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COMPACT WIDEBAND BANDPASS FILTER USING SINGLE CORNERS-CUT ISOSCELES TRIANGULAR PATCH RESONATOR

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Abstract—Compact and simple bandpass filter (BPF) structure using microstrip isosceles triangular patch resonator (ITPR) is proposed. The new filter design technique is based on two main ideas: Firstly, cutting the corners of the triangular structure, to make the filter size more compact. Secondly, etching slit in staircase form near the base of the triangle, in order to improve the filter performances. The proposed filter was designed and fabricated on Taconic CER-10 substrate with a relative dielectric constant of 10 and a thickness of 0.64 mm using standard photolithography process. The final dimension of the proposed filter is measured at 5.7 mm × 7.6 mm. Measured S-parameters showed that the filter achieves a 3-dB fractional bandwidth of 55% at center frequency of 10.36 GHz, with measured insertion loss of 2.08 dB and measured return loss better than 10 dB. The measured results are in good agreement with the simulated results.

1. INTRODUCTION

Modern wireless communication systems are struggling to overcome new challenges to miniaturize the design of RF/Microwave bandpass filters (BPFs) that are capable to perform well with the lowest possible losses to enhance the systems' performance. Patch resonators have many attractive features for the design of microstrip BPFs, for instance, high average power handling capability, low radiation loss and simple structure. Furthermore, it can be fabricated using simple printed circuit board (PCB) technology and characterizes main

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advantages in RF/Microwave filters like high performance, light weight and low cost.

The use of triangular patch resonators in designing microstrip BPFs was first reported by Hong and Lancaster [1]. Two three-pole microstrip triangular patch resonator filters were demonstrated both theoretically and experimentally. It was shown that by using two different modes of triangular patch resonators, finite-frequency transmission zeros can be implemented on either side of the passband.

Several types of microstrip patch resonators have been proposed and developed in order to achieve the above mentioned demanded characteristics of modern filters using circular patch resonators [2–4], square patch resonator [5, 6], and triangular patch resonator [7–10], as shown in Figs. 1(a)–(c) respectively. A microstrip triangular resonator BPF with transmission zeros and wide-band using fractal-shaped defection is presented in [11]. Simulated results showed that the filter exhibited fractional bandwidth of 48% with maximum insertion and return loss of 0.24 dB and 26.9 dB respectively, at center frequency of 7.6l GHz. However, the overall filter size is still considered large at 195 mm^2.

Another filter reported in [12] is a tunable BPF using microstrip triangular resonator. The filter with a fractal-shaped defection acts as perturbation, whereby the operating frequency and bandwidth can be controlled, and the responses of undesired resonant modes are greatly weakened even suppressed. Yet, the filter has maximum fractional bandwidth of 21% at center frequency of 7.62 GHz. However, the filter occupied an area of nearly 195 mm^2.

Filter size reduction and lower fabrication cost are critical issues in RF/Microwave filters development. Consequently, intensive

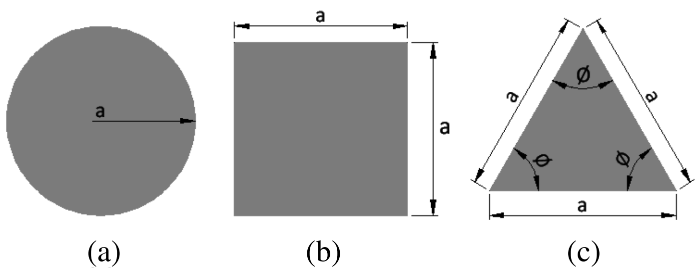


Figure 1. Geometry of some conventional microstrip resonators: (a) circular patch resonator. (b) square patch resonator. (c) equilateral triangular patch resonator.

research efforts have been focused on achieving compact low loss high frequency wideband BPFs using multilayer microstrip configuration. For instance, a wideband BPFs using microstrip hairpin resonator in multilayer configuration are presented in [13, 14]. The filters achieved 44% fractional bandwidth at center frequency of 10.2 GHz. The measured passband insertion loss is less than 2.3 dB and return loss is better than 10 dB. The filter structures are smaller, but yet, the multilayer configuration had complicate the filter design that could lead to more time consuming and higher cost for fabrication.

In this paper, isosceles triangular patch resonator (ITPR) design with corners cut and etched slit in staircase form near the base of the triangle is proposed to achieve miniaturization and improvement of the overall BPF performance offering the lowest possible losses.

2. TRIANGULAR MICROSTRIP PATCH RESONATOR CHARACTERISTICS

The triangular geometry of the microstrip patch resonator, shown in Fig. 2 is an isosceles triangle, which is beneficial for microstrip BPF designs; and has a wide variety of applications in the RF/Microwave systems mainly because of their lower conductor losses, tendency to have strong radiation and simple structure design. There is no exact method to design isosceles triangular shape, however, similar design method for the equilateral one as described in [15] is applied in this study. The proposed filter design is verified both by simulation and measurement.

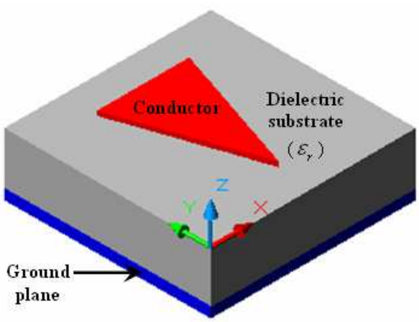


Figure 2. Schematic of triangular microstrip patch resonator.

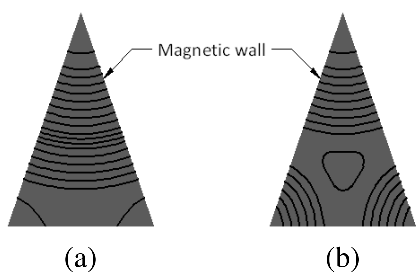


Figure 3. Magnetic field patterns in isosceles triangular microstrip resonator of the first two modes: (a) mode 1 ($\mathrm{tm}_{1,0,-1}$). (b) mode 2 ($\mathrm{tm}_{1,1,-2}$) [15].

Helszajn and James [15] reported a simple and more general expression; theoretical and experimental investigation for the resonant frequencies of electromagnetic field patterns of TM modes of an equilateral triangular microstrip planar resonator. The TM mode field patterns in a microstrip triangular-shaped resonator having no variation of the field patterns along the dielectric thickness of the resonator, are given by [15]:

$$\begin{aligned} E_z(x,y) &= A_{m,n,i}\left\{\cos\left[\left(\frac{2\pi x}{\sqrt{3}b}+\frac{2\pi}{3}\right)i\right]\ \cos\left[\frac{2\pi\,(m-n)\,y}{3b}\right]\right. \\ &\quad +\cos\left[\left(\frac{2\pi x}{\sqrt{3}b}+\frac{2\pi}{3}\right)m\right]\ \cos\left[\frac{2\pi\,(n-i)\,y}{3b}\right] \\ &\quad \left.+\cos\left[\left(\frac{2\pi x}{\sqrt{3}b}+\frac{2\pi}{3}\right)n\right]\ \cos\left[\frac{2\pi\,(i-m)\,y}{3b}\right]\right\} \end{aligned} \tag{1}$$

$$H_x = \frac{j}{\omega\mu_0\mu_r}\frac{\partial E_z}{\partial y} \tag{2}$$

$$H_y = \frac{-j}{\omega\mu_0\mu_r}\frac{\partial E_z}{\partial x} \tag{3}$$

$$H_z = E_x = E_y = 0 \tag{4}$$

where $A_{m,n,i}$ is a constant representing the mode amplitude, b is the effective length of the triangle side, ω is the angular frequency and m, n and i are indexes under condition of $m+n+i=0$, which determine the resonant mode of the triangular resonator and must satisfy the wave equation below:

$$\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+k_{m,n,i}^2\right)E_z = 0 \tag{5}$$

where $k_{m,n,i}$ is the resonance wave-number of an equilateral triangular resonator and it can be written as [15]:

$$k_{m,n,i} = \left(\frac{4\pi}{3b}\right)\left(\sqrt{m^2+mn+n^2}\right) \tag{6}$$

The general formulation for extracting the resonant frequency (f_r) corresponding to the various modes of an equilateral triangular microstrip patch resonator surrounded by perfect magnetic walls is given by [16]:

$$f_{r(m,n,i)} = \frac{ck_{m,n,i}}{2\pi\sqrt{\varepsilon_r}} = \left(\frac{2c}{3b\sqrt{\varepsilon_r}}\right)\left(\sqrt{m^2+mn+n^2}\right) \tag{7}$$

where c is the velocity of light in free space and ε_r is the relative dielectric constant of the substrate. According to Equation (7), there are an infinite number of resonant frequencies corresponding to different field distribution or modes.

For microwave resonator applications, it is desirable to know the field patterns of a relevant resonant mode, which are important and helpful to design the BPF. Fig. 3 shows the magnetic field patterns of the first two modes; fundamental $TM_{1,0,-1}$ mode and next higher order mode, which is the $TM_{1,1,-2}$ mode of equilateral triangular microstrip resonator, which can be obtained when $m = 1$, $n = 0$, $i = -1$, and $m = 1$, $n = 1$, $i = -2$ respectively, [15]. Fig. 4 plots some computed and simulated results of the resonant frequencies of the first two modes of an isosceles triangular microstrip resonator as a function of the vertical height h for a given base a. It can be seen that the resonant frequencies of the fundamental mode $TM_{1,0,-1}$ and the first higher order mode $TM_{1,1,-2}$ are dependent on the vertical height h. Thus, when the vertical height h increases the resonant frequencies decrease and vice versa. As shown in Fig. 4, the simulated resonant frequencies are slightly different from the theory values. The theory values are being calculated without considering the effect of input and output port where the resonator is excited, boundary condition, mesh numbers as well as losses due to the substrate and conductor, whereas in simulation, all of these parameters and more are taken into account to create a virtual environment for the resonator to be as close as the real measurement.

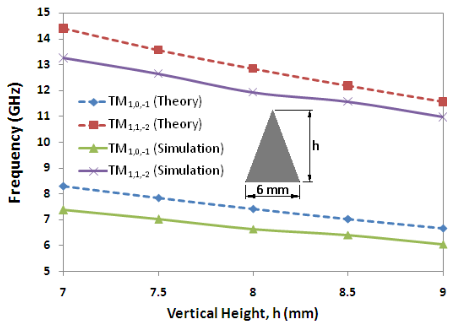


Figure 4. Computed and simulated resonant frequencies of the first two modes of a isosceles triangular microstrip resonator on a 0.64 mm thick dielectric substrate with a relative dielectric constant of 10, and triangular base of $a = 6$ mm.

3. CHARACTERIZATION OF THE PROPOSED FILTER

A BPF with a single microstrip ITPR was being investigated to demonstrate the application of the proposed triangular patch resonator. Cutting a corner of the triangular structure will result in reduction of the filter size and improve its performances in terms of the frequency responses. Fig. 5 shows the proposed design technique where the top of the ITPR triangle is cut with a height $t = 0.97$ mm. The other two corners were cut proportionately to the width of the $50\,\Omega$ microstrip feed lines, which will be attached to both sides of the triangle as it is found to yield the best expected results from simulation.

Accordingly, to meet the filter specifications, the proposed filter uses single microstrip ITPR with etched slit near the base of the triangle, which is used to obtain the best simulation results on the filter performances. Figs. 6 and 7 show the simulated S_{21} magnitude

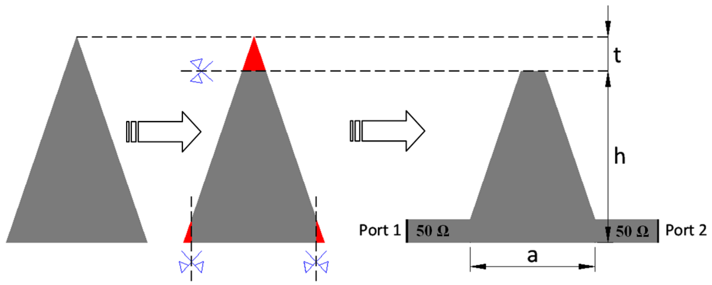
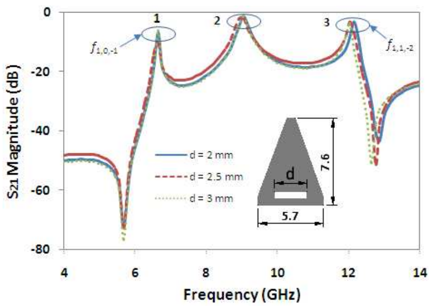


Figure 5. Design methodology of the proposed filter.



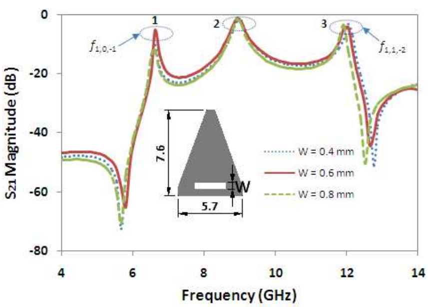


Figure 6. Simulated s_{21} magnitude of the proposed filter in the case of weak coupling, with variation in slit length, d.

Figure 7. Simulated s_{21} magnitude of the proposed filter in the case of weak coupling, with variation in slit width, w.

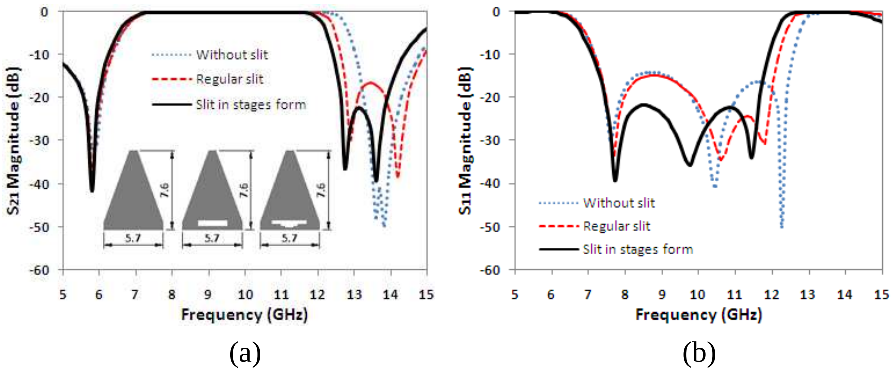


Figure 8. Simulated frequency responses of the proposed filter for three different cases: without slit, with regular slit, and with slit in staircase form: (a) Insertion loss (S_{21}) and (b) Return loss (S_{11}).

of the proposed filter in the case of weak coupling with triangular base of 5.7 mm, vertical height of 7.6 mm, varied etched slit length d, and varied slit width W, respectively. These two figures demonstrate that Equation (7) generates three main resonant modes within the frequency range of 6–14 GHz, which are later verified by an EM simulator [17]. They are $TM_{1,0,-1}$, $TM_{1,1,-2}$, and resonance number 2 (a degenerate mode of $TM_{1,1,-2}$). It is noticed that, the three resonant modes are not affected much by the length and width of the slit.

Figure 8 shows the simulated frequency responses of the proposed filter with fixed vertical height and triangular base for three different cases: without slit, with regular slit, and with slit in staircase form, respectively. It is found that, in the case of slit in staircase form augmented the most improvement of filter performances among the three in terms of passband sharpness and losses. Based on the above discussion, the proposed microstrip ITPR filter with multimode operation can be used to produce a wideband passband with transmission zeros at both sides of passband, if this proposed filter design is properly fed with I/O feed lines.

4. SIMULATED AND MEASURED RESULTS

The proposed filter shown in Fig. 9 was simulated by using CST Microwave Studio [17] to validate the idea. It was then fabricated using standard photolithography process on Taconic CER-10 substrate with dielectric constant $\varepsilon_r = 9$ (this value was obtained from a measurement of the dielectric permittivity of the chosen substrate, and the value

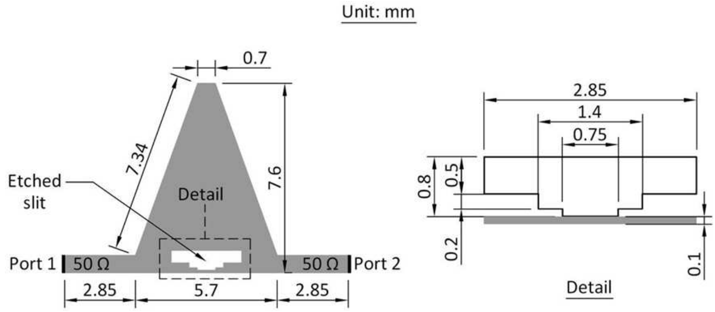


Figure 9. Geometry and dimensions of the proposed filter.

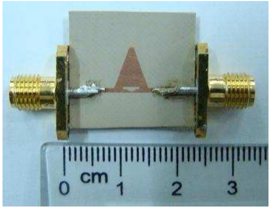


Figure 10. Photograph of the fabricated filter.

is still within the tolerance range given by the data sheet in [18]), thickness of 0.64 mm, and substrate loss of $\tan\delta = 0.0035$. Referring to the analysis made in the previous section, specifically shown in Fig. 8, the new filter design utilized etched slit in the staircase form near the base of the triangle to improve the filter performances. The photo of the fabricated filter prototype is presented in Fig. 10, where the etched slit in staircase form can be seen.

The experimental measurements were carried out using Anritsu 37347D vector network analyzer and results are depicted in Fig. 11. As Fig. 11 demonstrates, there are three transmission zeros in the stopband at these locations: 6.22 GHz, 14.08 GHz, and 15.34 GHz. The measured fractional bandwidth is approximately 55% at center frequency of 10.36 GHz, the minimum insertion loss is about 2.08 dB, and the return loss is greater than 10 dB. The existence of loss is mainly due to the substrate, conductor, and radiation losses. The simulated frequency responses show that the centre frequency is 10.2 GHz for the passband, whereas the measured centre frequency is slightly shifted by 0.16 GHz. The slight difference in the simulated frequency responses compared to the measured ones are caused by the fabrication tolerance and mismatch between the feed lines and

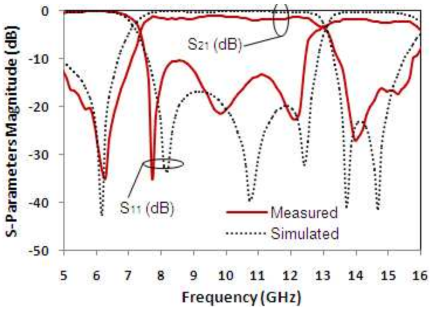


Figure 11. Performance of the proposed filter based on the structure of Fig. 9.

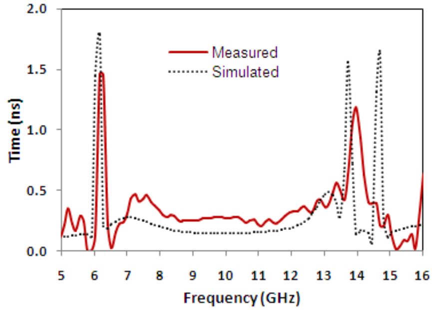


Figure 12. Measured and simulated group delay.

SMA connectors. Nonetheless, in terms of passband bandwidth, the simulated and measured responses agree well with each other. Fig. 12 shows the simulated and measured group delay which is stable across the passband.

Lately, there are researches proved that the size of the filters can be greatly reduced by using multilayer technology but here, the size of the proposed single layered ITPR wideband filter amounts to 5.7 mm $\times$ 7.6 mm, which indicates that this size is very compact. Compared to the single layer filters reported in [11] and [12], the proposed filter is more than 50% smaller in surface area. This new filter also leads to size reduction of 12% with respect to the multilayer filter reported in [14] at the same center frequency, with transmission zeros on both sides of the passband.

5. CONCLUSION

A simple, flexible, and efficient design method of BPF is presented — using a single ITPR with corners cut and etched slit in order to characterize main advantages demanded in RF/Microwave filters: (1) compact size is achievable without coupling gaps, which is usually unavoidable; (2) lower insertion loss and better return loss (e.g., compared to the filters reported in [13, 14] at the same center frequency); (3) attractive design; only, at lower cost. It is suitable for RF/Microwave circuit application, which operates in X-band like radar application systems.

REFERENCES

1. Hong, J.-S. and M. J. Lancaster, "Microstrip triangular patch resonator filters," *IEEE MTT-S Dig.*, Vol. 1, 331–334, 2000.
2. Li, J. L., J. X. Chen, J. P. Wang, et al., "Dual-mode microstrip bandpass filter using circular patch resonator with two transmission zeros," *Microwave and Optical Technology Letters*, Vol. 46, No. 1, 28–30, 2005.
3. Weng, M.-H. and H.-D. Hsueh, "A novel compact dual-mode circular-patch bandpass filter with improved second spurious response," *Microwave and Optical Technology Letters*, Vol. 47, No. 3, 203–206, 2005.
4. Singh, Y. K. and A. Chakrabarty, "Miniaturized dual-mode circular patch bandpass filters with wide harmonic separation," *IEEE Microwave and Wireless Components Letters*, Vol. 18, No. 9, 584–586, 2008.
5. Xiao, J. K., S. P. Li, and Y. Li, "Novel planar bandpass filters using single patch resonators with corner cuts," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 11, 1481–1493, 2006.
6. Wang, J., H. Zhang, L.-X. Ma, and H.-Y. Xu, "Study on two compact CPW-FED bandpass filters using dual-mode patch resonator," *Progress In Electromagnetics Research C*, Vol. 1, 55–61, 2008.
7. Wang, X., W. Ji, and Y. Li, "Microstrip bandpass filter using one single patch resonator with two transmission zeros," *Electronics Letters*, Vol. 39, No. 77, 1255–1256, 2003.
8. Hong, J. S. and S. Li, "Theory and experiment of dual-mode microstrip triangular-patch resonators and filters," *IEEE Trans. Microwave Theory and Techniques*, Vol. 52, No. 4, 1237–1243, 2004.
9. Lugo, C. and J. Papapolymerou, "Bandpass filter design using a microstrip triangular loop resonator with dual-mode operation," *IEEE Microwave and Wireless Components Letters*, Vol. 15, No. 7, 475–477, 2005.
10. Liu, H. W., Z. Q. Cheng, and L. L. Sun, "Dual-mode triangular-patch bandpass filter using spur-lines," *Electronics Letters*, Vol. 42, No. 13, 762–763, 2006.
11. Xiao, J.-K., Q.-X. Chu, and S. Zhang, "Novel microstrip triangular resonator bandpass filter with transmission zeros and wide bands using fractal-shaped defection," *Progress In Electromagnetics Research*, Vol. 77, 343–356, 2007.

12. Xiao, J.-K., "Triangular resonator bandpass filter with tunable operation," *Progress In Electromagnetics Research Letters*, Vol. 2, 167–176, 2008.
13. Adam, H., A. Ismail, M. A. Mahdi, M. S. Razalli, A. R. H. Alhawari, and B. K. Esfeh, "X-band miniaturized wideband bandpass filter utilizing multilayered microstrip hairpin resonator," *Progress In Electromagnetics Research*, Vol. 93, 177–188, 2009.
14. Adam, H., A. Ismail, M. A. Mahdi, and A. R. H. Alhawari, "Compact wideband bandpass filter using hybrid hairpin and half wave parallel coupled resonator in multilayer microstrip configuration for X-band application," *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 14–15, 1855–1865, 2009.
15. Helszajn, J. and D. S. James, "Planar triangular resonators with magnetic walls," *IEEE Trans. Microwave Theory and Techniques*, Vol. 26, No. 2, 95–100, 1978.
16. Bahl, I. J. and P. Bhartia, *Microstrip Antennas*, 143–144, Artech House, USA, 1982.
17. Computer Simulation Technology (CST) Microwave Studio, Version 2006B.
18. Taconic advanced dielectric division: http://www.taconic-add.com.