Microstrip Dual Mode Multi-bandpass Filters Based on Tree Fractal Slotted Resonator for Wireless Communication

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ABSTRACT

Dual mode microstrip multi-bandpass filter is proposed with tree fractal slot on a square patch resonator. The tree fractal slotted resonators are generated from conventional square patch using an iterative tree fractal generator method. A single square patch is used for realizing both dual and tri-bandpass filters exploiting the dominant, higher order and its corresponding degenerate resonant modes by the tree fractal iteration on the diagonal unequal slots on the square patch.The resonant peaks, transmission zeros and bandwidth of the pass bands can be tuned by varying the length and width of the fractal slot. By optimizing various parameters dual mode dual and tri-band pass filters are simulated, fabricated and measured. The proposed filter finds application in wireless communication devices and falls in the bands of GSM, WLAN, Bluetooth, Zigbee, WiMax and WiFi.

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1. INTRODUCTION

Wireless communication applications necessitate the deployment of transceivers in radio frequency range with enhanced performance, compactness, low weight, and multiband characteristics. Microwave filters are inevitable part of radio frequency transceivers which play a key role in effectively transmitting the desired signals in certain pass-band regions while attenuating all the undesired signals in the remaining regions. The major techniques used in the design of microwave filters are presented by Ralph Levy et al in [1]. The recent advances of novel materials and fabrication technologies have simulated the rapid development and use of microstrip and other filters [2]. R.N Baral et al reported several techniques and initiatives made for improved response and enhanced performance of microwave planar filters [3].

A patch resonator is characterized by infinite number of resonant frequencies corresponding to different modes [4]. Dual mode multiband filters can be realized by coupling the resonant and its corresponding degenerate modes. Usually the degenerate modes of the square resonator are excited and coupled using orthogonal feed lines and in addition to any of the methods like crossed slots, shorting pin, addition of patches and corner patch cuts [4].

Various dual mode bandpass microstrip filters with orthogonal feeding and unequal diagonal cross slots acting as perturbation element for the patch, have been reported in [5-7]. In [8, 9] the detailed study of the coupling between degenerate modes are well explained for a microstrip loop resonator. S.Shen et al presented how compactness is achieved by the increased path length created by the slots over the patch and reducing the resonant frequency to a lower side in [10]. A dual band filter with size reduction using cross slotted patch and square etched slot for a dual mode bandpass filter is reported by Min-Hang Weng et al in [11]. In [12], Kenneth S. K et al realized a dual-band bandpass filter by coupling each of the shunt resonators with an additional identical shunt resonator through a J-inverter. In various systems stepped impedance filters are reported for dual band applications [13-14]. Dual-band bandpass filter using stub-loaded resonator in which even-mode resonant frequency can be conveniently tuned is explained in [15]. Open loop ring resonator and a folded coupled line resonators are also alternatives for bandpass filter design [16].

Fractals are geometries having self-similarity and space filling properties with non-integer dimension. Fractal geometry is generated in an iterative fashion, leading to self-structure. These unique properties combined with electromagnetic theory finds applications in fractal electrodynamics [17]. Self-similarity property of fractal geometries can be successfully applied to the design of multi-band filters while the space-filling property can be utilized for miniaturization. In fractal structures each sub-section has the characteristics of the whole structure in a smaller scale [18]. A dual mode T- square fractal dual band bandpass filter which uses shorting pin as perturbation element is reported in [19].Jian-Kang Xiao et al reported a single trapezoidal patch bandpass filter incorporating fractal defection slots for realizing a single wide band, dual-band and tri-band dual mode behavior [20]. A left handed multiband metamaterial with tree fractal structure is presented by Xu He-Xiu et al in [21]. Dual mode compact bandpass filters based on patch, ring and semi fractal CSRR structures are reported in [22-27].

This paper presents a tree fractal slotted square patch resonator exciting the dominant and higher order modes. Tree fractal is a simple fractal structure which provides flexibility in tuning the resonant peaks, transmission zeros and bandwidth of the pass bands of the filter designed. Not all slotted fractal structures on a patch excites higher order and its degenerate modes but it is easily achieved by increasing the iteration levels of tree fractal slot on the same patch. Dual and tri-bandpass responses are generated by increasing the fractal iteration on the same structure without additional coupling or added structures as used for realizing multiband filter. Each resonator act as doubly tuned resonant circuit and the number of resonators needed for designing an nth order filter is reduced by half.

2. RESEARCH METHOD

2.1 Tree Fractal Generation Process

The schematics showing the generation process of the tree fractal structure is given in Figure 1.The procedure to create a tree fractal starts off with a line of length L and width d as in Figure 1(a) which acts as the generator. At the first level of iteration, the length L is divided into three equal segments. A line segment with one third of the length L is introduced perpendicular to the initial line L at the first point of division and also a segment with the same length is positioned at the second point of division, again perpendicular to the initial line L but in the opposite direction. Fig 1(b) depicts the structure after first iteration. This forms the basic step for the formation of the tree fractal. Fractal dimension D is given by

$$D = \frac{\log(N)}{\log(r)} \tag{1}$$

where N is the number of self-similar line segments after each iteration level and r is the scaling factor [28-29]. After the first level iteration there are five equal line segments. In the consecutive iteration process, each segment is considered as the initial line segment and following the same procedure will attain the second iterated structure as in Fig 1(c).Further the third level iteration results in the fractal structure as shown in Fig 1 (d).

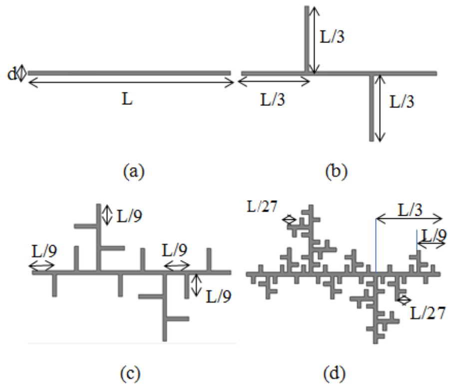


Figure 1. Schematics of the formation of the tree fractal geometry (a) generator (b) first level iteration (c) second level iteration (d) third level iteration

2.2 Dual Mode Square Patch Resonator

The orthogonal feed lines along with unequal diagonal slots with length c and g and width of the slots, d mm will perturb the symmetry of a square patch and excite degenerate modes [5, 10]. The perturbation to the symmetry of the patch resonator splits the resonant frequency into two close frequencies. The field distributions of the dominant and its degenerate mode are no longer orthogonal and the modes couple each other [19]. Such a conventional dual mode square patch filter is given in Figure 2(a)[5]. Fig 2(b) gives the coupling structure for the conventional dual mode filter in which R and R” denotes the resonators corresponding to the dominant and its degenerate mode respectively.

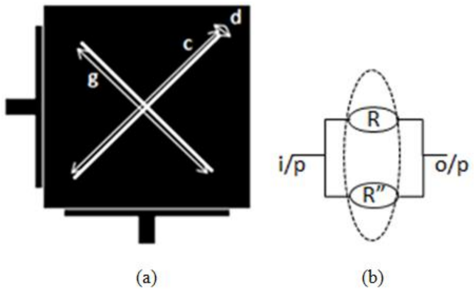


Figure 2 (a) Layout of the conventional dual mode filter (b) Coupling structure for the conventional dual mode filter.

The electromagnetic fields in the square patch resonator can be explained in terms of TM^{Z}_{mn0} modes [4] with Z perpendicular to the ground plane. The resonant frequency of the cavity is given as

$$fmn_0 = \frac{c}{2\Pi\sqrt{\mu_r \varepsilon_r}}\sqrt{(\frac{m\pi}{a})^2 + (\frac{n\pi}{b})^2} \quad (2)$$

where a and b are the sides of the square patch resonator. ε_r is the dielectric constant of the substrate used. Square patch resonator supports fundamental degenerate modes TM_{100} and TM_{010} and an infinite number of higher order modes. For a square geometry every mode is degenerate, having same resonant frequencies [4].

The simulated s-parameter characteristics for the filter with varying g and d values are shown in Figures from 3(a-c). The depth of the mode splitting increases as difference between the length of two slots increases [5]. As the slot width d increases the resonant frequency shifts to the lower end. The increased length seen by the electric current causes a leftward shift or reduction in the resonant frequency. Figure 3(d) gives the simulated surface current distribution of the conventional dual mode filter at 2.3 GHz. The current density is equal and opposite throughout both vertical and horizontal directions [5].

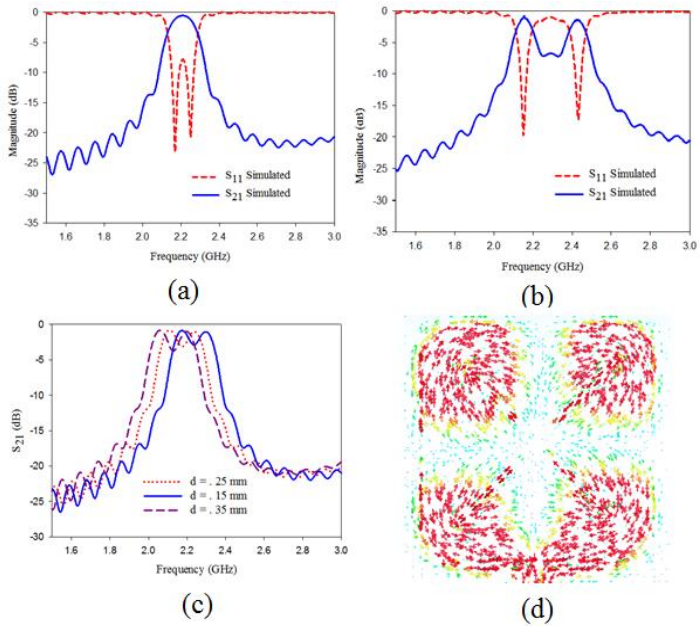


Figure 3. (a) Simulated s-parameter plot for c = 30 mm g = 28 mm and d = 0.2 mm (b) Simulated S parameter plot for c = 30 mm and g =25 mm and d = 0.2 mm (c) Simulated S_{21} plot for d = 0.15 mm, 0.25 mm, 0.35 mm (d) Surface current distribution of the conventional dual mode filter at 2.3 GHz.

3. RESULTS AND DISCUSSION

3.1 Tree Fractal Dual Mode Dual Bandpass Filter

Tree fractal iteration performing on the diagonal slots, excites and couples the higher order and its corresponding degenerate modes. First level tree fractal iteration was introduced only on slot c. Slot g is placed diagonal to slot c. The proposed bandpass filter for dual band operation is depicted in Figure 4(a) and the coupling structure is plotted in Figure 4(b). The ith resonator which is corresponding to the i^{th} mode is denoted by R_i, and i^{th} degenerate mode is R_i” for i = 1, 2. The first pass band is introduced by the coupling of the resonators R_1 and R_1” and the second pass band is introduced by the coupling of the resonators R_2 and R_2”.

From the S_{11} and S_{21} simulated results shown in Figure 5(a) and 5(b), it is evident that the dominant, first higher order and their corresponding degenerate modes are excited for g values 28 mm and 25 mm with slot c length of 30 mm. As the difference in the length of c and g slots increases, the perturbation to the symmetry of patch increases allowing a wider split between the resonant peaks of the coupled modes. Measured S parameters can be observed from Figure 5 (c - d).Table 1 gives the performance of the dual band filters. To verify the design all the proposed filters are fabricated on RT/Duroid 5880 substrate having a relative dielectric constant of 2.2. The surface current distribution for the filter at 4.2 GHz is given in Figure 6(a).The current flow indicates that first level tree fractal iteration introduces an increase in the electrical length of the current path compared to Figure 3(d).The photograph of the fabricated dual band filter is shown in figure 6(b).

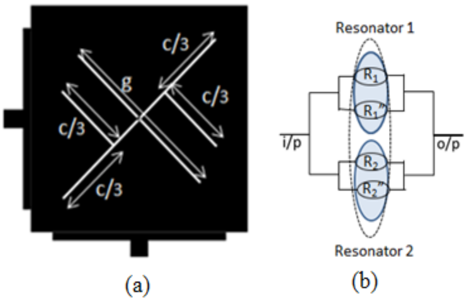


Figure 4(a)Layout of the dual mode dual bandpass filter (b)Coupling structure of the dual mode dual bandpass filter.

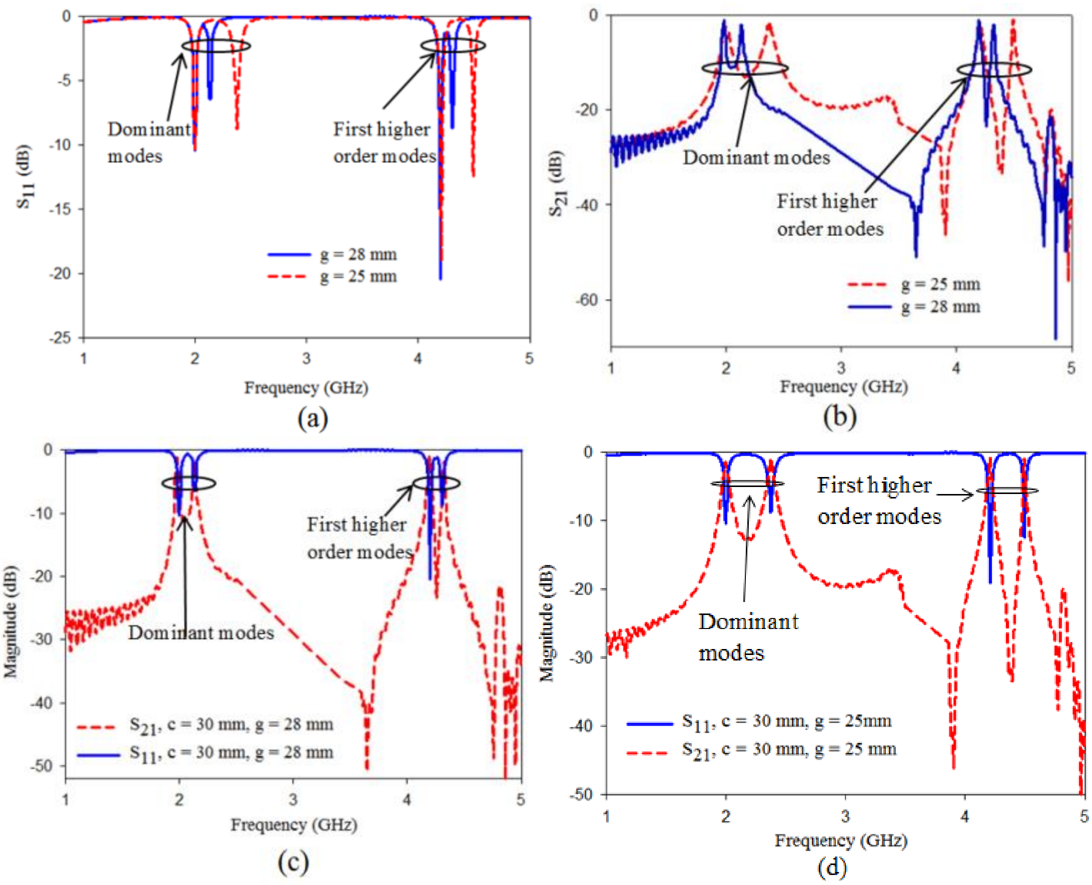
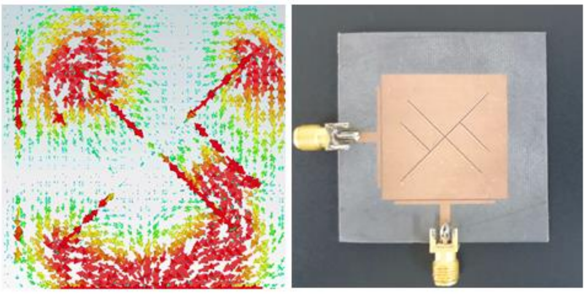


Figure 5(a) Simulated S_{11} plot of the filter for varying values of g (b) Simulated S_{21} plot of the filter for varying values of g (c) Measured S parameters for the filter with c = 30 mm, g = 28 mm, d = 0.2 mm (d) Measured S parameters for the filter with c = 30 mm, g = 25 mm, d = 0.2 mm.

Table 1. Measured parameters for the dual band filters.

Performance Parameters	Transmission Bands (GHz)	Resonances (GHz)	Insertion Loss (dB)	Return Loss (dB)	Transmission Zeros between pass bands (GHz)
Filter1- c = 30 mm g = 28 mm d= 0.2 mm	Band 1: 1.97 - 2.14 Band 2: 4.18 - 4.32	1.97, 2.23 4.19, 4.30	0.71, 1.20 0.60, 1.32	10.49, 9.01 20.56, 9.73	Band 1 & 2: 3.64
Filter2- c = 30 mm g = 25 mm d = 0.2 mm	Band 1: 1.97 – 2.44 Band 2: 4.17 – 4.51	1.99, 2.40 4.20, 4.49	0.86, 1.02 0.71, 0.87	10.55, 9.08 19.25, 12.32	Band 1 & 2: 3.89

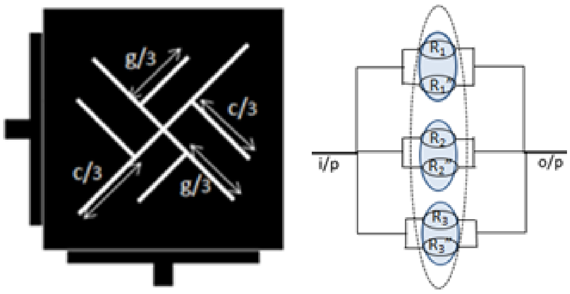


(a) (b)

Figure 6(a) Surface current distributions of the dual band filter at 4.2 GHz (b) Prototype of the dual band filter.

3.2 Dual Mode Tri-Band Bandpass Filter

In the tri band filter, first level tree fractal iteration is carried out for both the slots c and g. The structure of the filter is given in Figure 7(a) and the coupling structure is shown in Figure 7(b). From the S_{11} and S_{21} simulation plots in Figure 8(a) and 8(b), the dominant, first and second higher order mode splits can be observed for c = 30 mm and for varying g values of 28 mm and 25 mm with slot width d = 0.2 mm.The fractal extension of slot g and c exploits the higher order modes. The measured magnitude responses for length c = 30 mm, d = 0.2 mm and for g values 28 mm, 25 mm is given in Figure 8(c) and 8(d) respectively. By optimizing the filter for the required bands for WLAN, WiMAX, Bluetooth and Zigbee, the filter parameters are set for c = 30 mm, g = 22 mm and d = 0.2 mm and measured magnitudes are given in figure 8(e).



(a) (b)

Figure7 (a) Layout of the first level iterated tri-band bandpass filter (b) Coupling structure of the tri-band filter.

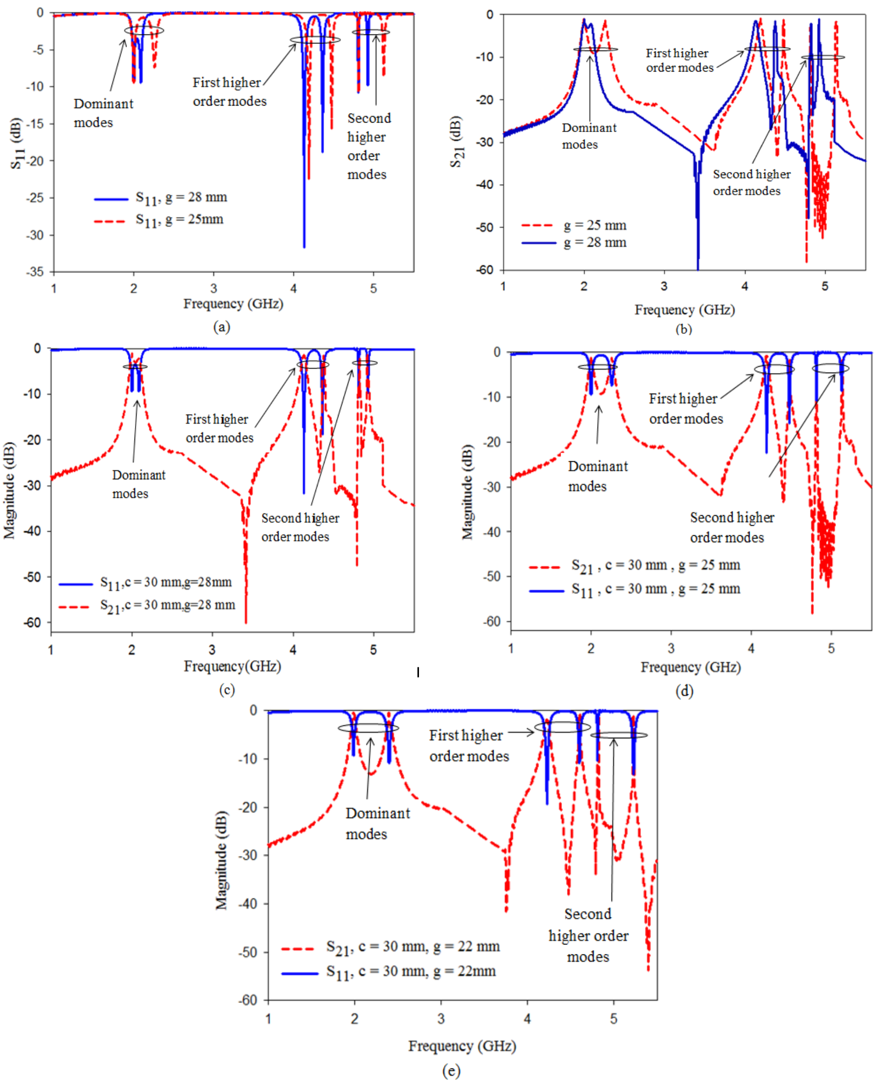


Figure 8(a) Simulated S_{11} plot of the filter for varying values of g (b) Simulated S_{21} plot of the filter for varying values of g (c) Measured S parameters for the filter with g = 28 mm (d) Measured S parameters for the filter with g = 25 mm (e) Measured S parameters for the filter with g = 22mm.

Table 2. Performance of the tri-band filters.

Performance Parameters / Tri-band Filters	Transmission Bands (GHz)	Resonances (GHz)	Insertion Loss (dB)	Return Loss (dB)	Transmission Zeros between pass bands (GHz)
Filter1- c = 30 mm	Band 1: 1.97 - 2.10	1.98, 2.08	0.80, 0.81	9.89, 9.86	Band 1 & 2: 3.04
g = 28 mm	Band 2: 4.09 – 4.38	4.13, 4.36	1.02, 1.10	31.9, 19.03	Band 2 & 3: 4.78
d= 0.2 mm	Band 3: 4.80 – 4.94	4.82, 4.92	1.32, 1.08	11.01, 10.20	
Filter2- c = 30 mm	Band 1: 1.97 – 2.27	1.99, 2.25	0.90, 0.98	10.01, 9.03	Band 1 & 2: 3.64
g = 25 mm	Band 2: 4.10 – 4.48	4.19, 4.41	0.54, 1.12	22.2, 15.85	Band 2 & 3: 4.77
d = 0.2 mm	Band 3: 4.79 – 5.14	4.80, 5.11	0.82, 0.92	10.7, 9.56	
Filter3- c = 30 mm	Band 1: 1.97 – 2.43	1.98, 2.41	0.33, 0.33	10.01, 10.9	Band 1 & 2: 3.76
g = 22 mm	Band 2: 4.18 - 4.62	4.22, 4.61	1.01, 0.69	19.2, 10.9	Band 2 & 3: 4.78
d = 0.2 mm	Band 3: 4.80 - 5.38	4.81, 5.30	0.93.0.86	10.7, 13.8	

The measured values for the parameters of the tri-band filters with varying g values are given in Table 2. From the tabulated measurements and the plots it is evident that for each transmission band there is a pair of resonances. The bandwidth of each transmission band, location of transmission zeros between the pass bands, insertion and return losses at three pass bands vary according to the parameter g. All the filters possess good insertion losses better than 1.32 dB and good return losses. Figure 9 shows the relation between the resonant frequency and the length of slot g. The plot reveals that for the decrease in the length of slot g from 28 mm to 22 mm, the coupling between the modes increases and we can observe a larger splitting between the resonant peaks. As the value of g decreases, the difference between length c and g increases, and correspondingly the depth of perturbation to symmetry of the filter structure increases causing modes to split apart further. Surface current distribution of the first level iterated filter at 4.9 GHz is as shown in figure 10(a) and the photograph of the filter is given in 10(b). The layout of the second and third level iterations on the slots, results in tri-band filter structures as shown in Figure 11 (a) and (b) respectively.

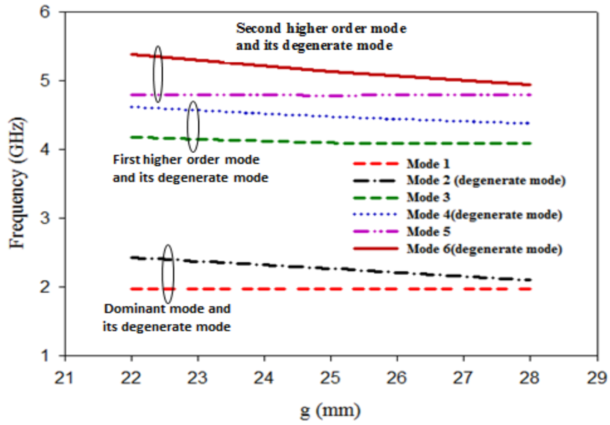


Figure 9. Relationship between resonant frequency and parameter g for c = 30 mm and d = 0.2 mm.

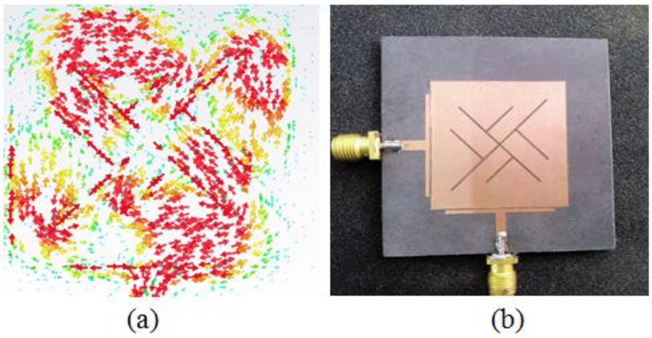


Figure 10 (a) Surface current distributions of first level iterated tri-band filter at 4.9 GHz
(b) Prototype of the first level iterated tri-band filter.

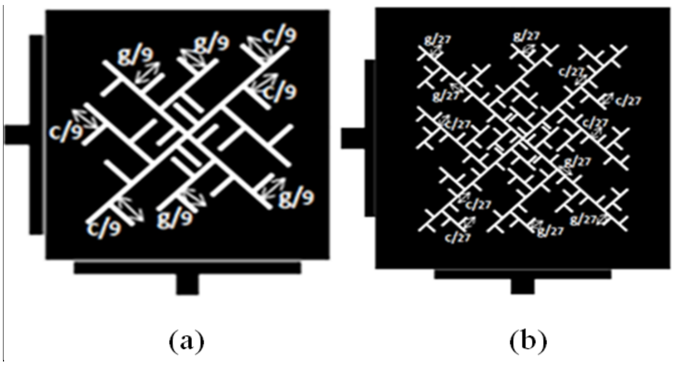
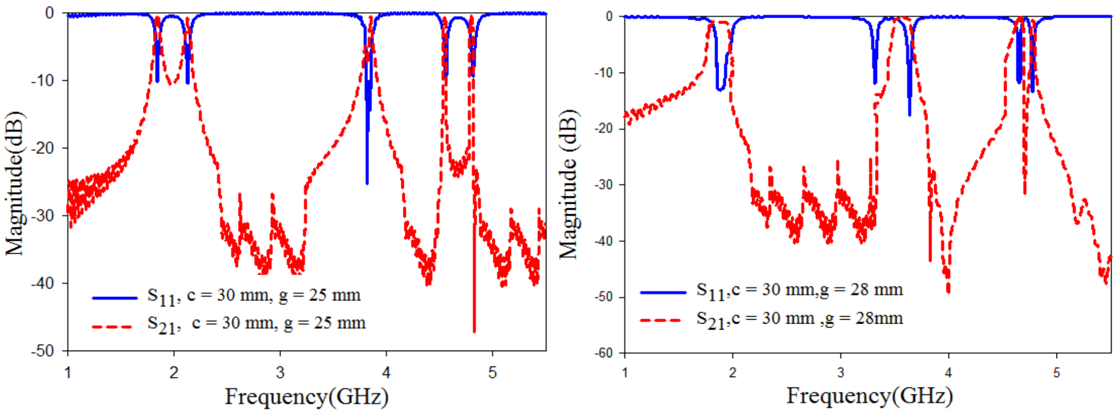


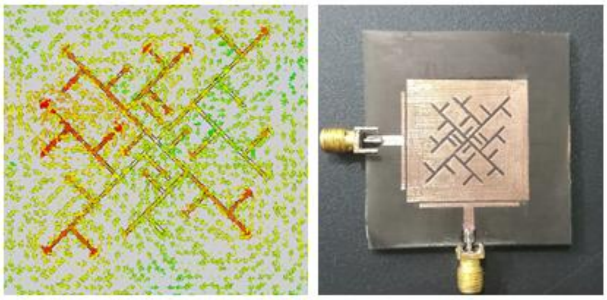
Figure 11. Layout of the tri-band dual mode bandpass filter (a) Second level iteration (b) third level iteration

The magnitude responses for the second and third level iterated tree fractal tri-band filters, optimized for frequency bands suitable for wireless communication applications are shown in Figure 12(a) and (b) respectively. From figure 12(a), the three pass bands are of 340 MHz having fractional bandwith 17.2% centered at 1.97 GHz, 100 MHz about 2.6% centered at 3.8 GHz and 290 MHz about 6.4% centered at 4.6 GHz. The frequency, at which the excited modes resonates shift further to the lower frequency side as the area of the tree fractal slot increases further for the second iteration level compared to first level. As shown in Figure 12(b), the S_{21} response gives three considerable pass band response of 230 MHz about 12.2% centered at 1.87 GHz, 190 MHz about 5.3% centered at 3.5 GHz and 210 MHz about 4.46% centered at 4.7 GHz. Insertion losses are better than .57 dB and return losses greater than 10 dB for both the filters. Increasing the level of iteration and varying the g value results in tri-band filters with controllable bandwidth and passband resonant peaks. Figure 13(a) depicts the surface current distributions for the second level iterated tri-band tree fractal filter at 4.6 GHz and 13(b) shows the second level iterated tri-band filter prototype. Figure 14(a) shows the surface current distributions for the third level iterated tri-band tree fractal filter at 4.7 GHz and 14(b) shows the photograph of the corresponding filter prototype.



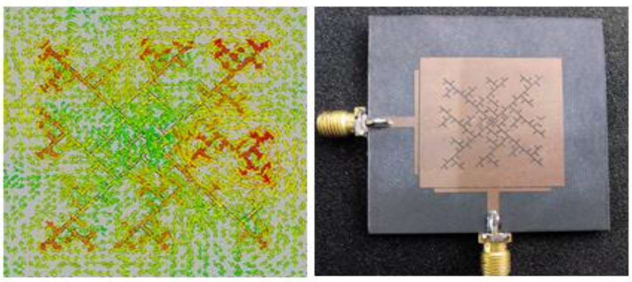
(a) (b)

Figure 12 (a)Measured S parameters for the filter with c =30 mm, g = 25 mm and d = 0.2 mm for second level iterated tree fractal tri-band filter (b) Measured S parameters of the filter with c =30 mm, g = 28 mm and d = .2 mm for third level iterated tree fractal tri-band filter.



(a) (b)

Figure 13. (a) Surface current distributions on the second level iterated tri-band filter at 4.6 GHz (b) Prototype of the second level iterated tri-band filter.



(a) (b)

Figure 14. (a) Surface current distributions on the third level iterated tri-band filter at 4.7 GHz (b) Prototype of the third level iterated tri-band filter.

Table 3 gives the comparison of the proposed work with similar works reported. Not all fractal slotted structures on patches excites higher order modes.In [24] the third iteration Greek-cross fractal sections will give only a single pass band while the proposed work results in tripple pass bands .The increase in iteration level of the tree fractal slot shifts the resonant peaks to the lower frequency side, implies the property of miniaturization which is not obtained in [20], [24] and [27]. The proposed filter exhibits good insertion and return losses in the three pass bands in comparison to the other reported works.

Table 3. Comparison of proposed work with existing works

Ref	Fractal Slot	Iteration Level	Pass Band Center Freq (GHz)	Side Length of the patch (mm)	No of Pass Bands
[20]	Trapezoidal Defection		3.73, 6.72, 10.2	12	Tripple
[22]	Sierpinski	2nd	5.4, 9.05	9	Dual
[24]	Greek-cross	3 rd	1.65	19.2	Single
[27]	Koch Fractal	2nd	2.4	10.18	Single
This Work	Tree Fractal	3rd	1.87, 3.5, 4.7	28	Tripple

4. CONCLUSIONS

A novel single square patch filter based on tree fractal slot is designed, analyzed and measured for dual-mode, dual and tri-band responses. As otherwise needed for realizing multiband filters, the proposed multiband filter is simple without coupling gaps between various structures. The pass band frequency, transmission zeros and fractional bandwidths of the filter are controllable by varying the parameters g and d at various levels of tree fractal iterations for meeting the design requirements.The simulated and measured responses are in good agreement and the filter finds application in various wireless communication systems which fall in the frequency bands of GSM, Wi-Fi, WLAN, Wi-Max, Zigbee and Bluetooth.

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