DESIGN AND FABRICATION OF LOW PROFILE MULTIBAND SLOTTED FRACTAL ANTENNA FOR BROADBAND COMMUNICATION SYSTEMS

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Abstract
The Antennas required for modern communication devices should be compact in size. It must have low profile, increased efficiency, high bandwidth and high gain. To achieve the above-mentioned advantages; fractal antenna is a better choice because of its high bandwidth, high gain, efficiency, cost effectiveness, fabrication process and the size (physically small and electrically large). The proposed antenna design is composed of circular slots in rectangular patch of dimension (44 x 44) mm^2 using FR4 substrate of thickness 1.6mm. The dimensions of the patch, substrate and ground are same. The antenna is simulated and fabricated in three iterations. The characteristics of the antenna are analyzed by co-polarization of E-plane and H-plane of measured radiation patterns in final iteration. The improvement in reflection coefficient is selected by changing the length of the micro strip fed line to different values of (17 – 20) mm. The antenna has wide bandwidths of (2 – 3.8) GHz and the scattering parameter of - 15.7dB at the resonance frequency of 2.4GHz in the first iteration. It covers the bandwidths of ISM, Bluetooth, WiMAX, WiBro and WLAN applications. The final iteration of antenna has the band widths of (2.2 – 3) GHz, (5.15 – 5.32) GHz and (8.2 to 8.8) GHz and suitable for WiMAX, WiBro, WCDMA, ISM, LTE, UMTS 11 and Bluetooth devices. The simulated gains of the antenna are 3.68dBi, 5.57dBi and 6.47dBi at the resonance frequencies of 2.4GHz, 5.2GHz and 8.2GHz. The simulated and measured radiation patterns are nearly omnidirectional. The proposed antenna is simulated by using CST and fabricated in three iterations. The different parameters such as the radiation patterns, the scattering parameters, and the variation in length of micro strip fed line and their effect on reflection coefficient, voltage standing wave ratio and current distribution in the radiating patch are analyzed and compare both the results.

INTRODUCTION

The modern communications systems prefer the antennas having larger bandwidth, high gain and compact size. There is tremendous research since the last decade to achieve the desired goals. One of the very useful alternatives is to design antenna by using fractal geometries. The fractal shapes make the antenna small in size while enhancing the electrical size of the antenna and provide high bandwidth. The performance of antenna parameters such as Gain, radiation pattern and input impedance depend on the electrical size of the antenna [1-3]. The iteration techniques apply on the fractal geometries by subdividing the particular shapes in multiple copies of it make the antenna physically small in size [4]. In 2000s the research works on fractal technology exhibit advantages in applications such as RFID [5] and mobile phones [6]. Since 2011s fractal element techniques used in antennas have been widely used commercially [7]. The characteristics and behaviors of fractal antenna have remarkable advantages and overcome the limitations in bandwidth, multiband and small area [8]. Due to constructive interference by electrically large size provides improvement in gain have compact size [9]. The slotted microstrip antenna is analyzed for linear and circular polarization and broadband characteristics for different communication devices in [10, 11]. The advancement in the satellite communication in last decade the antenna having circular polarized is studied for reducing the nature loss in the receiver [12]. Multiband fractal antennas are studied in recent years having triangle and circular shaped slots for communication devices such as CDMA, LTE, WiMAX, and WLAN in [13]. For WLAN application of 5.8GHz broadband fractal antenna using sector shaped fractal geometry is analyzed in [14]. A wideband antenna is designed using square slot and metamaterial is used in [15]. A dielectric resonator antenna using cylindrical shaped fractal geometry having wide bandwidth from 2.6GHz to 4.34GHz is studied in [16]. A wideband employing plus shaped fractal slot with modification in ground plane for broadband applications in [17]. A hexagonal slotted antenna which is high gain and wide bandwidth from 1.31GHz to 6.81GHz is studied in [18]. Dual Band operating antenna using star slot is analyzed and implemented in [19].

The aim of proposed antenna is to design broadband antenna which have efficient radiation properties by using fractal geometries. The other purpose is to design such antenna which is easily fabricated, simple structure and an inexpensive. In order to achieve all these, fractal antenna having circular slots in three iterations are designed and fabricated. The microstrip fed line of dimension 3 x 17 mm^2 is used whose dimensions and position are varied to obtain batter performance. The antenna is simulated using CST Microwave studio and simulation results of reflection coefficient, radiation patterns in E-Plane & H-Plane are verified and compare with the measurement results. The proposed antenna having compact size of 44 x 44 x 1.6 mm^3 having bandwidth of (2.036 - 3.77) GHz is suitable for ISM, Bluetooth, WiMAX, WiBro and WLAN applications in first iteration while in final iteration its operating band widths of (2.11 – 3.12) GHz can be use in WiMAX, WiBro, WCDMA, ISM, LTE, UMTS 11 and Bluetooth devices. The FR4 substrate of relative permittivity of 4.4 is used between patch and ground which is inexpensive and easily available. The reflection coefficient, the omnidirectional radiation patterns, voltage standing wave ratio, current distribution of radiating patch and gain of antenna are analyzed. The simulation results are compared with measured results which show similarity. The antenna is compact in size, low profile, ease of fabrication, inexpensive and wide bandwidths suitable for various modern communication systems. The section 2 of the research article describes the problem statement, section (3) explains the materials and geometry of the proposed antenna, simulations are discussed in section 4 and finally the research work is concluded in section 5.

2. Problem Statement:

WLAN, Bluetooth, ISM band, WiMAX, WiBro require wide bandwidth for the application specific purposes. Slotted micro strip fractal antenna usually have narrow bandwidth which makes it not suitable for various communication applications. Therefore slotted micro strip fractal antenna is required for Bluetooth, ISM band, WiMAX, WiBro applications. To design an ultra-wide band (UWB) antenna i.e. compact in size, low profile, multiband, high radiation efficiency for modern communication devices is a crucial task for the specified applications.

3. Materials and Geometry:

To resolve the issues, the circular shaped fractal geometry is employed which is composed of simple structure and easy to design and fabricate a low profile multiband antenna in three iterations. The bandwidth of antenna in all the iterations are carefully analyzed and studied parametrically such as by changing the feed dimension and location. The operating frequencies are suitable to use in many communication devices. The circular based slotted fractal antenna in first iteration is illustrated in fig.1. Three circles of diameter d_2 are made in first iteration inside the first circle of diameter d_1.The dimensions of the ground (W_g x L_g) mm^2 and substrate (W_s x L_s) mm^2 are the same. The FR4 substrate of relative permittivity of ε_r = 4.4 and thickness of 1.6mm is used. The micro strip feeding line of dimensions (W_f x L_f) is fed at the middle of the structure at the bottom.

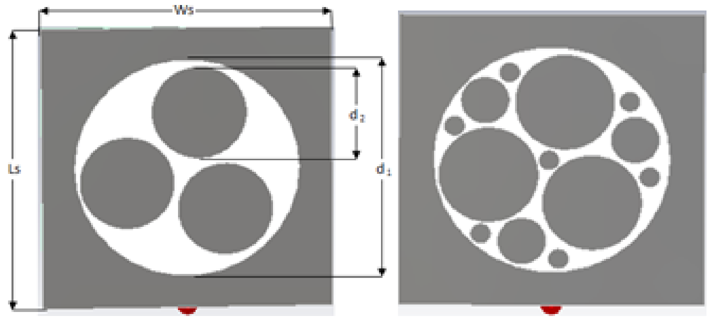

Figure 1: Geometrical representation of first Iteration and third iteration of proposed antenna.

The parameters which are used to represent the dimensions and values in mm are listed in the table 1.

W_g	44mm	L_s	44mm	d_1	34mm
L_g	44mm	W_f	3mm	d_2	10.7mm
W_s	44mm	L_f	17mm		

Table 1: Parameters of first and third iterations of circular based fractal antenna

The third iteration of circular based slotted fractal antenna in fig.1 have the dimensions of the ground (W_g x L_g) mm^2 and dimensions of the substrate (W_s x L_s) mm^2. The dimensions of ground and substrate are same. The diameter of largest circle is 34mm and the diameter of the three asymptotic circles is 10.7mm. And the diameter of the small circle has 7mm. The FR4 substrate of relative dielectric constant of ε_r = 4.4 and thickness h= 1.6mm is used in designing the antenna. The width and length of the ground plane and substrate are 44mm.

The fig. 2 shows the photographs and measured scattering parameter of the fabricated circular based slotted fractal antenna in its third iteration. Three circles of diameter d_2 are made in first iteration inside the first circle of diameter d_1. The dimensions of the ground (W_g x L_g) mm^2 and substrate (W_s x L_s) mm^2 are (44 x 44) mm^2. The FR4 substrate of relative permittivity of ε_r = 4.4 and thickness of 1.6mm is used. The micro strip feeding line of dimensions of (W_f x L_f) is fed at the middle of the structure at the bottom. The various parameters are listed in the table 2.

Figure 2: Photographs of back and front sides and scattering parameter of fabricated slotted based circular based fractal antenna at third iteration.

W_g	44mm	L_s	44mm	d_1	34mm
L_g	44mm	W_f	3mm	d_2	10.7mm
W_s	44mm	L_f	17mm		

Table 2: Parameters of third iteration of circular based fractal antenna.

4. Simulations and Discussions:

The simulations are carried out through CST MW Studio software. Its observed from the simulations that the gain and directivity of antenna is affected by the dimensions of micro strip supply. The length of the micro strip feed is changed to (17- 20) mm and the scattering parameters are depicted in figures below. The gaps between the feed and ground plane also affect the antenna characteristics. Figure 3 shows the reflection coefficient at first iteration. At the operating frequency of 2.2 GHz the return loss is -21db and the return loss is -26db at 3.6GHz i.e. much lower than -10db.

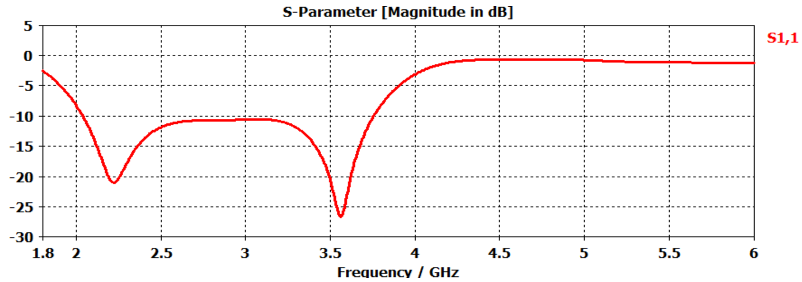

Figure 3: Return loss of Circular based slotted fractal antenna (First Iteration).

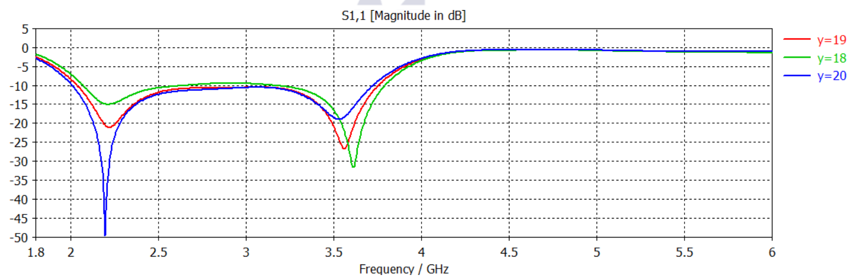

Figure 4: Effect of position of the feed on antenna performance (first iteration).

The figure 4, establishes the variation of antenna performance with different supply positions. By changing the position of the supply between (19 – 21) mm resonance frequencies of the antenna is shifted towards the lower resonance point in the final iteration of the antenna.

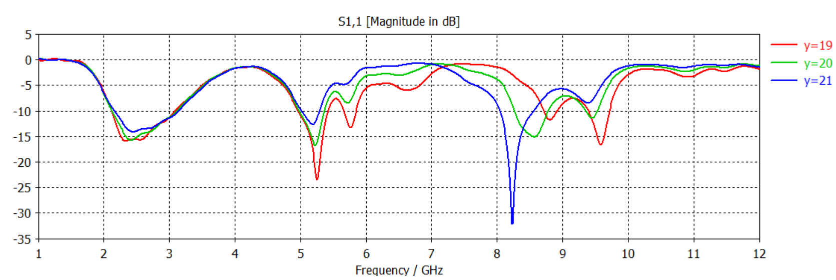

Figure 5: Return loss plot for position of the supply 19mm, 20mm, 21mm (Third Iteration).

The band of the antenna ranges from 2.036GHz to 3.77GHz and it's concluded that the bandwidth 1.734GHz is suitable for many wireless applications. Such useful applications are depicted in Table 3.

Antenna bandwidth	From 2.036GHz to 3.77GHz
ISM	(2.4 – 2.484)GHz
Bluetooth	(2.4 – 2.484)GHz
Wi MAX	(2.11 – 2.2)GHz
WiBro	(2.3 – 2.39)GHz
WLAN	(2.39 – 2.51) & (3.60 – 3.70)GHz

Table 3: First iteration of proposed Antenna suitable for wireless applications.

The figure 6, illustrates the reflection coefficient of the antenna in the third iteration. The antenna resonates in three resonance frequencies with high bandwidth. The first band has the bandwidth of 1.01GHz ranging from (2.11 to 3.12) GHz the scattering parameter of - 15.7dB at the resonance frequency of 2.4GHz. The range of frequencies is suitable for many wireless applications which are summarized in the table 3.

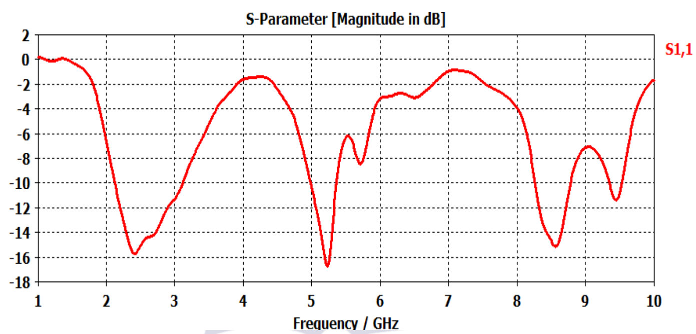

Figure 6: (|S11|, dB) plot of circular based fractal antenna at third iteration

The second band of the antenna resonates in the frequencies range from (5 to 5.38) GHz and the band width is 0.38GHz. This bandwidth of the antenna is sufficient to cover the WLAN applications ranging from 5.15 GHz to 5.32 GHz. At the third band; antenna resonates in the frequency range of (8.2 to 8.8) GHz and the bandwidth 0.6 GHz. This bandwidth is sufficient for many wireless applications as shown in the Table 4.

Table 4: Antenna (third iteration) is suitable for wireless applications.

Applications	First Band (Third Iteration)
Proposed Antenna BW	2.11GHz-3.12GHz
WiMAX	2.11GHz – 2.2GHz
WiBro	2.3GHz –2.39GHz
WLAN	2.4GHz
ISM	.4GHz - 2.484GHz
LTE	2.5GHz - 2.69GHz
UMTS 11	2.5GHz – 2.7GHz
Bluetooth	2.4GHz-2.484GHz

The broad band characteristics of the antenna depends upon the space between the radiating patch and the ground. The separation between the feed and ground affects the behavior of the antenna radiation patterns and scattering parameters. On the other hand the dimensions of the ground and feed also have high impact on the antenna's wideband characteristics. The current distributions on the surface of the patch at different operating frequencies and at first and third iterations of the antenna have been analyzed and the dimensions and gaps between the patch, ground and the feed are adjusted to enhance the efficiency of the proposed antenna. The simulated current distribution in the antenna in first iteration at the resonance frequencies of 2.4GHz and 3.67GHz is shown in the figure 7. The current distribution at the lower resonance frequency is larger and longer path is available for the flow of current which result in lower resonance frequency. At the higher band the current distribution is less and shorter path is available for the flow of the current which result in upper resonance frequency. So longer path is available for surface current flow at the lower resonance frequency 2.4GHz as compared with that at the resonance frequency 3.67GHz.

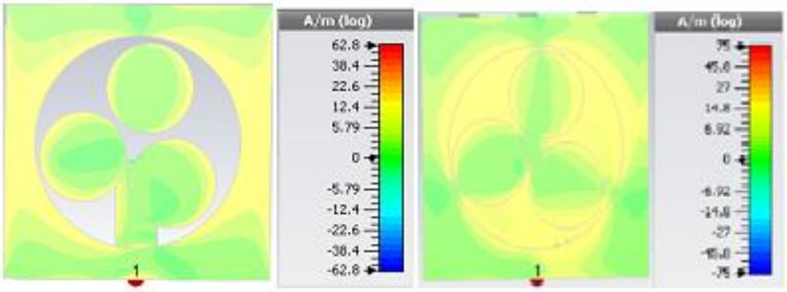

Figure 7: Current distribution of first iteration of circular slot based fractal antenna at 2.4GHz and 3.67GHz.

In order to discuss the electromagnetic behavior of the antenna, the surface current distribution of the antenna in third iteration is analyzed in fig.8. The simulated surface current is analyzed at the micro strip feed position of L_f = 17mm and W_f = 3mm. At the resonance frequency 2.4GHz the current distribution is more and larger path is available for the current flow than the higher resonance frequencies that as 5.2GHz and 8.4GHz. Which result in lower resonance frequencies. At higher resonance frequencies the current distribution is less and shorted path is available for the flow of current which result in higher resonance frequencies that are 5.2GHz and 8.4GHz.

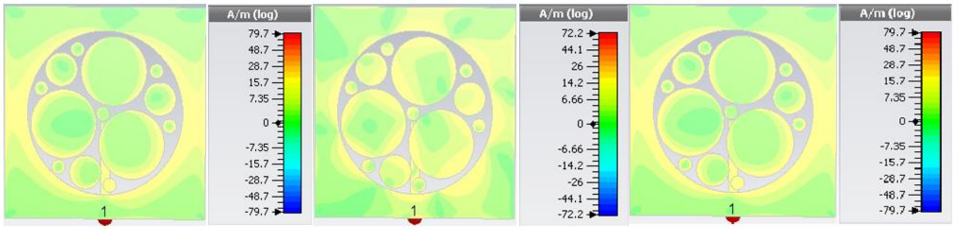

Figure 8: Distribution of surface current at third iteration of circular based slotted fractal antenna (a) 8.4GHz (b) 2.4GHz (c) 5.2GHz.

The VSWR is illustrated in fig. 9 which shows that the antenna impedances are matched perfectly in its first iteration. The VSWR is within the range from 1.2 to 1.8 approximately.

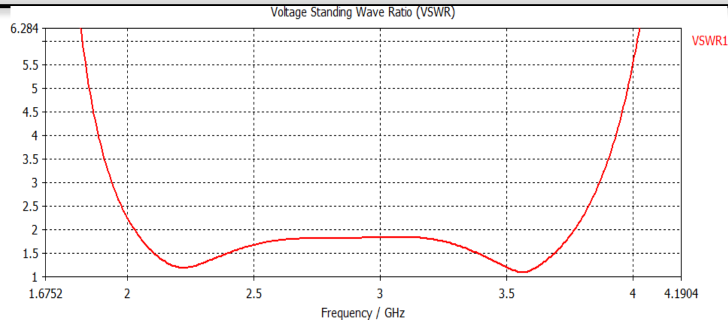

Figure 9: Voltage standing Wave ratio of circular based fractal antenna (first iteration).

The fig.10, illustrate the impedances matching of the proposed antenna in third iteration.

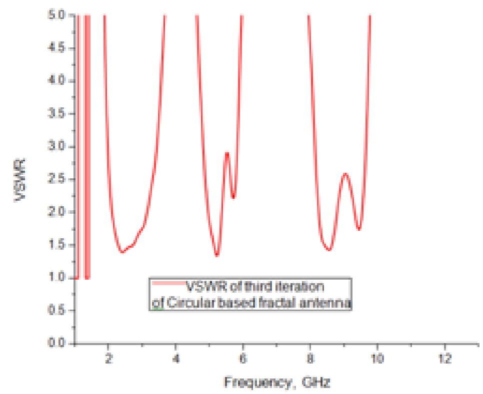

Figure 10: VSWR of circular based fractal antenna at third iteration.

The antenna is good impedances matching with VSWR range from 1.3 to 1.5.

The figure 11, demonstrates the three dimensional radiation patterns of antenna in first iteration.

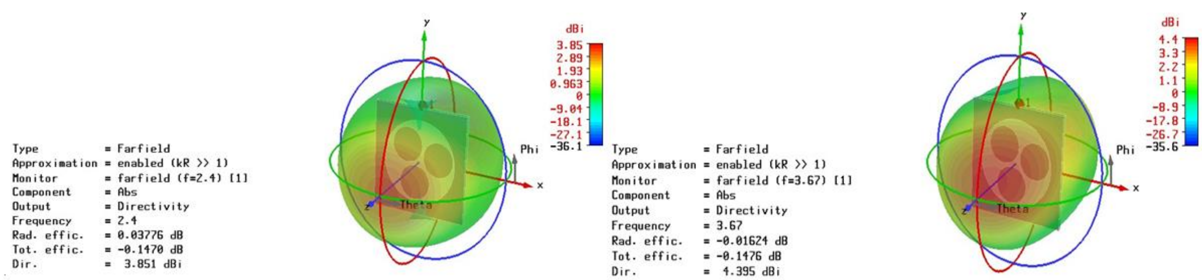

Figure 11: 3D radiation patterns of circular based fractal antenna at 2.4GHz and 3.67GHz (First Iteration).

At the feed dimension W_f = 3mm and L_f= 17mm the gain and directivity of the first iteration of proposed antenna at the resonance frequency 2.4GHz are 3.85dBi and 3.851dBi respectively. And at the central frequency of 3.67GHz are 4.4dBi and 4.395dBi respectively.

At third iteration in fig. 12, shows the radiation patterns at the micro strip feed dimensions of (L_f x W_f) is (17 x 3) mm^2 and at the resonance frequencies of 2.4GHz, 5.2GHz and 8.4GHz. The gain and directivity of the antenna is affected by the dimension of the supply. The three dimensional radiation patterns at the resonance frequency 2.4GHz the simulated gain of the antenna is 3.68dBi and directivity of 3.683dBi. At the second band of frequency 5.2GHz the gain and directivity of the antenna is 5.57dBi and 5.568dBi. The gain and directivity of antenna at the second band is higher than the first band. The gain of the antenna at the resonance frequency 8.4GHz is 6.47dBi and directivity of 6.475dBi. The gain of third band is higher than the first and second band.

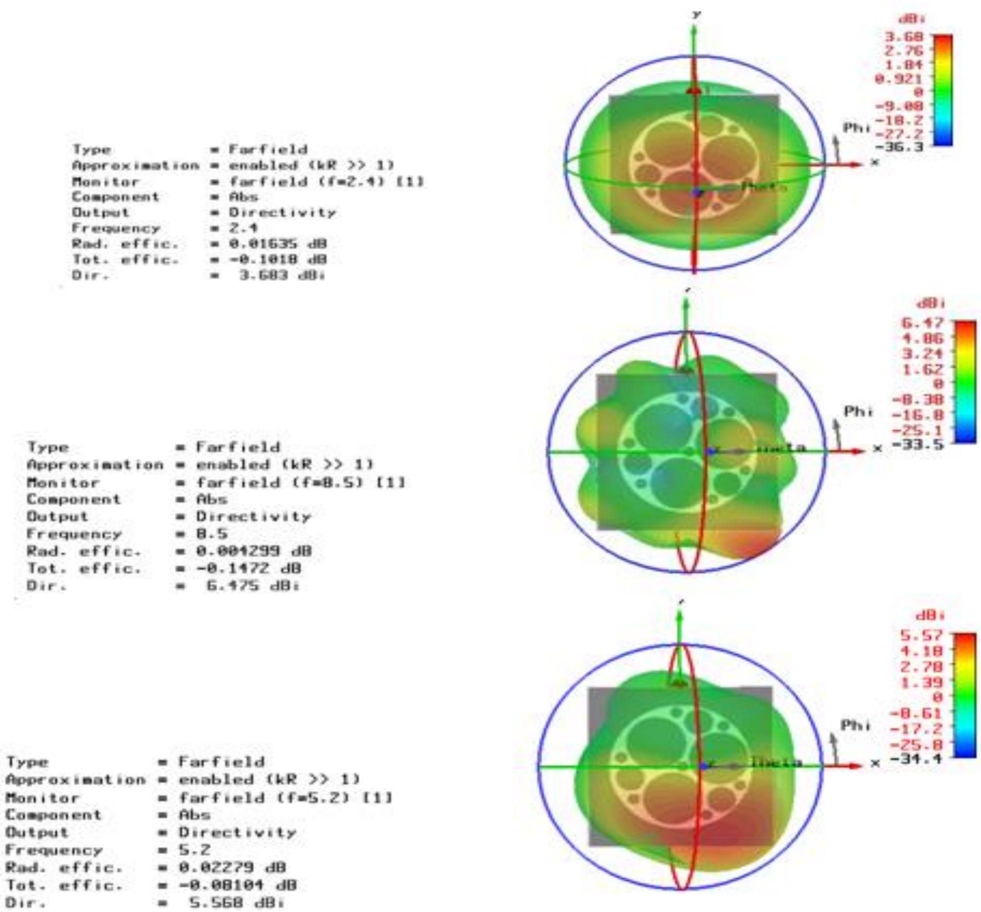

Figure 12: 3D Radiation pattern of Circular based fractal antenna at the resonance

The figure 13, illustrates the measured reflection coefficient of the antenna in third iteration. The antenna resonates in three resonance frequencies with high bandwidth. The first band has the bandwidth of 1.01GHz ranging from (2.11 to 3.12) GHz the scattering parameter of - 15.7dB at the resonance frequency of 2.4GHz.

Figure 13: S-parameter of third iteration of slotted based circular fractal antenna.

This range of frequencies is suitable for many wireless applications which are summarized in the table 5.

Table 5: Proposed Antenna is suitable for wireless applications.

Proposed Antenna bandwidth	2.11GHz – 3.12GHz
WiMAX	2.11GHz – 2.2GHz
WiBro	2.3GHz – 2.39GHz
WCDMA	1.92GHz - 2.16GHz
ISM	2.4GHz - 2.484GHz

E-plane and H-plane of Co-polarization of Radiation patterns of third iteration of circular based fractal antenna.

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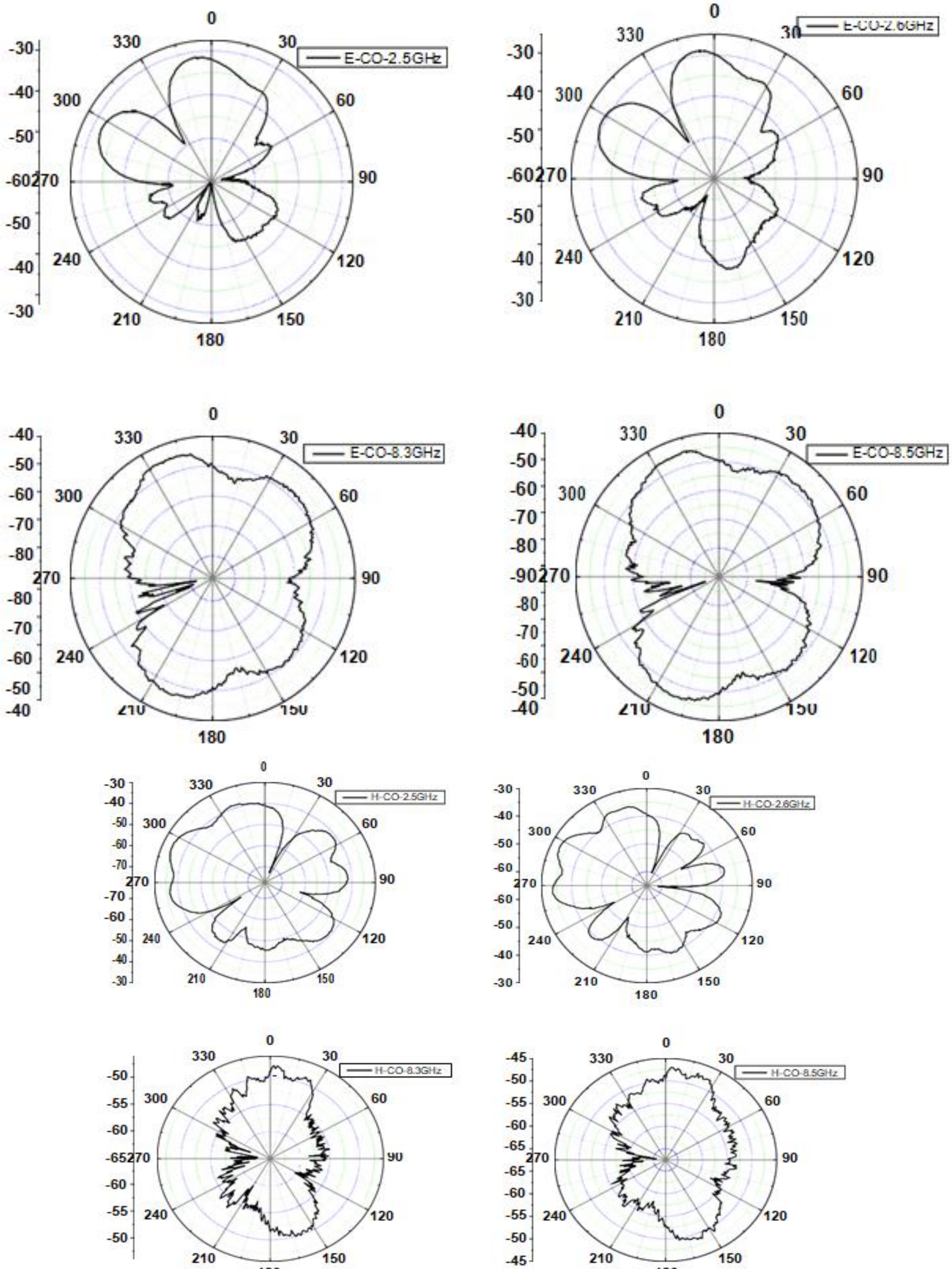

Figure 14: E-plane and H-plane co-polarization of third iteration of circular based fractal antenna at 2.5GHz, 2.6GHz, 8.3GHz and 8.5GHz.

Conclusion: The proposed antenna is designed in three iterations using fractal concept of circular slots of different scales which enables it to be multiband fractal antenna and it has very compact size when fabricated. The larger bandwidth of the antenna in all three iterations is suitable to cover WLAN, Bluetooth, ISM band, WiMAX, WiBro and WCDMA bands applications. The radiation patterns are nearly omnidirectional. The optimal design has wide bandwidth, low profile, efficient, simple, inexpensive and can be easily fabricated. These characteristics make the antenna more suitable to use in the modern telecommunication devices.

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