Quad Band Split Koch Snowflake Antenna for LTE/WLAN/WiMAX Applications

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Abstract— In this paper, Multiple Split Koch Snowflake Fractal is investigated as resonating element. It was found to resonate at 0.77–0.82 GHz, 2.3–2.42 GHz, 3.6–3.7 GHz and 5.3–6 GHz with center frequency of 0.8 GHz, 2.35 GHz, 3.65 GHz and 5.5 GHz which covers the LTE/WLAN/WiMAX spectrum. The antenna was realized on a FR4 epoxy substrate with dimension $0.08\lambda_o \times 0.08\lambda o \times 0.042\lambda_o$ (30 mm × 30 mm × 1.6 mm). Parametric analysis was performed on the dimension of various elements of the antenna. Fractal structure was responsible for multiband resonance and the addition of split element in the fractal enhanced the ability of the antenna to resonate at lower frequency. Further the antenna was fabricated and tested.

1. INTRODUCTION

Developing an Antenna system has always been a challenging task. Recent trends in wireless communication demands a compact low profile antenna resonating at multiple frequency bands. This has resulted in the development of many multiband antennas for portable devices.

WiMAX is a standard set under IEEE 802.16 family for wireless communication providing high speed data rates for fixed stations. The IEEE 802.11 a/b/g/n/ac (2.4 & 5.2 GHz) and also known as WLAN has been utilized extensively to provide wireless service over a specified area [1]. Long term evolution which is popularly known as 4G LTE is the latest technology in wireless standards providing very high data rates for portable devices on the go. LTE TDD (Band 44 703–803 MHZ) which is a subset of LTE where the uplink and downlink shares same frequency but only time multiplexed is yet to be fully exploited.

The increase in number of antennas in portable wireless devices goes hand in hand with the number of frequency bands allocated for its use, while the volume may remain the same or reduced. This has a serious consequence of reduced antenna efficiency, data rates and coverage [2]. One of the possible solutions to these problems is to use frequency reconfigurable antenna [3, 4]. A recent survey carried on various mobile phones has revealed that PIFA and Monopole are widely used antennas to achieve multiband resonance [5]. Structures like fractals, metamaterials are yet to be implemented on these devices to achieve multiband operation at compact size.

Metamaterials have recently been dealt with great enthusiasm as part of the antenna to achieve miniaturization [6, 7]. These materials exhibit negative refractive index due to simultaneous negative permittivity and permeability. A Fractal is a mathematical set which exhibits self-similarity at every scale. Fractal as antennas has been dealt with similar enthusiasm as metamaterials to achieve multiband resonance [8, 9].

In this paper, the proposed antenna structure is inspired from split ring resonator (SRR) which is a metamaterial and 1st iteration of Koch snowflake fractal.

2. ANTENNA DESIGN

The geometry and the dimension of proposed antenna is shown in the Fig. 1. The antenna is realized on a fr4 epoxy substrate ($\varepsilon_r = 4.4$) with loss tangent of 0.02 at a standard thickness of 1.6 mm. The substrate dimension is 30 mm × 30 mm × 1.6 mm. It is excited using a normal microstrip line feed technique.

2.1. Microstrip Patch

It consists of three Koch snowflakes of first iteration with gradual increase in perimeter. The Koch snowflake fractals has split element. Each Koch fractal is of the thickness 0.5 mm with split element of width 0.4 mm is separated by a distance of 2 mm. The width of the transmission line is tapered to improve the impedance matching [10]. At the feed point, the width of the transmission line is $wf = 1.5$ mm. $wl1 = 1.2$ mm, $wl2 = 0.96$ mm.

2.2. Ground Plane

The ground plane consists of a protruding structure of length 13.63 mm. The protruding element is of the width 2.5 mm and displaced slightly to the left w.r.t center of the substrate.

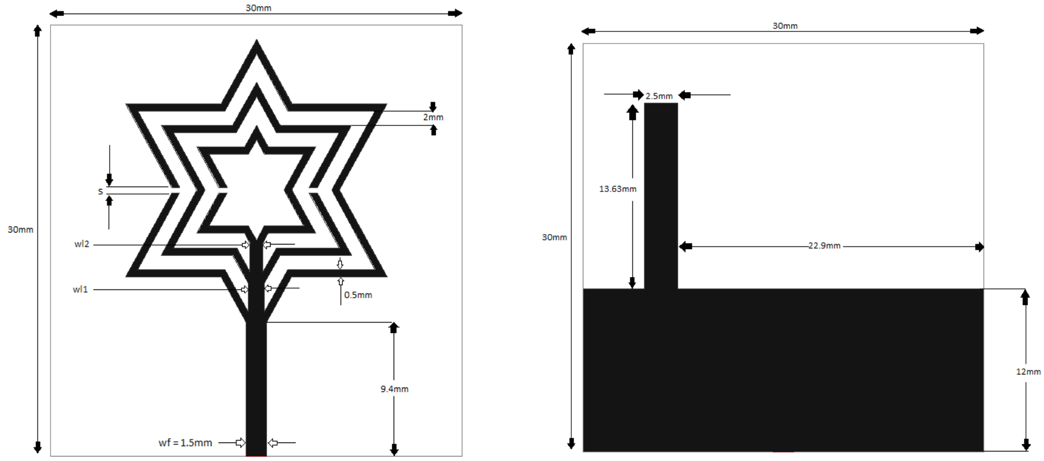

Figure 1: The geometry of proposed antenna and its ground plane with protruding element. $s = 0.4\,\mathrm{mm}$, $wl1 = 1.2\,\mathrm{mm}$, $wl2 = 0.96$.

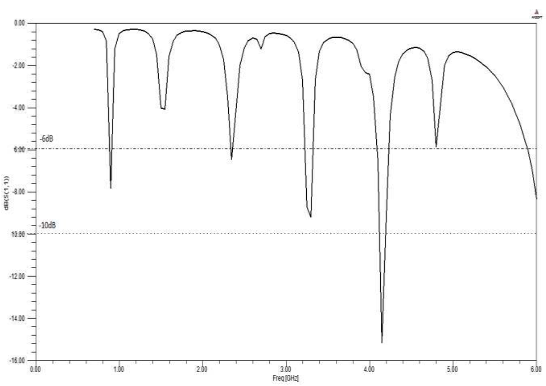

Figure 2: S_{11} with normal ground plane and split structure retained.

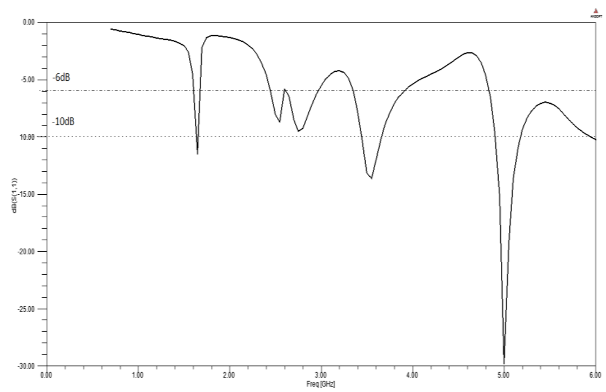

Figure 3: S_{11} without split element but retaining the proposed ground plane.

3. RESULTS AND DISCUSSION

The proposed design was simulated using a finite element method solver-HFSS and the result of these simulations are discussed below.

3.1. With Normal Ground Plane and the Split Element in Koch Snowflake Retained

Here the protruding element in the ground plane was removed and the ground plane was designed to cover the entire substrate of $30\,\mathrm{mm} \times 30\,\mathrm{mm}$ dimension. The antenna resonated at frequencies of 0.9 GHz, 2.35 GHz, 3.22 GHz–3.32 GHz with -6 dB return loss as shown in the Fig. 2. Careful observation reveals that the antenna did not resonate well at WLAN band of 5.17–5.82 GHz. The antenna resonated with -10 dB return loss bandwidth only at 4.15 GHz which was not a useful band.

3.2. Without the Split Element in the Koch Snowflake and Retaining the Proposed Ground Plane Design Containing Protruding Structure

The split element is found in the metamaterial SRR. Here the antenna was simulated without the split element in the Koch snowflake and was found to resonate with -10 dB bandwidth at 1.63–1.65 GHz, 3.44–3.65 GHz and 4.9 to 5.2 GHz as shown in Fig. 3. Comparing Fig. 2. and Fig. 3, It's clear that the lowest resonant band of 0.9 GHz was found missing due to the absence of split element in Koch snowflake

3.3. Proposed Antenna

Finally, the proposed antenna is simulated retaining both protruding structure in ground plane and split element in the Koch snowflake as shown in Fig. 1. Multiband resonance was achieved. -10 dB return loss bandwidth was obtained from 2.3–2.41 GHz, 3.6–3.7 GHz and 5.3–6 GHz bands. Further -6 dB return loss bandwidth was obtained from 0.77 GHz to 0.82 GHz. -6 dB magnitude of return loss is sufficient for antennas in compact devices [11]. The center frequency of these bands were 0.8 GHz, 2.35 GHz, 3.65 GHz and 5.5 GHz as shown in Fig. 4. The obtained bands very well cover LTE/LTE-TDD bands (band 42, 43, 44) [12], WLAN dual band, WiMAX (2.3 GHz) band.

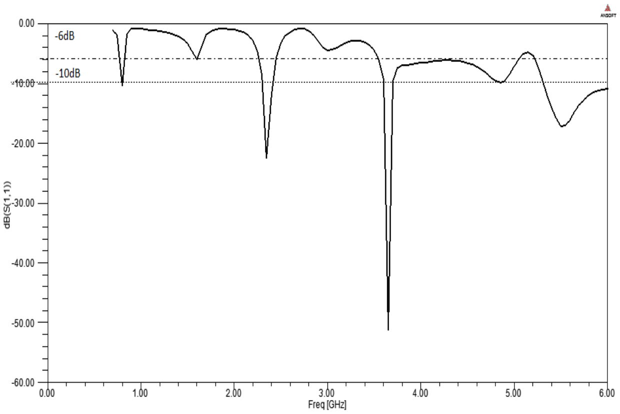

Figure 4: S_{11} graph of proposed antenna.

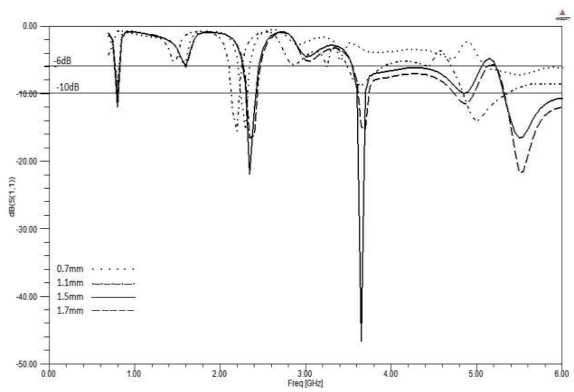

Figure 5: S_{11} graph of parametric analysis when the width of the transmission line is varied from $wf =$ 0.7 mm to 1.7 mm.

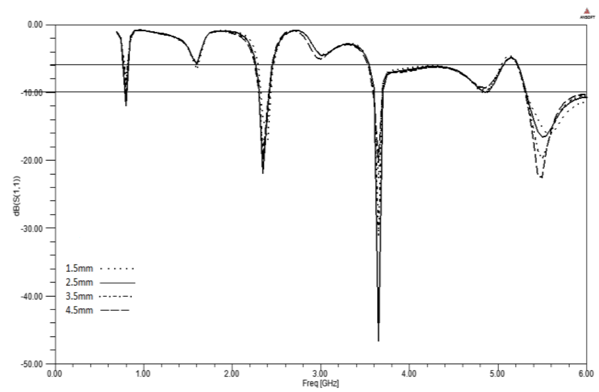

Figure 6: S_{11} graph of parametric analysis when the width of the Protruding structure in ground plane is varied from $pw = 1.5$ mm to 4.5 mm

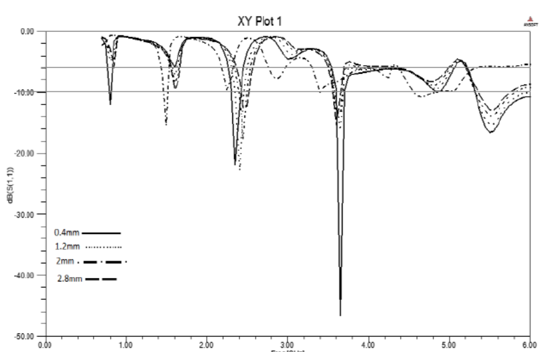

Figure 7: S_{11} graph of parametric analysis when the position of the structure in the ground plane is shifted from the original position to its left.

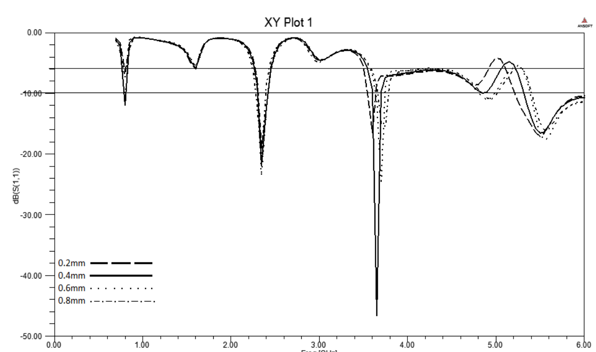

Figure 8: S_{11} graph of parametric analysis when the width of the split element is varied from $s = 0.2$ mm to 0.8 mm.

Also with the inclusion of split element in Koch snowflake fractal, the lowest resonant frequency of 0.8 GHz was achieved. Further inclusion of protruding structure in ground plane resulted in an additional 5.2–6 GHz band [13].

The transmission line is varied from $wf = 0.7$ mm to 1.7 mm. of the Protruding structure in ground plane is varied from $pw = 1.5$ mm to 4.5 mm.

3.4. Parametric Analysis

Parametric analysis were carried out extensively to study the behavior of antenna by varying the dimensions of width of transmission line, width and position of the protruding structure, and width of the split element in Koch snowflake and the results obtained are shown in Fig. 5 to Fig. 8.

3.5. Radiation Pattern

Figures 9, 10, 11 and 12 show the radiation pattern of the proposed antenna with E and H plane for the center frequency of resonant bands.

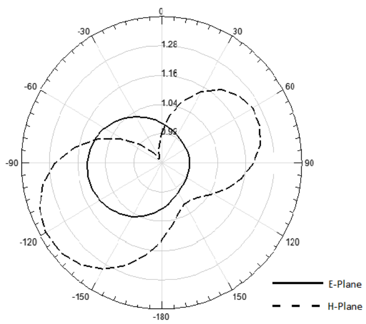

Figure 9: E-plane and H-plane Radiation pattern at 0.8 GHz.

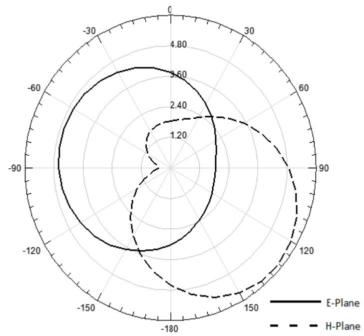

Figure 10: E-plane and H-plane Radiation pattern at 2.35 GHz.

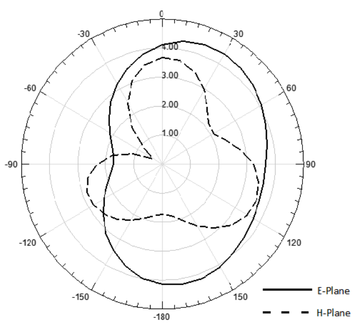

Figure 11: E-plane and H-plane Radiation pattern at 3.65 GHz.

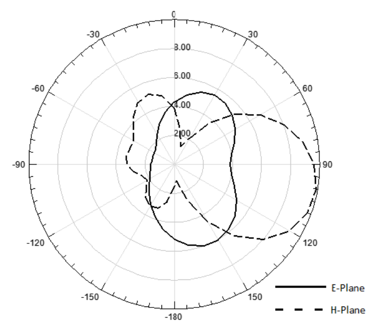

Figure 12: E-plane and H-plane Radiation pattern at 5.5 GHz.

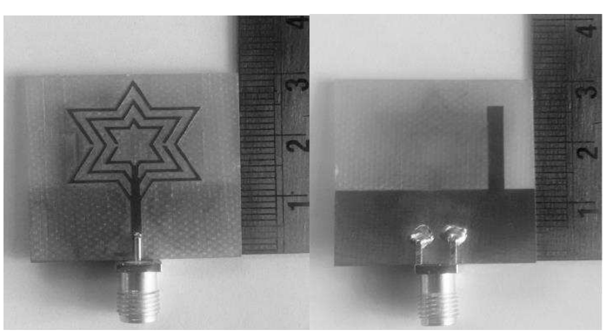

Figure 13: Fabricated antenna.

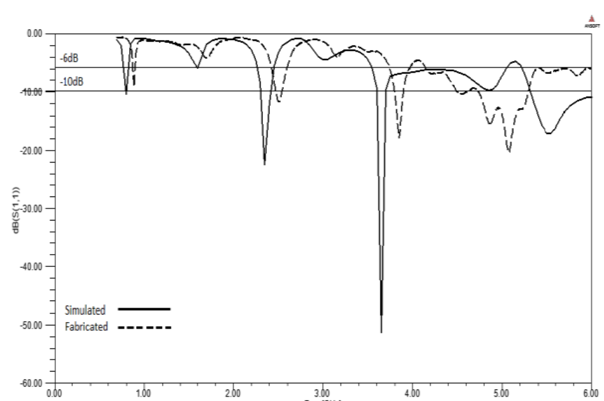

Figure 14: S_{11} graph of simulated and fabricated result.

4. FABRICATION RESULTS

Figure 13 shows the fabricated antenna. The S_{11} graph of simulated and fabricated antenna is shown in Fig. 14.

5. CONCLUSION

A quad band antenna for LTE/LTE-TDD, WLAN and WiMAX application is presented. The Koch snowflake fractal is responsible for multiband resonance. The split element inspired from metamaterial SRR in the Koch snowflake gives an additional low frequency band of 0.8 GHz. The protruding structure in ground plane is responsible for resonance at 5 GHz band. Resonant bands of 0.77–0.82 GHz, 2.3–2.4 GHz, 3.6–3.7 GHz and 5–5.3 GHz with center frequency at 0.8 GHz, 2.35 GHz, 3.65 GHz and 5.1 GHz covering all the essential bands mentioned for wireless communication and applications.

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