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Design of Microstrip Filtering Antenna for 5G band and LTE Applications

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ABSTRACT- A filtering antenna is a type of antenna that not only receives or transmits electromagnetic signals but also filters out unwanted frequencies or interference. It combines the functions of an antenna and a filter, typically a bandpass filter, to only allow specific frequency ranges to pass through while rejecting others. The goal of the current work is to design a Snow flake-Koch fractal microstrip filtering antenna to operate at 2.1GHz and 4.98GHz for 2.1GHz band 5Gn1 LTE Applications and Wi-Fi applications. Better impedance bandwidth is by optimizing the shape of the patch using snow flake fractal up to 2nd iteration. To achieve the filtering characteristics to utilize the proposed design at mentioned applications a Stepped Impedance Resonator (SIR) band pass filter is used with appropriate dimensions. The 10dB return loss bandwidth of the proposed design is 11%, with the maximum gain values of 2.4dB and 2.08dB. It is observed that there is very good agreement between the simulated results and measured results.

General Terms: Microstrip Antenna, LTE, Wi-Fi, Impedance Bandwidth, Return Loss.

Keywords: Triangular patch, Snow flake-Koch fractal, Stepped Impedance Resonator filter, Filtering antenna.

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1. INTRODUCTION

We ask that authors follow some simple guidelines. In essence, we ask you to make your paper look exactly like this document. The easiest way to do this is simply to download the template, and replace the content with your own material. Microstrip antennas are very good choice for many wireless applications due to its planar structure. These are very easy to integrate on VLSI circuit boards [1]. Broad band and multi band antennas play a major role in electromagnetic applications as single antenna can serve many applications which reduces the overall size of the hardware [2]. Fractal geometries are very much useful to achieve the wideband and multi band operations because of their space filling geometries [3]. Fractal antennas are a kind of antenna configuration that makes use of patterns that repeat in a self-similar manner, showing similar structures and traits across various scales to enhance their functionality, especially in aspects like frequency range and shrinkage in size [4]. These complex repeating patterns allow fractal antennas to operate over a wide bandwidth of frequencies and provide better performance in areas such as impedance matching, efficiency in radiating energy, and control over the direction of the radiation [5]. Various fractal geometries are available in the literature like, Sierpinski geometry [6], Koch fractal geometry [7], Minkowski geometry [8], Mandelbrot geometry [9], Hilbert curve geometry [10] and Peano curve geometry [11] used to achieve wideband characteristics. These geometries increase the design complexity and also increases the measured losses. A simple Snow flake-Koch fractal geometry is used due to its simple structure.

To achieve the frequency selective characteristics from the operating band an RF microwave filter should be attached for the microstrip antennas. Many filtering design methods are proposed in the recent literature like filter synthesis approach [17], Substrate Integrated waveguide structures [18-20], defected microstrip structure [21], defected ground structures [22]. These tunable antennas use Radio-Frequency (RF) switches, mechanical actuators and active components like PIN diodes [23], RF-MEMS [24-25] and varactor diodes [26] into the design to achieve frequency tunability. However, due to the involvement of these active elements increases the overall cost and extra circuitry increases the size of the antennas [27]. In recent years, several tunable microstrip BPFs have been introduced to design a compact, efficient, and reconfigurable planar filters with a wide tuning. These are very useful since they may be printed directly on the dielectric substrate

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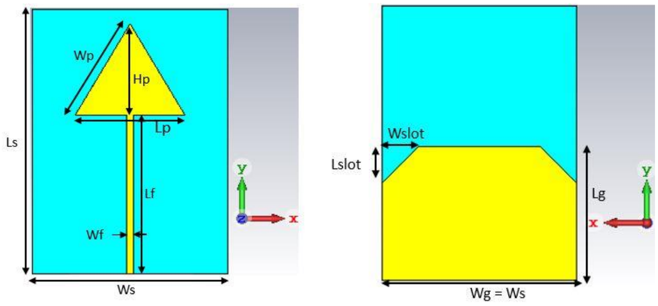
materials. There is no need of designing the microstrip antenna and filter separately rather, the filter is joined directly to the patch resulting in more compact structures and improving the entire performance of the RF and MW systems.

In this article, to achieve the tunable characteristics without increasing the fabrication losses and system size a 2nd order SIR filter is integrated with the radiating element. The proposed antenna is very compact and useful for 2.1GHz band 5G LTE applications. It is implemented on low cost FR4 substrate with dielectric 4.4, tanδ of 0.002 having height 1.6mm. The filtering antenna simulated by CSTMWS software and measured using MS2037C vector network analyser to verify the validity of simulated results.

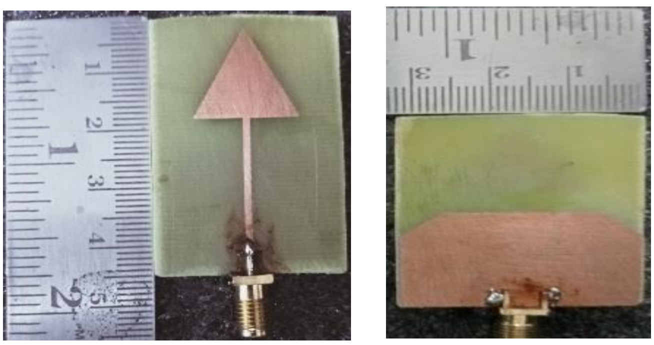
2. FILTERING ANTENNA DESIGN

2.1 Triangular Patch Antenna Design

Microstrip antennas are preferred due to the planar structure and compact size. The triangular shaped patch is chosen triangular to reduce the unnecessary metallization and which leads to surface wave propagation. The triangular patch is implemented on low cost FR4 substrate with dielectric constant 4.4 and tanδ=0.0025 having the dimensions of 45×32×1.6〖mm〗^3. The defected ground structure (DGS) is implemented on the bottom side of the substrate having dimension of 22×32〖mm〗^2. The right angle triangular shaped slots are etched from the rectangular shaped DGS.



(a) Simulated Design



(b) Fabricated Design

Figure 1. Geometry of the proposed triangular patch microstrip patch antenna

Table 1. The dimensions of the proposed triangular microstrip patch antenna

S. No	Dimension	Value (mm)
1.	Ws	32
2.	Ls	45
3.	Lf	27
4.	Wf	1
5.	Lp	16
6.	Wp	22.6
7.	Hp	16
8.	Wg	32
9.	Wslot	6
10.	Lslot	6
11.	Lg	22

The geometry of the proposed simulated and fabricated triangular shaped microstrip patch antenna is depicted in *figure 1* and the dimensions are tabulated in *Table 1*. The simulated and measured S_{11} values of the proposed triangular microstrip antenna is shown in *figure 2*. There is very good agreement is observed between the simulated and measured values.

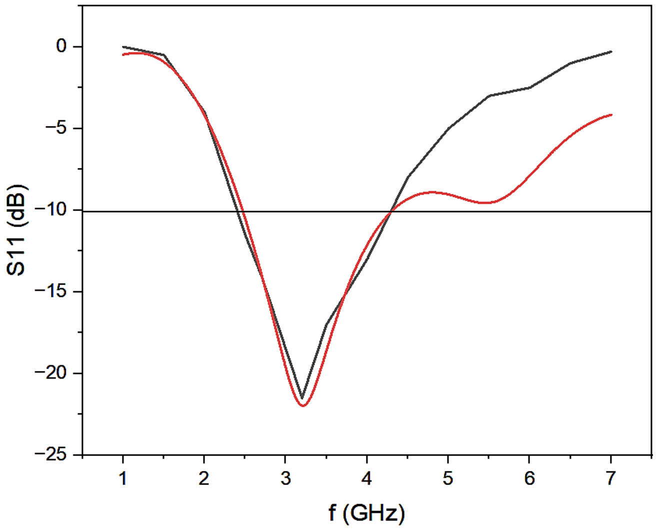


Figure 2. Simulated and measured S_{11} plot of the triangular patch microstrip antenna

The S_{11} plots indicate that the proposed antenna is operating at 3.2GHz with operating bandwidth of 1.8GHz spanning from 2.4GHz-4.32GHz. This proposed design is well suited for Wi-Max applications. The simualted and measured VSWR plot of the proposed triangular antenna is shown in *figure 3*. From the plot it is observed that VSWR<2 for the entire operating frequency *i.e.*, 2.4GHz-4.32GHz band.

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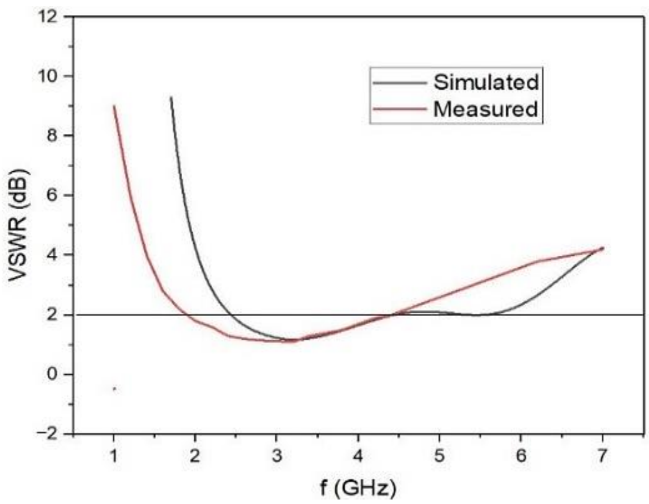


Figure 3. Simulated and measured VSWR plot of the tringular patch microstrip antenna

The far-field directivity plot of the proposed triangular patch microstrip antenna is shown in *figure 4*. The peak diectivity of 2.17dB is achieved at 3.1GHz.

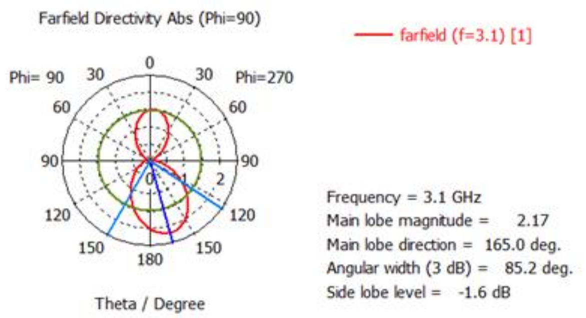


Figure 4. Directivity plot of the triangular patch microstrip antenna

2.2 Design of Fractal Patch

To increase the operating bandwidth the proposed design implemented with snow flake fractal structure. The Snowflake-Koch fractal can be constructed using mathematical equations. The equilateral triangle with each side length is (L) and considered it as 0th iteration. For 1st iteration, divide each side into 3 equal parts (L/3). Replace the middle segment with two segments of lengths L/3, forming an equilateral triangle and follow the same procedure for remaining two sides of the n triangle. Repeat the same procedure for further iterations. The Snowflake-Koch fractal geometry up to 2nd iteration is shown in *figure 5*. The 2nd order fractal optimized patch is fabricated to compare the performance of the proposed antenna. The simulated and fabricated designs of 2nd order fractal patch design is depicted in *figure 6*.

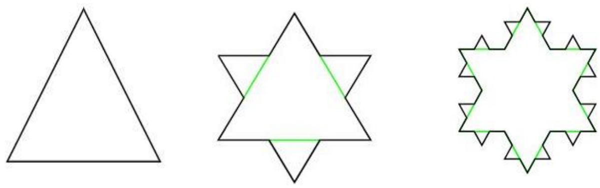
$$\text{Let } V_0(X) = X \text{ (0}^{th}\text{ iteration)} \quad (1)$$

$$V_1(X) = (1/3)\, X + (1/3) \text{ (1}^{st}\text{ iteration)} \quad (2)$$

$$V_2(X) = (1/9)\, X + (2/9) + (1/9)\, X \text{ (2}^{nd}\text{ iteration)} \quad (3)$$

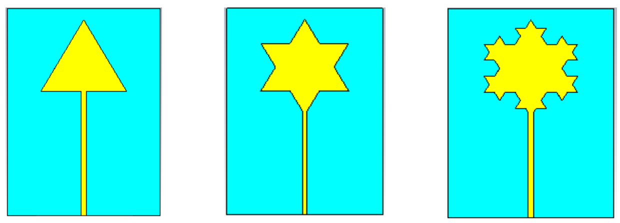
$$\ldots\ldots$$

$$V_n(X) = (1/3)^n\, X + \ldots \text{ (n}^{th}\text{ iteration)} \quad (4)$$



0th Iteration 1st Iteration 2nd Iteration

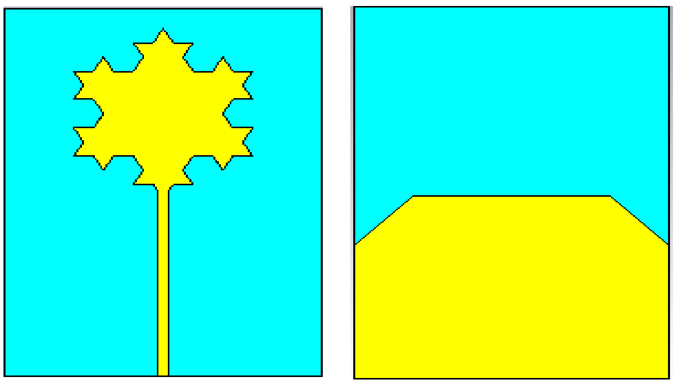
(a) Snowflake-Koch fractal iteration geometries



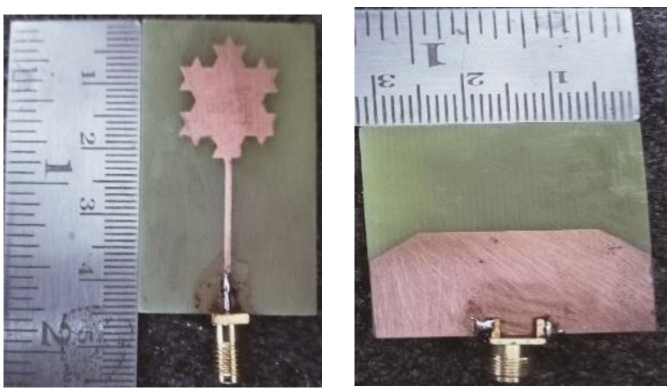
0th iteration 1st iteration 2nd iteration

(b) Simulated geometries

Figure 5. Simulated stages of fractal antenna up to 2 iterations



(a) Simulated Design



(b) Fabricated fractal antenna

Figure 6. Simulated and fabricated prototype of the fractal antenna

The comparison of the S_{11} plots for each iteration from 0th to 2nd is shown in *figure 7*. From the plot is clearly observed that for 2nd iteration wide band of operation is achieved with minimum S_{11} of -43.17dB at 5.19GHz. The bandwidth achieved is 4.48GHz with operating frequency from 2.41GHz -6.9GHz band.

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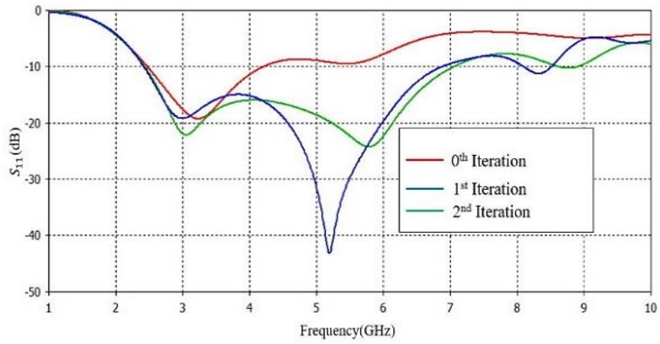


Figure 7. Comparison of S_{11} plots for 0th -2nd iteration of the fractal microstrip antenna

The simulated and measured S_{11} plot of the proposed fractal microstrip antenna is shown in *figure 8*. *Figure 9* shows the predicted and measured VSWR plot of the proposed fractal antenna.

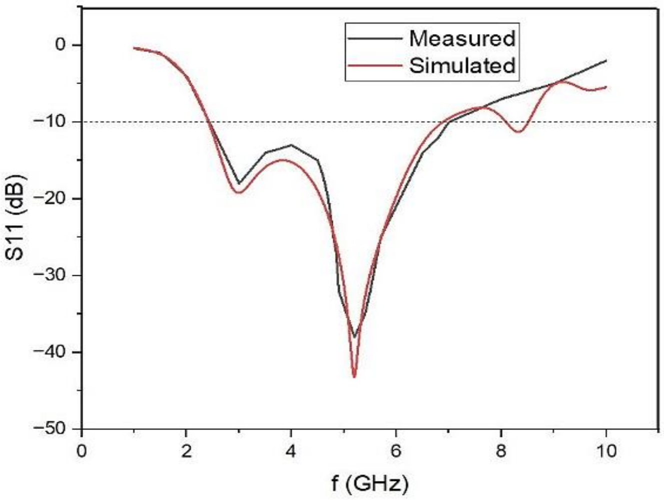


Figure 8. The simulated & measured S_{11} plot of the fractal microstrip antenna

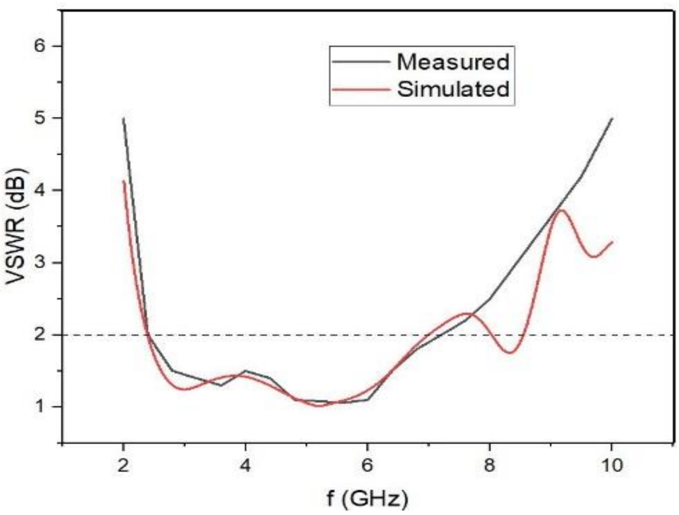


Figure 9. The simulated & measured VSWR plot of the fractal microstrip antenna

From the plots it is observed that there is very good agreement between the simulated and measured results. The far-field 3D radiation pattern of the 2nd iterated fractal antenna is shown in *figure 10*. From the plot it is clearly observed that 2.17dB of peak directivity is achieved at 5.19GHz.

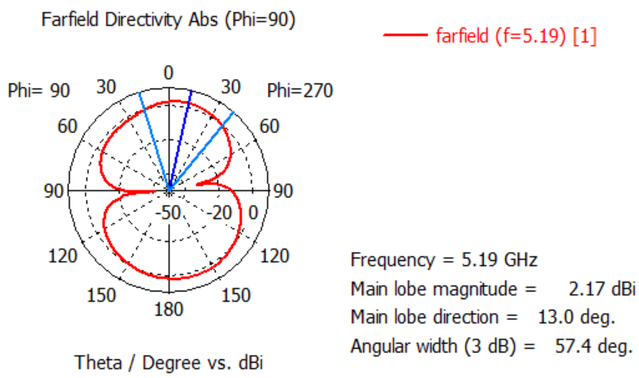


Figure 10. 3D-far field radiation plot of the proposed fractal microstrip antenna

2.3 Filtering Antenna Design

To achieve the filtering characteristics in the operating frequency the Stepped Impedance Resonator (SIR) filter is designed and implemented with fractal antenna. The structural design of the SIR filter is shown in *figure 11*. Stepped Impedance Resonator (SIR) can be considered as two transmission lines of different lengths and characteristic impedance.

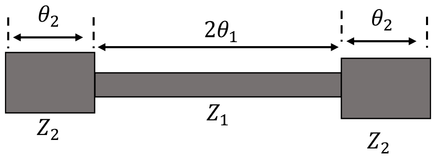


Figure 11. The structural design of the SIR filter

Its design parameters are controlled by both length and impedance ratio. The current density along the transmission line can be controlled by the alternating segments of high and low characteristics impedance lines. The condition of resonance for SIR signal is given by

$$\frac{Z_2}{Z_1} = \tan\beta_1 l_1 \tan\beta_2 l_2 = K \quad (5)$$

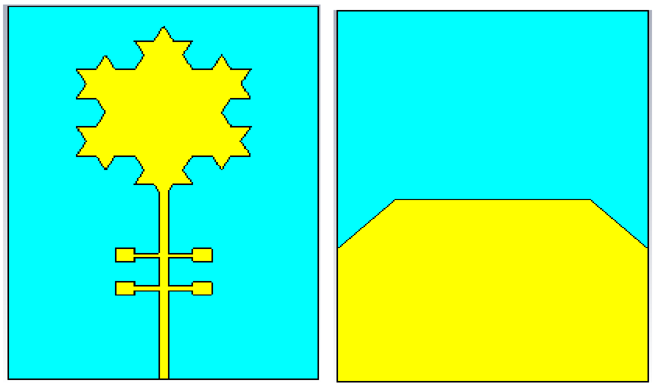
$$K = \frac{\tan\theta_1 * (\tan\theta_T - \tan\theta_1)}{1 + \tan\theta_T \tan\theta_1} \quad (6)$$

$$\theta_1 = \beta_1 l_1 \quad (7)$$

$$\theta_T = \theta_1 + \theta_2 \quad (8)$$

$$\theta_2 = \theta_1 = \tan^{-1}\left(\frac{2\sqrt{K}}{1-K}\right) \quad (9)$$

Where Z_1 is the impedance of narrow section, Z_2 is the impedance of wider section and θ_1 and θ_2 are the electric lengths of narrow and wider sections having characteristic impedance Z_1 and Z_2 the total electrical length θ_T of the transmission line.



(a) Simulated design

(b) Fabricated design

Figure 12. Simulated & Fabricated filtering microstrip antenna

The simulated and fabricated microstrip filtering antenna in depicted in *figure 12*. The SIR filter is connected to the feed line of the microstrip antenna. Initially 1st order SIR filter is connected to select one frequency band from the entire operating band. Further, one more filter is added to select one more frequency band. The S_{11} characteristics of the 1st order SIR filtering antenna and 2nd order filter is shown in *figure 13*.

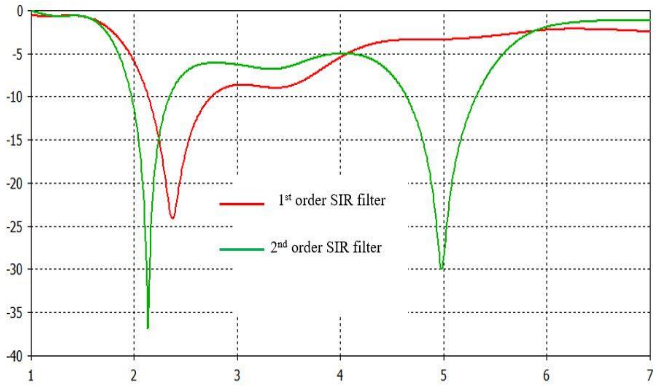


Figure 13: S_{11} plot of the 1st & 2nd order filtering antenna

The simulated and measured S_{11} plot of the proposed filtering microstrip antenna is shown in *figure14*. From the *figure 14* it is clearly observed that frequency selectivity is achieved due to SIR filter. Due to the 1st order filter 2.1GHz-2.76GHz band is selecting from the entire operating band of fractal antenna *i.e.*, from 2.41GHz-6.9GHz.

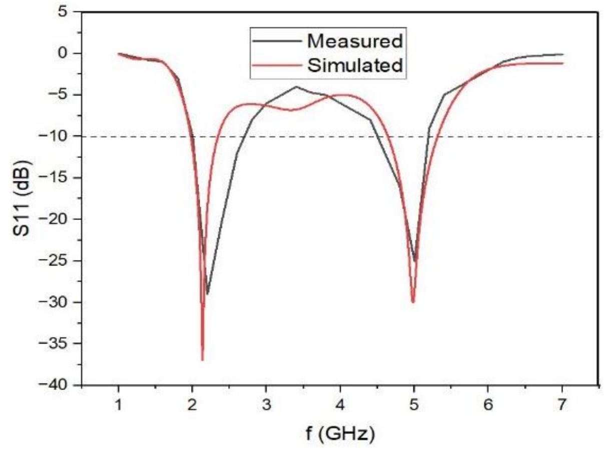


Figure 14. Simulated & measured S_{11} plot of the 2nd order filtering antenna

The bandwidth offered is 619MHz. Another frequency is selected by incorporating 2nd order SIR filter 4.63GHz-5.31GHz band is selected along with the previous band. The bandwidth offered is 681MHz.

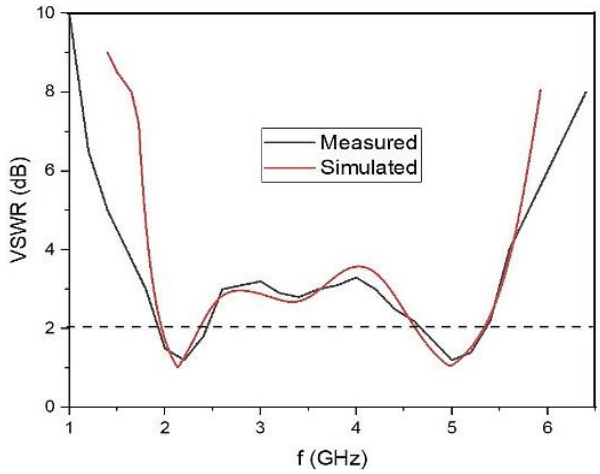
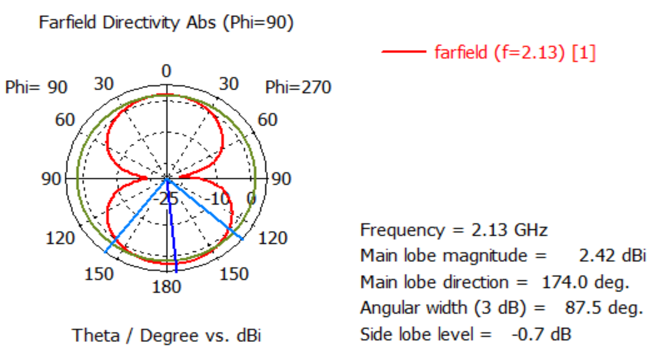
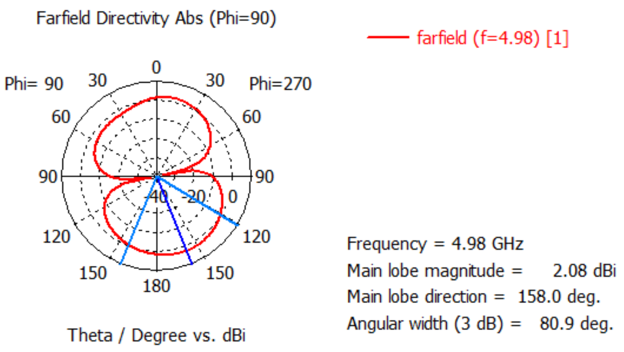


Figure 15. Simulated & measured VSWR plot of the filtering antenna

The comparisson of simualted and measured VSWR plot of the proposed filtering antenna is shown in *figure 15*. The VSWR < 2 at both frequency bands. The far-field radiation patterns of the filtering antenna are shown in *figure 16*. The directivity of 2.42dBi and 2.08dBi is achieved at 2.13GHz and 4.98GHz respectivily.



(a) At 2.13GHz



(b) At 4.98GHz

Figure 16. farfiled directivity plot of filtering antenna

Table 2 summarizes and compare the current work with other works.

Table 2. Comparison of proposed work with some recent works

S. No	Overall Size (mm^3)	UWB coverage (GHz)	Selected bands (GHz)
[12]	27 × 30 × 1.6	2 to 7.65	2.6; 3.5; 4.2; 4.5; 5; 5.5
[13]	58 × 66 × 1.6	2.1 to 10.6	2.47; 3.8; 5.36
[15]	29 × 34 × 1.5	1.2 to 8	1.8; 2.1; 2.2; 2.4; 2.6; 3.5; 4;5
[17]	40 × 50 × 1.6	1.1 to 5.7	1.8; 2.1; 2.4
[21]	58×48×1.6	2 to 6	2.3, 2.4, 2.5
[26]	39 × 37 ×1.6	2 to7	2.45, 3, 5.2
Current work	32 × 45 × 1.6	2.1-6.9	1.8 to 2.12, 5.78 to 5.95

3. CONCLUSION

The proposed fractal filtering antenna provides better frequency selectivity with less circuit complexity. Good agreement is observed between simulated and measured results. The proposed filtering antenna provides moderate gain and good directivity at both the operating frequencies. The sharp pass bans and stop bands are observed due to the SIR filter. Both the frequency bands are well suited for both Wi-Fi and 5Gn1 LTE applications. Small variations in the results are observed due to the small imperfections in the hardware design. This work may be extended in future for triple band and multiple bands also by increasing the order of the SIR filter.

Conflicts of Interest: "The authors declare no conflict of interest"

5. ACKNOWLEDGMENTS

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