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Design of an Ultra-Wide Band Fractal Antenna for Various Wireless and IoT Applications

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Abstract— *This paper presents design and simulation of Fractal microstrip patch antenna within the ultra-wide band frequency range from 3-10 GHz. This ultra-wide band frequency range was achieved by introducing slots and partial ground plane. The simulated antenna performance was obtained by technology Microwave Studio (CST MWS). The antenna performance was investigated by analyzing its Return loss (S11), VSWR, Radiation pattern, Surface Current radiation parameters. This designed antenna has advantage of low profile, light weight, Ultra-wide band frequency range (3 to 10 GHz) and it can be easily fabricated which helps in covering major applications of IOT. This antenna operates within the frequency range of Wi-Fi (3.6-3.7 GHz), WiMAX (3.4-3.6,3.7-4.2 GHz), WLAN (5.3-6.3 GHz), DSRC (5.8-5.9GHz), Hiper LAN (5.1-5.8GHz).*

Keywords— *Ultra Wide Band (UWB), Wireless Communication, Fractal Antenna.*

I. INTRODUCTION

Modern telecommunication systems require antennas with wider bandwidths and smaller dimensions than conventionally available antennas. Most antennas that are employed in many devices are single frequency antennas. If one device has to cover a large bandwidth, these antennas fail.

In the world of wireless communication, there is a requirement for multi-functional and multi-band antennas. Microstrip antennas are best suited to these applications as they have the advantages of low profile, light weight, low cost, easy to manufacture and easy integration into a compact system [1]. Due to the self-similar property within the fractal geometry of proposed fractal antenna it has the ultra-wide band operation. Space filling property is other essential property which determines the decrease in the size of the antenna. The necessity of compact size antenna in every application of wireless communication makes it necessary to have one antenna covering wider bandwidth than many antennas with different frequencies.

In recent years several fractal geometries are introduced for antenna applications and has been very successful in improving the characteristics. Some of these geometries have been effectively useful in reducing the dimensions of the antenna, while other designs aim at incorporating ultra-band characteristics. These antennas are mainly used because it can operate at UWB frequency range which allows us to use it for several IoT applications like Wi-Fi (3.6-3.7 GHz), WiMAX (3.4-3.6, 3.7-4.2 GHz), WLAN (5.3-6.3 GHz), DSRC (5.8-5.9 GHZ), Hiper LAN (5.1-5.8 GHz).

This paper presents design and analysis of a Fractal microstrip patch antenna on FR4 Lossy substrate. Computer Simulation Technology Microwave Studio (CST MWS) simulation program has been used for design and analysis during this study. Simulated results consistently show that this antenna works in UWB frequency range from 3 -10GHz.

Section II describes the antenna design and section III provides details of the bandwidth enhancement methods. The results are discussed in section IV. The conclusion is presented in the section V.

II. ANTENNA DESIGN

The simple, compact and cost-effective design is usually preferred in the field of technology. Keeping this in mind, a single layer substrate and microstrip feedline method is chosen.

Fig. 1 shows the geometry of the front view of the proposed antenna with dimensions. FR408 substrate was chosen in the antenna design with dielectric permittivity €r of 3.75 and dimension of FR408 Substrate is 26.5 mm x 14 mm x 1.6 mm. Annealed copper conductor of thickness is 0.035 mm was used for the antenna patch and ground plane.

To design the specific antenna within the Ultra-Wide Band region (3.1 GHz to 10.6 GHz), the initial operating frequency is chosen to be at 8 GHz. The antenna design equations are as follows.

Step 1: The length and width of the basic patch is calculated as

$$l_p = w_p = \frac{c}{2*f_r*\sqrt{\varepsilon_r}} = 9\text{mm} \quad (1)$$

Step 2: The wavelength of the antenna is given by

$$\lambda_0 = \frac{c}{f_r} = 40.5\text{mm} \quad (2)$$

Where fr is the resonant frequency of antenna and c is the velocity of light

Step 3: The effective dielectric constant is given by:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\sqrt{\left[1+\frac{12h}{w}\right]} = 3.248 \quad (3)$$

Microstrip line feeding with quarter wave transition technique is used in antenna feed line. We optimized the values of the feed line width Wf=2 mm and length Lf=10 mm for the 50ohm line impedance and the width and length of quarter wave line are 1mm and 5mm respectively. The GND plane dimensions are Wg=14 mm, Lg=26.5 mm. The patch length is Lp = 9mm and Patch Width is Wp= 9mm.Thus, the antenna design has been completed and antenna simulation

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results analysis will be given in the next section. Table 1 shows the physical dimensions of the antenna.

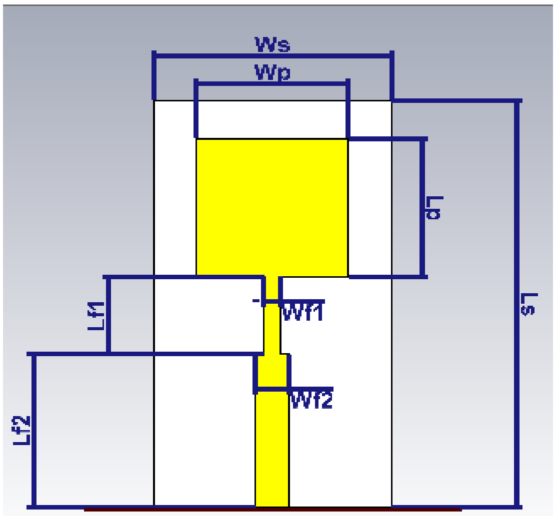

Fig. 1. The geometry of the radiating patch on the front surface of antenna

As a result of the simulation, the return loss (S11 - parameter) versus frequency graph is shown in Fig. 2 with only one resonance frequency at 7.383 GHz. This graph shows that maximum return loss is -15.68dB and resonance frequency band is between the 7.175 GHz – 7.604 GHz (Band Width is 0.426 GHz).

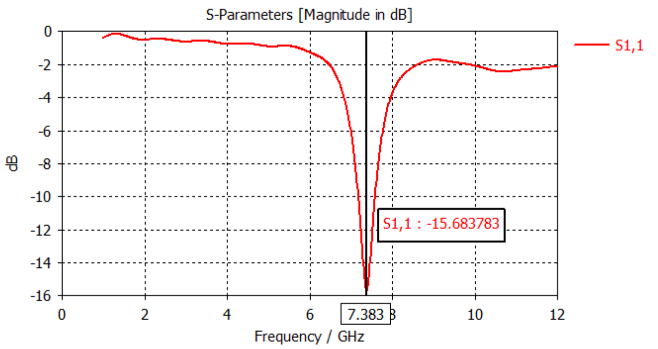

Fig. 2. Return loss versus Frequency graph of Patch antenna

TABLE 1. Design specifications of base patch antenna

Parameter	Value (in mm)
h	0.035
Wf1	1
hs	1.6
Wf2	2
Lf1	5
Wp	9
Lp	9
Lf2	10
Lg1	26.5
Lg2	11.9
Ws	14
Wg	14
Ls	26.5
Ws1	3
Ws2	1
Ws3	0.4
Wgs1	3
Wgs2	2

Where, h is the thickness of the patch and hg is the height of the substrate.

III. BANDWIDTH ENHANCEMENT

Our target was to design a multi-band antenna, with wide bandwidth. But the result obtained from previous section shows that the bandwidth is very narrow. The main challenge in designing the broad band microstrip antenna is to increase the bandwidth. For Ultra-Wide Band application, the minimum bandwidth requirement is 25%. Various methods to increase the bandwidth are listed as:

i. Increasing the Patch Width.
ii. Increasing the substrate height.
iii. Increasing the Dimension of the feed Line.
iv. Length and Position of Slot on the radiating edge.
v. Insertion of Notch on the Corner of Patch.
vi. Suitable size of the Substrate.
vii. Use of Partial Ground surface (Reducing the Size of the Ground surface).

Besides these many researchers also utilize other ways to enhance the bandwidth which includes:

i. Aperture coupling feeding method.
ii. Use of multi-layer substrate.
iii. Shorting pin method.

In this paper, the effect of partial ground plane, effect of notch and effect of slots to enhance the bandwidth will be studied in the following sections.

(i) First Iteration antenna: Conventional microstrip antennas have larger ground surface. The effect of the ground surface is to confine the waves and hence influence the directivity of the antenna. Antenna characteristic may be enhanced by reducing the ground plane [6]. It has been used to increase efficiency [7], improve impedance matching [8], enhance the front-to-back ratio [9] and also increase bandwidth of rectangular antennas [10].

The first iteration of the antenna is done by partially reducing the GND plane keeping all other dimensions of the antenna constant as shown in Fig. 3 with partial ground plane (Wg=14 mm, Lg=11.9 mm). The modified first iteration antenna resonates at two frequencies at 3.509 GHz and 5.901 GHz with a bandwidth of 4.02 GHz as shown in Fig.4. All other simulated results are tabulated in the Table 2.

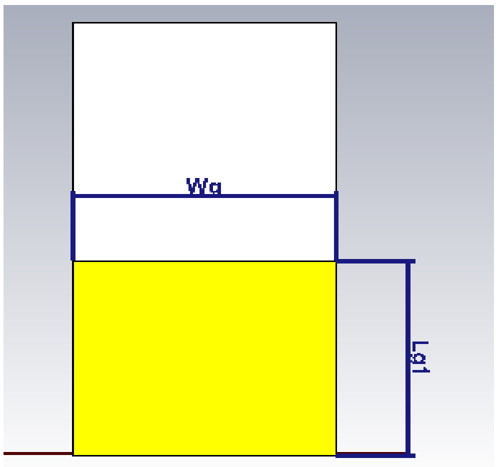

Fig 3. The geometry of ground on the back surface of antenna.

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TABLE 2. Results of the antenna parameters

	Zeroth iteration antenna	First iteration antenna		Second iteration antenna		Third iteration antenna		Fourth iteration antenna	
Frequency (GHz)	7.396	3.509	5.901	3.565	5.56	3.52	5.875	3.46	6.34
Directivity (dB)	5.544	2.966	4.050	2.884	3.726	2.984	4.086	2.004	2.575
Gain(IEEE) (dB)	2.167	1.488	2.054	1.623	2.024	1.535	2.027	1.348	1.567
Realized gain (dB)	1.862	1.438	1.986	1.459	1.966	1.492	1.968	1.337	1.556
Peak surface current (A/m)	90.73	83.42	94.98	78.66	96.74	89.30	101.38	86.56	102.34
Reflection Coefficient |S11| (dB)	15.62	41.09	31.48	20.26	32.8	49.41	34.6	28.6	33.30
VSWR	1.397	1.018	1.055	1.215	1.047	1.007	1.038	1.077	1.044
Radiation Efficiency in dB	-3.377	-1.48	-1.99	-1.26	-1.71	-1.45	-2.06	0.67	0.61
Total Efficiency	-3.682	-1.53	-2.06	-1.43	-1.76	-1.49	-2.12	0.67	0.60
Bandwidth (GHz)	0.429	4.02		4.03		4.05		6.9366	

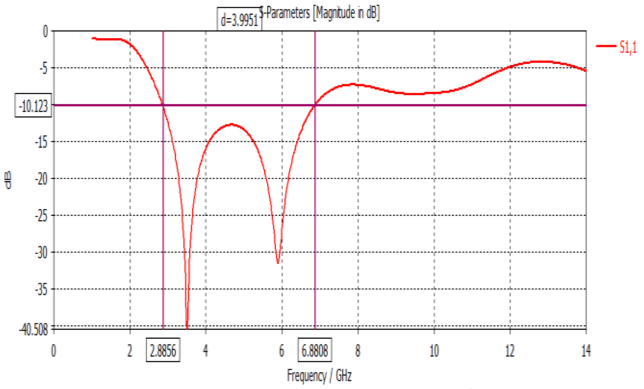

Fig 4. Return loss S11 versus Frequency graph of First Iteration

(ii) Second Iteration antenna: A slot is a narrow two-dimensional planer structure etched in the metallization on one side of the substrate. Because of its planer geometry, it is well suited in microwave integrated circuits. The effect of the slot is capacitive in nature. It provides a very low cross polarization. Its main advantage is that it increases the bandwidth of the microstrip antenna. The position of the slot on the patch is important to study because if it is not made at suitable position, an antenna may suffer from undesired mode such as parallel plate mode excitation and its performance tends to degrade.

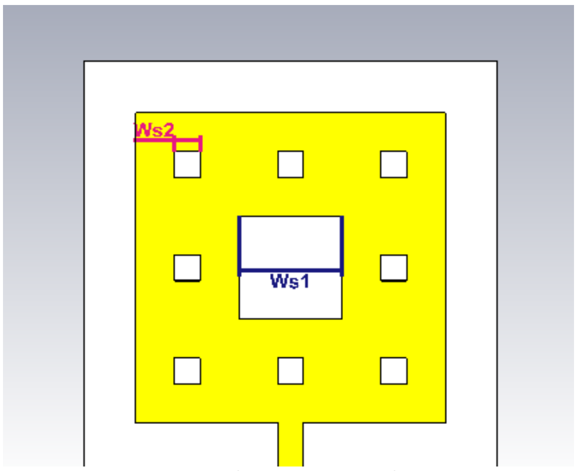

Fig. 5. The geometry of radiating patch of Second Iteration

The modified geometry of second iteration antenna is as shown in Fig 5. Introduction of slots either in plane or an microstrip patch is the technique employed to increase bandwidth. Here the square slots are introduced in the patch.

After introducing the slots, the bandwidth of the antenna increased as shown in the Fig. 5. The modified second iteration antenna resonates at two frequencies at 3.565GHz and 5.56GHz. The VSWR of the second iteration is less than 2 and is as shown in Fig. 6. The ground dimensions of second iteration is same as the first iteration.

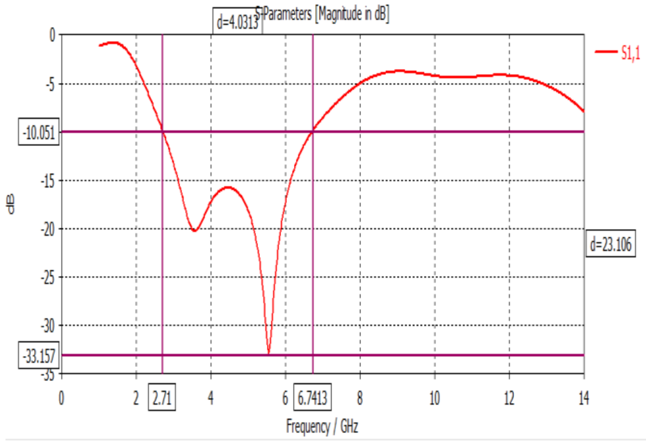

Fig. 6. Return loss S11 versus Frequency graph of Second Iteration

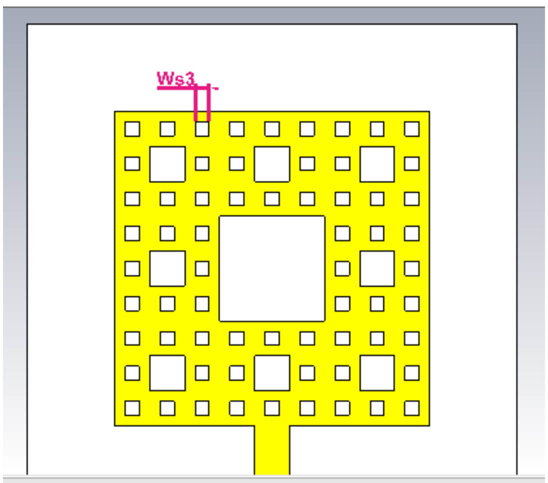

Fig 7. The geometry of radiating patch of Third Iteration

(iii) Third Iteration antenna: The number of slots on patch was increased at higher rate to achieve a higher bandwidth and the fractal shape is achieved as shown in Fig 7. Many slots

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were introduced to modify the basic geometry of the antenna with right dimensions to obtain multi band slot antenna. Here, the feed line and the GND dimensions are unaltered. The modified third iteration antenna resonates at two frequencies at 3.52GHz and 5.875GHz. The VSWR of third iteration antenna is also less than 2. After the introduction of additional slots the bandwidth of the antenna increased from 4.03 to 4.05 as shown in Fig 8.

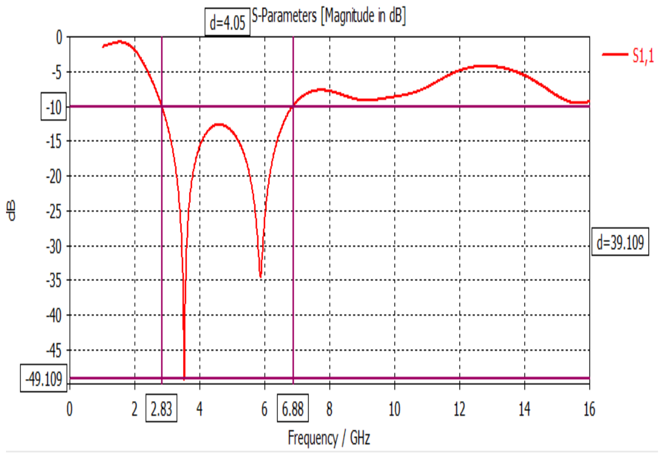

Fig. 8. Return loss S11 versus Frequency graph of Third Iteration

(iv) Fourth Iteration antenna: In order to achieve best possible operating frequency range the were introduced in the ground plane as shown in Fig 9. Here, the feed line and the patch dimensions are unaltered. The final proposed fourth iteration antenna resonates at two frequencies at 3.46GHz and 6.34GHz. The slots were introduced at four corners of the partial ground plane. Here, the dimensions of the introduced corner slots is 2.00 mm x 2.00 mm. And, the dimensions of the slot introduced at the center is 3.00 mm x 3.00 mm. This results in the increase of bandwidth from 4.05GHz to 6.94GHz as shown in Fig 11. The front view of the fourth iteration antenna remains same as the third iteration antenna. This iteration is the final proposed antenna design.

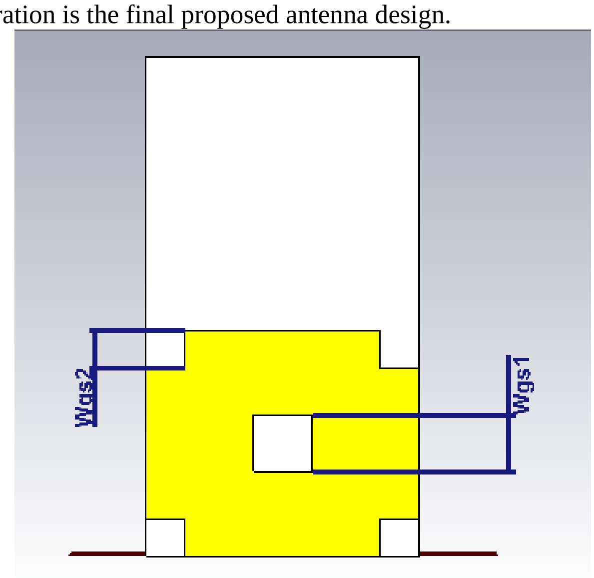

Fig. 9. The geometry of the ground plane of Fourth Iteration (Proposed Design)

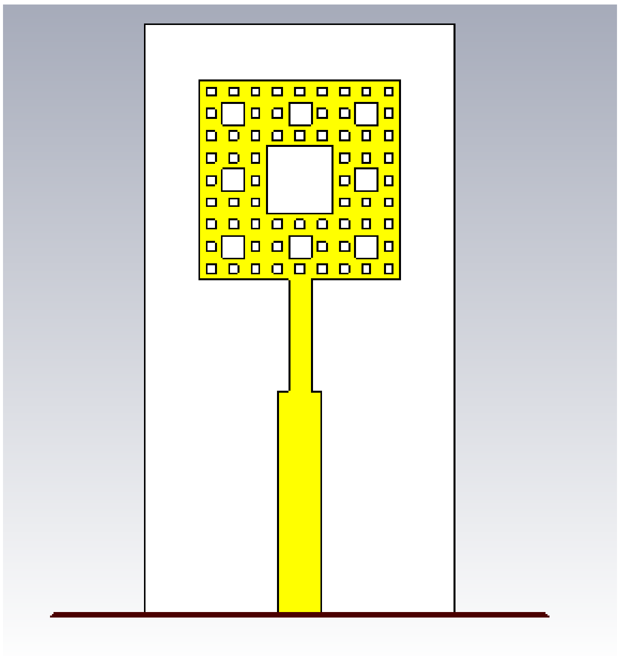

Fig. 10. The geometry of radiationg patch of Fourth Iteration (Proposed Design)

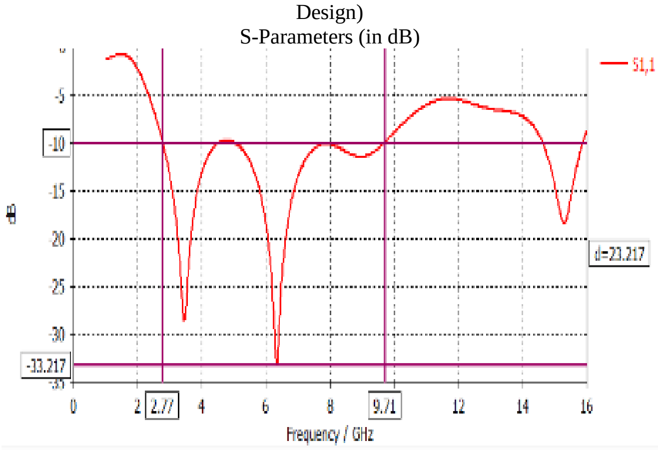

Fig. 11. Return loss S11 versus Frequency graph of Fourth Iteration

IV. RESULTS

The resonant frequency decreases as the number of slots are increased because the path of the current increases due to the slot. Effectively this means that the half wavelength increases along the radiating edge. As the number of slots is increased, the effective patch area decreases which in turn reduces the gain of the antenna. This is clearly observed in the Table 1, for the proposed fourth iteration antenna, where the gain is 1.348dBi for a VSWR of 1.0722 and the gain is 1.567dBi for a VSWR of 1.0442. The product of gain and bandwidth of antenna remains constant and in this present work bandwidth enhancement is focused at the cost of gain of antenna.

Return loss S11 graph is considered for the design and simulation. After obtaining the optimum return loss parameter graph other parameters were evaluated. The return loss graph includes the resonance cutoff frequencies of the antenna, the bandwidths, the number of bands, and the resonance frequency maximum return loss information.

V. CONCLUSION

The numerical study of UWB fractal microstrip antenna was performed using CST Microwave Studio. In this paper UWB antenna is designed using concept of Fractals. Wide band frequencies are obtained by applying this concept and miniaturization of antenna is attained. The physical dimension of the antenna is 2.65cm x 1.4cm which is compact in size. UWB microstrip antenna is widely used due to low power consumption and compact size in IOT applications. Ultra-wide band frequency range of 2.77 GHz to 9.71 GHz have been obtained for IOT applications with appropriate bandwidth and return losses. This designed antenna covers technologies such as of Wi-Fi (3.6-3.7 GHz), WiMAX (3.4-3.6,3.7-4.2 GHz), WLAN (5.3-6.3 GHz), DSRC (5.8-5.9GHz), Hiper LAN (5.1-5.8GHz).

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