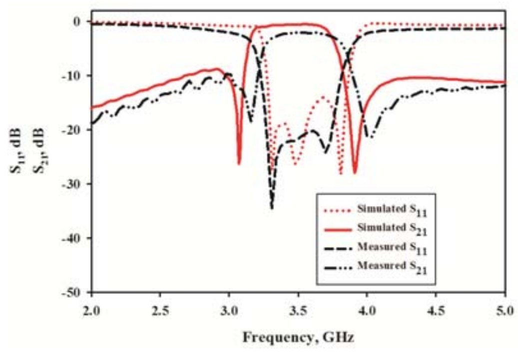
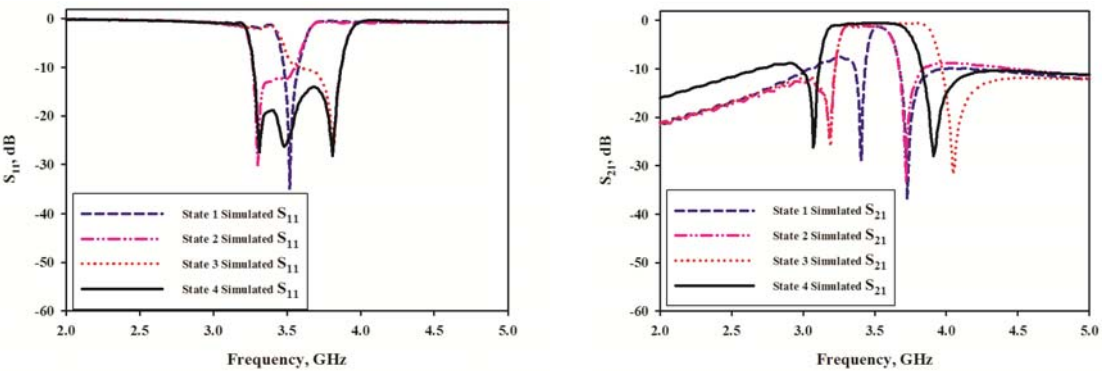
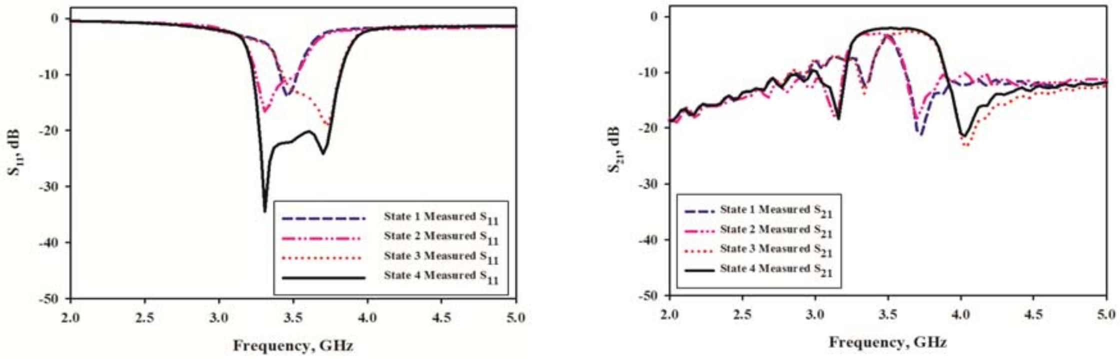


Figure 8. Simulated and Measured state 4 results



(a) (b)

Figure 9. Simulation Results of all states (a) S11 (b) S21



(a) (b)

Figure 10. Measured Results of all states (a) S11 (b) S21

Table 1. Operating Frequency and Bandwidth at different states

	STATE 1		STATE 2		STATE 3		STATE 4	
	Center frequency	Bandwidth	Center frequency	Bandwidth	Center frequency	Bandwidth	Center frequency	Bandwidth
Simulated	3.52	100.1	3.41	288.9	3.67	286.4	3.57	597
Measured	3.47	126.8	3.38	279.2	3.62	393.6	3.52	598

The results were simulated using CST microwave studio and validated through fabrication and measurement in the laboratory. The comparison between the simulated and measured results of each state of the tunable bandpass filter is shown in figure 5 to 8. A plot of both the frequency and transmission zeros are shown. A slight disparity between the simulated and measured results exists as a result of the non-ideal fabrication and measurement process as compared with the simulations. Each filter state is seen to possess a Sharp rejection and low insterion loss. The filter is seen to have a Chebyshev response.

Figure 9 and 10 shows the combined plot in tuning the frequency and transmission zeros of the simulated and measured results respectively. The results are depicted in Table 1. The filter simulation results shown in figure 9 can be tuned to operate at 3.52, 3.41, 3.67 or 3.57 GHz. The measured results in figure 10 can operate at 3.47, 3.38, 3.62 or 3.52GHz respectively. The flexibility of the proposed filter shows it is a good candidate for multifunctional devices where interference with adjacent band is an issue. The fabricated Prototype of the filter is shown in Figure 11.

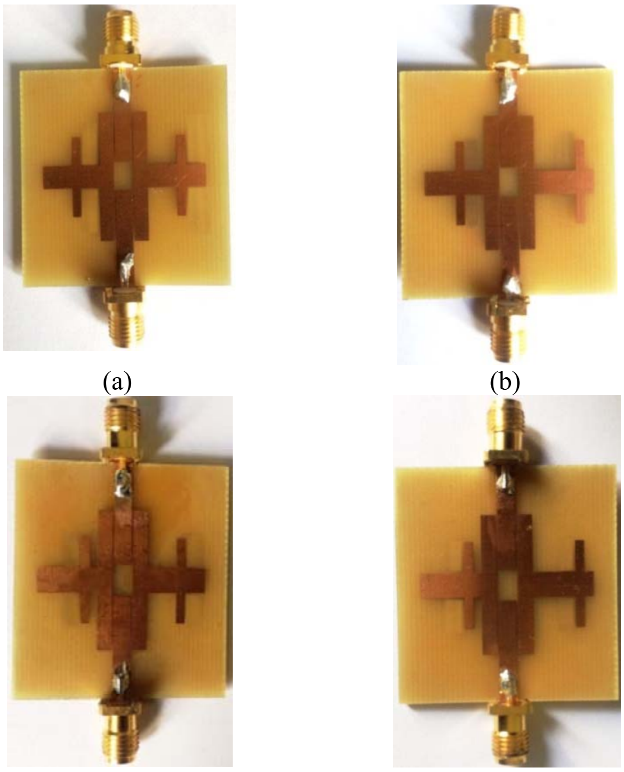

(a) (b)
(c) (d)

Figure 11. Fabricated prototype (a) State 1 (b) State 2 (c) State 3
(d) State 4

4. CONCLUSION

This paper presents a novel way creating the transmission zero of an T-shaped open-ended resonator. The filter consists of a T shaped resonator on parallel sides of the transmission line. The vertical resonators positioned across the open-end affects the frequency at which the transimmion zero occurs. The proposed bandpass filter is designed at four different states to prove the concept . Depending on the position of the vertical resonator, the filter can operate at 3.47, 3.38, 3.62 or 3.52 GHz center frequency. Each state has varying bandwidths while maintaining good filter rejection characteristics. The design is suitable for multifunctional devices which are predominantly available for present day modern communication systems.

ACKNOWLEDGEMENTS

This work is supported by Universiti Teknologi Malaysia, grant reference number: Q.J130000.2623.14J18

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NOOR ASNIZA MURAD obtained her first degree in 2001 from Universiti Teknologi Malaysia (UTM), Malaysia, with Honors, majoring in telecommunication engineering. Shortly after graduated, she joined UTM as a tutor attached to the Department of Radio Communication Engineering (RaCED), Faculty of Electrical Engineering (FKE), UTM. She received her MEng. in 2003 from the same university and later has been appointed as a lecturer in April 2003. She joined Emerging Device Technology Group, University of Birmingham, UK and obtained her Ph.D in 2011 for research on micromachined millimeterwave circuits. Her research interests include antenna design for RF and microwave communication systems, millimeterwave circuits design, and antenna beamforming. Currently, Noor Asniza Murad is a member of IEEE (MIEEE), Member of Antenna and Propagation (AP/MTT/EMC) Malaysia Chapter, and a Senior Lecturer at Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM).