On the Design of Tree-type Ultra Wideband Fractal Antenna for DS-CDMA System

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***Abstract* – This article describes the CPW-feed ultra wideband tree type monopole fractal antenna and it's backscattering. The prototype antenna is fabricated with optimized dimension. The experimental result of this antenna exhibits the ultra wideband characteristics from 5.0 GHz to 14.0 GHz. The experimental and simulated results are in good agreement. The effects of various design parameters on impedance bandwidth have also been studied in detail using EM simulator. The nature of H and E – plane radiation patterns are omni-directional and bidirectional respectively. The measured group delay is almost constant throughout band. This indicates the phase linearity. The monostatic RCS of antenna is also simulated iteration-wise for antenna and structural scattering mode. This antenna can be useful for UWB system, Microwave Imaging and vehicular radar and military high data rate wireless communications.**

***Index Terms* –** Planar Monopole antenna, Fractal Geometry, CPW- Feed, Group Delay and UWB system and backscattering.

I.   INTRODUCTION

The Ultra wideband (UWB) technology opens new door for wireless communication system, since the current wireless system increasing exponentially. Recently, UWB technology with an extremely wide frequency range has been proposed for imaging radar, communications, and localized applications [1]. In 2002, Federal Communication Commission (FCC) authorized unlicensed use of UWB band ranging from 3.1 GHz to 10.6 GHz. In this, there are two main approaches for UWB system i.e MB-OFDM (Multi-Band Orthogonal Frequency Division Multiplexing) and DS-CDMA (Direct-Sequence Code Division Multiple Access). The DS-CDMA approach uses three spectral modes of operation, low band (3.1–5.15 GHz), high band (5.825–10.6 GHz), and multi-band (low band plus high band) while MB-OFDM approach divides its full band 3.1–10.6 GHz into 14 sub-bands with each bandwidth of 528 MHz. Each sub-band consists of 128 tones and is modulated with OFDM. The DS-CDMA approach uses high band (5.825 GHz - 10.6 GHz) as a mandatory mode [2-3]. In this article, we will focus on the UWB antenna design for the DS-CDMA system over the frequency range 5.825 GHz - 10.6 GHz with omni-directional radiation pattern, constant group delay and phase linearity.

In the open literature, many planar monopole antennas for multiband and UWB have been reported [4-10]. Werner et. al. [5] and N. Cohen [6] have reported the multiband antenna using fractal geometry. The fractal geometry has space filling and self-similarity properties. The space filling properties of fractal geometry is reported in [7] and is useful to reduce the antenna size. While self-similar properties of fractal offers the multiband/UWB feature of antenna. Several UWB fractal antennas with CPW-feed have also been reported so far [8-10] using fractal properties. The RCS of the UWB fractal antenna is also necessary to study to predict the antenna potential for military applications. It is reported that antenna scattering is significantly contribute to the total radar cross section (RCS) of low - observable platforms. The antenna scattering is related with its feed port termination. This scattering may be the problem for the design of antenna with low RCS and good radiation characteristic simultaneously [11-12]. So, it is essential to design low RCS antenna with good radiation pattern. The UWB antenna with low RCS is useful for many applications such as UWB radars, military high data rate wireless communications etc.

This article discusses the proposed antenna with detail parametric studies and its backscattering. The antenna has been implemented experimentally. The experimental and simulated results are in good agreement. The radiation patterns, group delay, phase linearity, and peak gain have been discussed. The backscattering of antenna has also been discussed and calculated in operating band. This antenna can be used for frequency band from 5.825 GHz – 10.6 GHz along with wireless local area network (WLAN), secure transmission and military high data rate wireless communications.

II. ANTENNA GEOMETRY

The proposed antenna with each iteration is shown in Fig. 1. The antenna geometry has been initiated with 12 dimensional structures (Dodecagon) of side length 2.524 mm as shown in Fig. 1a. In each side length of 12 dimensional structures, a pentagonal with side length of 1.468 mm is connected as shown in Fig. 1b. This is the base of antenna structure or called zeroth iteration. In the 1st iteration, the initial base structure is scales down with factor of 0.74. This scale down structure is subtracted from initial base structure. This is the 1st step of 1st iteration. After this, the initial structure is scale down by 0.58 in x and y co-ordinates and united with the first step of 1st iteration. This is called the 1st iteration of the antenna. In 2nd iteration, the 1st iterative structure has been scale down by the factor of 0.58 and united with 1st iterative structure. This is called the step in 2nd iteration. Then the zeroth iteration structure has been scale down twice with the scale factor of 0.58 and united with step. This is called the 2nd iteration of antenna as shown in Fig. 1d. After this the process is repeated in similar fashion for third iteration. The third iteration of final antenna structure is shown in Fig. 1e. This tree-type fractal antenna structure is fed with CPW-feed. The proposed antenna with CPW-feed is shown in Fig. 2 with optimized dimension.
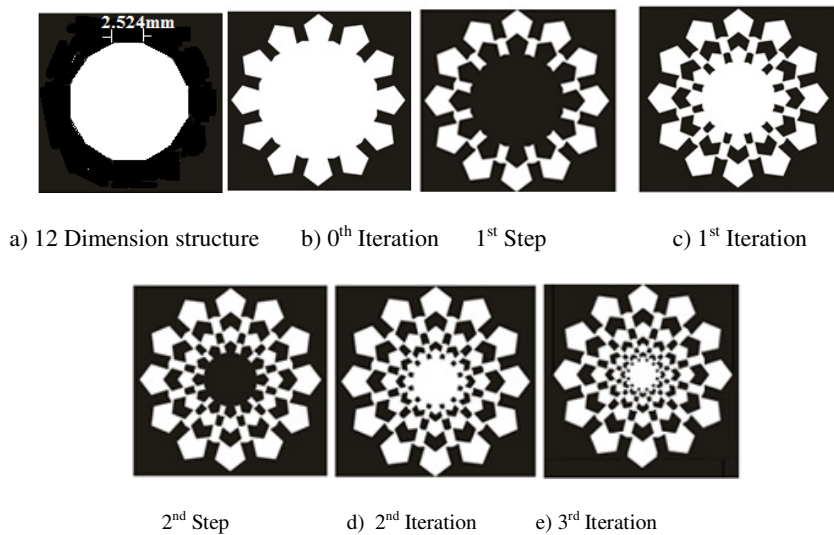
a) 12 Dimension structure   b) 0th Iteration   1st Step   c) 1st Iteration

2nd Step   d) 2nd Iteration   e) 3rd Iteration
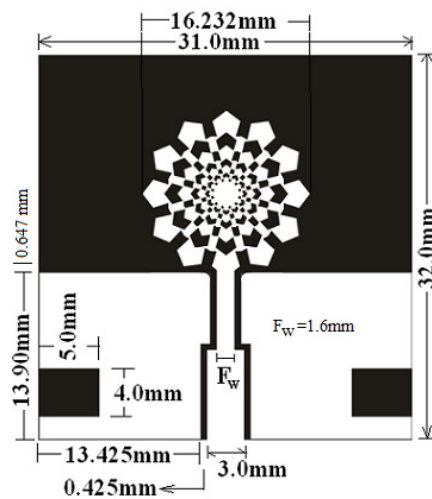
Fig. 1. Iteration wise fractal antenna

Fig. 2. Proposed tree- type fractal Antenna

III.   EFFECT OF DESIGN PARAMETERS

The proposed tree-type fractal antenna has been simulated with respect to design parameters and a detail study has been done. It is understood that current distribution over the antenna plays the main role to design the UWB antenna. The current distribution over the antenna at 6 GHz is shown in Fig. 3. The current distribution on the antenna is along the edges of the patch, on the ground near the patch along x-axis and along the length of ground near feed. Keeping in view the current distribution, the gap between patch and ground, gap between feed width and ground, ground width and circumference of patch are critical to achieve the desire impedance matching in the operating band.
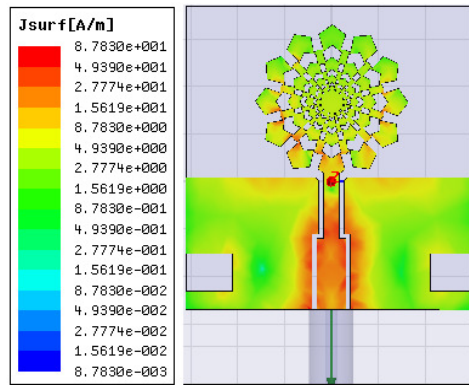
Fig. 3. Current distribution at 6 GHz

A. *Effect of each iteration*

The proposed tree-type fractal antenna has been simulated using HFSS10 with respect to each iteration. The simulated results are shown in Fig. 4. It is clear from the simulated results as the iteration increases, there is little variation in first resonant frequency to lower frequency side as well as improvement in reflection coefficient at the lower and higher frequency side. This improves overall impedance bandwidth of antenna to some extent. In this, third iterative antenna is fabricated with optimized dimension to validate with simulated result.
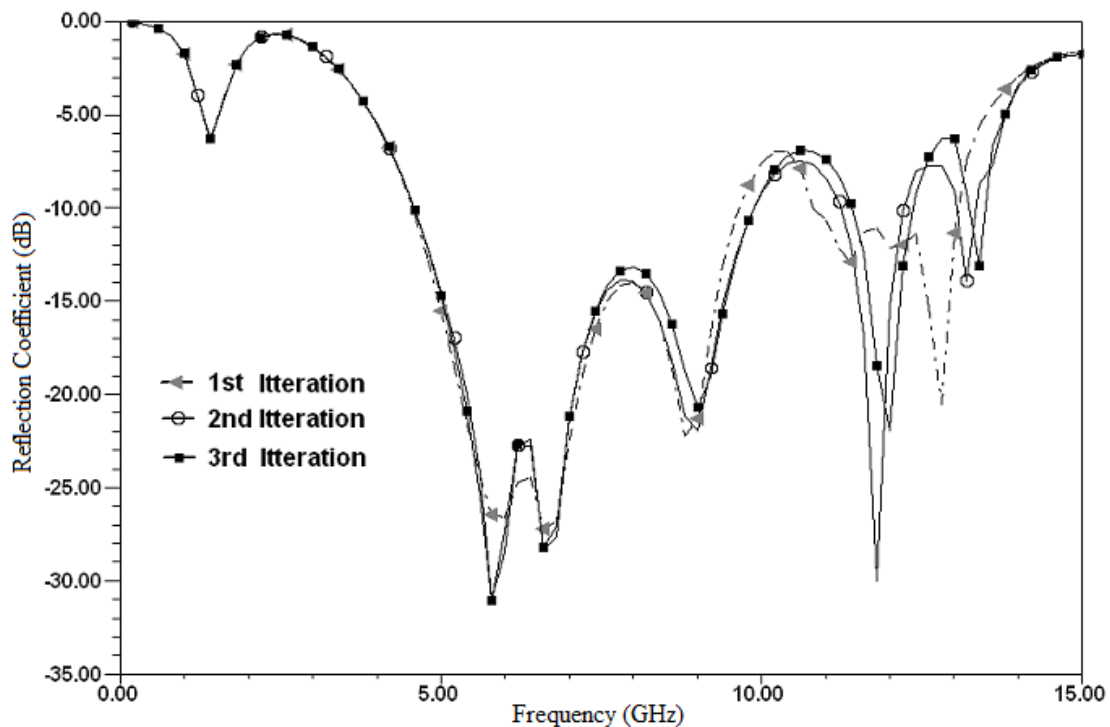
Fig. 4. Simulated results of each iteration of antenna

B. *Effect of the Gap between feed and ground*

The proposed tree–type antenna is simulated for gap between feed width and ground. This gap is important for input matching to the radiating element. The proposed antenna has been simulated for various value of the gap between feed and ground with the step of 0.1 mm from 0.275 mm to 0.575 mm. The simulated results are shown in Fig. 5. The effect of the gap is clearly visible in the simulated results. The optimum value of gap has been achieved 0.475 mm. The feed width has been optimized in two step i.e near coaxial connector W=3.0mm and near the patch FW = 1.6 mm. Initially value of feed width and gap for optimization have been taken W=3.2 mm and G=0.275 mm. For this optimized G=0.475 mm, W=3.0 mm, Fw = 1.6 mm and fixing other parameters, the reflection coefficient is achieved better than -10 dB throughout band.
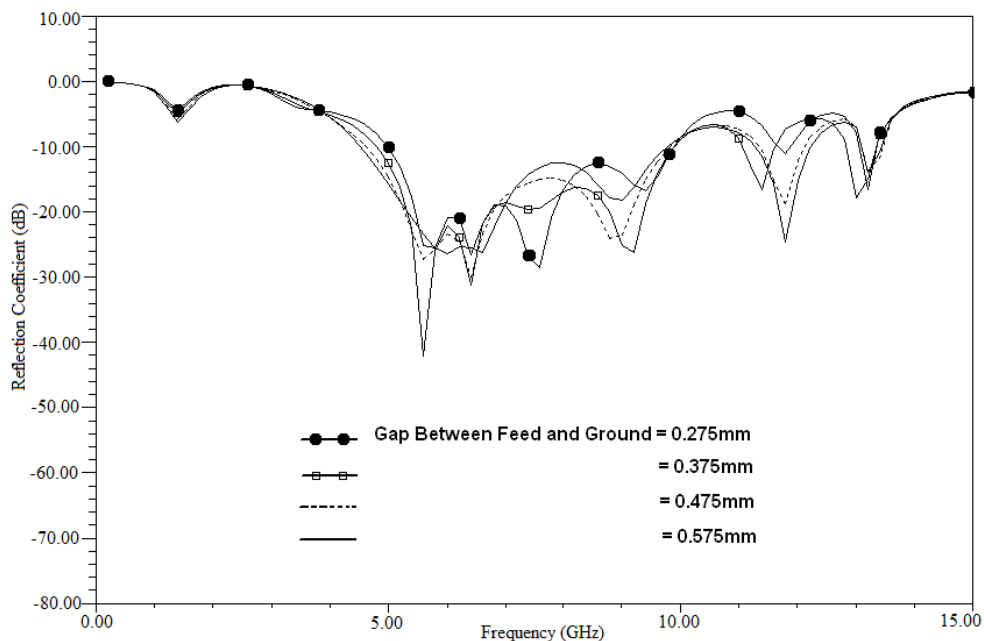

Fig. 5. Simulated results of various gap between feed and ground

C. *Effect of Gap between patch and ground*

The proposed tree-type fractal antenna has also been simulated for the gap between patch and ground. This gap is very critical for the proper coupling of EM energy for wide bandwidth because the current density resides more on edge of patch and on the ground edges near the patch. The simulated result for the various gaps is shown in Fig. 6 for 0.48 mm to 1.08 mm with the step of 0.2 mm. As the gap between patch and ground increases the matching at lower end frequency improves. The overall bandwidth of the antenna increases. The optimum gap between the patch and ground has been achieved 0.68 mm for this proposed antenna. As this gap further increases the impedance matching in the operating band starts deteriorate.
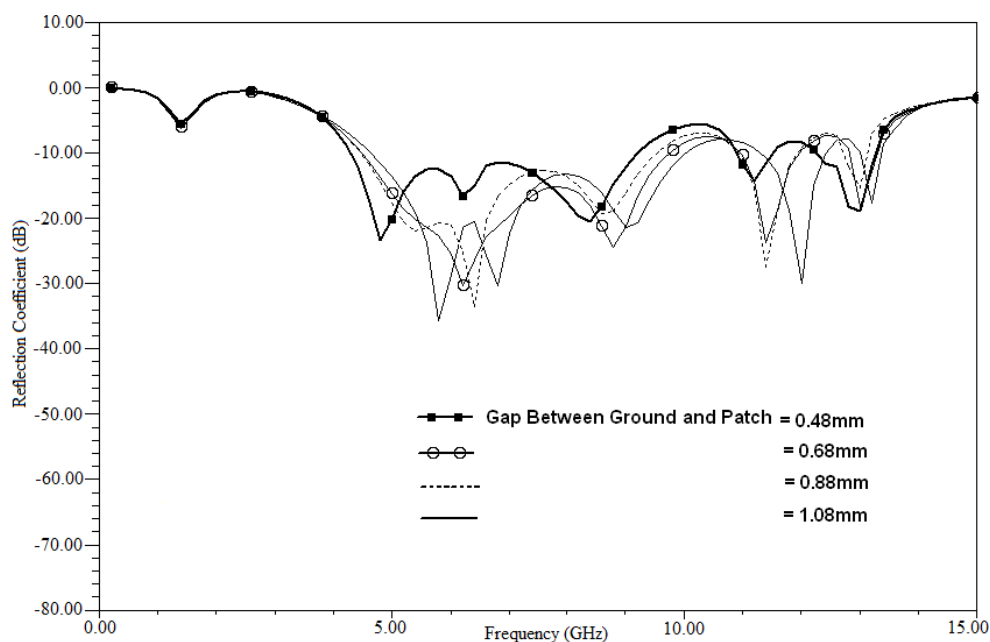
Fig. 6. Simulated results of various gap between ground and patch

D.   *Effect of the Ground Plane Length*

The proposed tree-type antenna has been fed with CPW-feed as shown in Fig. 2. In the proposed antenna, the ground shape is rectangular shape. In the CPW-feed antenna, the rectangular ground plane, feed and radiating patch all are on same side of substrate. In the CPW – feed monopole antenna, the length of the ground plane is very important. The proposed antenna has been simulated for various length of the ground. The length of the ground is optimized. The simulated results of various length of the ground are shown in Fig. 7. It has been optimized with the step of 2 mm from 11.9 mm to 15.9 mm ground length. A little frequency shift is observed at lower frequency side and almost no effect at higher frequency side. This indicates the ground length effect is insignificant. The optimized length for this antenna is achieved 13.9 mm. The quarter wavelength of the ground plane of antenna at 5.0 GHz is 15.0 mm. With this optimized ground length, antenna exhibits the proper bandwidth. Now, overall size of antenna is 31 mm x 32 mm.
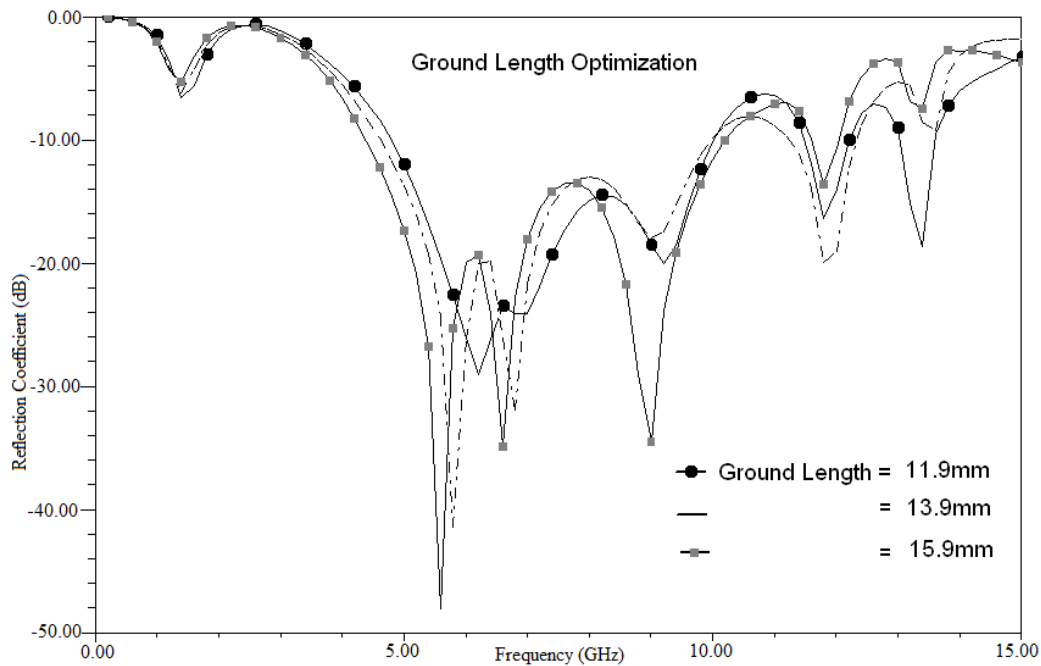
Fig. 7. Simulated results of various ground length

E.   Effect of the Ground Plane Width

Here, the width of the ground plane of proposed tree–type fractal antenna has been optimized and its effect on the antenna bandwidth has been observed. The proposed antenna has been simulated for various ground plane width from 11.425 mm to 15.425 mm with step of 2 mm as shown in Fig. 8. It is observed as the ground width increases, the first resonant frequency slightly shifted to lower frequency side. The width effect is also observed at higher frequency. There is an optimum value of width for wide impedance matching. The ground width affects the impedance matching in the full band because ground acts as a resonant circuit. For proper matching and compact size of antenna, the optimized one side ground width has been achieved 13.425 mm by fixing all others optimized parameters.
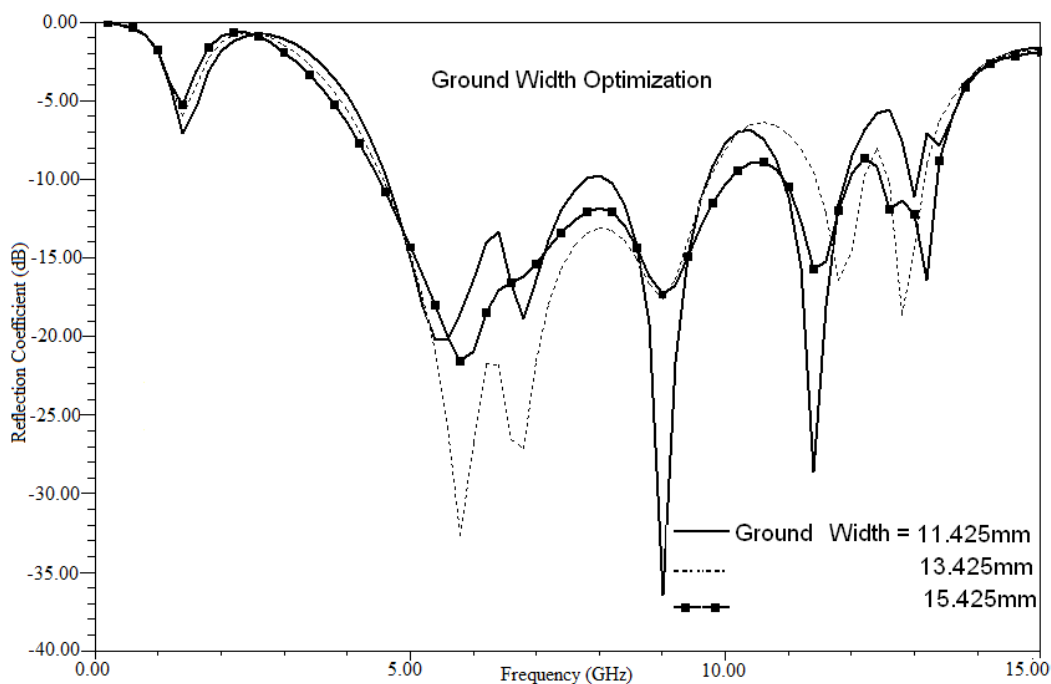
Fig. 8. Simulated results of various ground width

IV.   EXPERIMENTAL RESULTS AND DISCUSSION

The proposed fractal antenna has been fabricated with optimized dimension as shown in Fig. 2. The antenna has been tested using R & S VNA ZVA40. The experimental result of proposed antenna exhibits the excellent UWB characteristics from 4.9 GHz to 14.0 GHz at VSWR 2:1. It corresponds to 96.296 % impedance bandwidth. The antenna is simulated using EM simulator HFSS with optimized dimension. The experimental and simulated results are in close agreement as shown in Fig. 9. The experimental result slightly varies from the simulated result. This may be due to the tolerance in manufacturing, uncertainty of the thickness and the dielectric constant and lower quality of SMA connector (VSWR = 1.3). The differences between simulated and experimental values may also be caused due to the soldering effects of an SMA connector, which have been neglected in our simulations. The SMA connector is not taken into account in all of the simulations so as to ease the computational requirements. It is noticed that this SMA port mainly affects the higher order resonances by shifting their resonant frequencies.

The peak gain of this proposed antenna has also been simulated and shown in Fig. 10. The peak gain of this antenna increases as the frequency increase. This is because the effective area of the antenna increases at the higher frequency because of shorter wavelength at high frequency. Beyond 14.0 GHz, the peak gain of antenna starts decreasing because reflection coefficient becomes poor beyond 14.0 GHz. The maximum value of peak gain is around 6 dBi at 11.5 GHz.
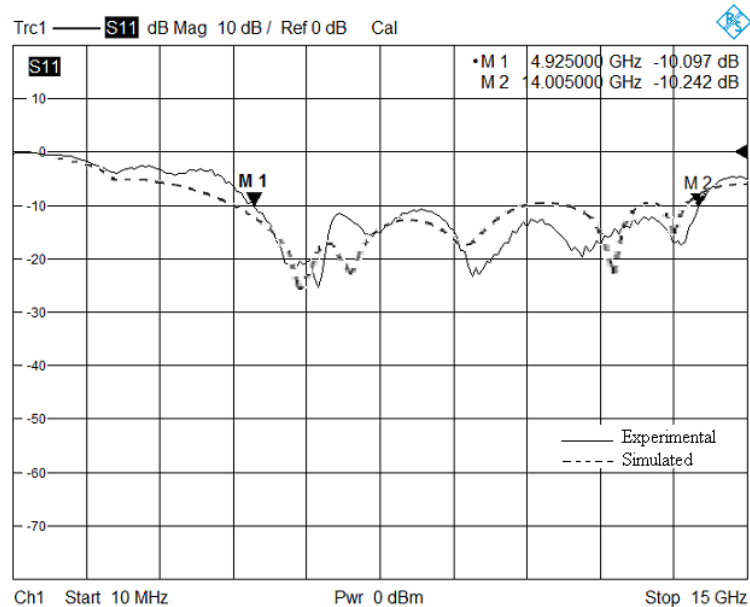
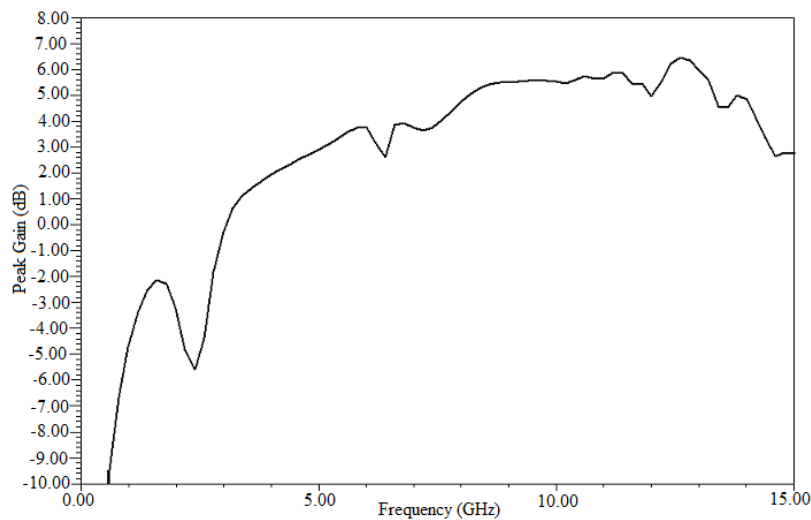Fig. 9. Experimental and simulated result of proposed antenna

Fig. 10. Simulated peak gain of proposed antenna with respect to its iteration

V.   RADIATION PATTERNS

The antenna radiation of this proposed tree–type fractal antenna has been simulated at selective frequencies 4.8 GHz, 6.0 GHz and 8.0 GHz. The E and H – plane radiation patterns on these frequencies are shown in Fig. 11, 12 and 13 respectively. The nature of the radiation patterns in H plane are nearly omni - directional throughout the band. In E-plane, natures of radiation patterns are figure of eight or bidirectional. The radiation patterns in the E and H-plane are almost stable throughout the band except some slight variation.
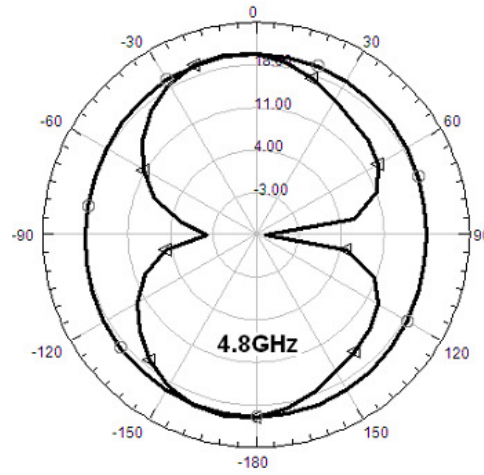
Fig. 11. Simulated E and H-plane radiation pattern of proposed antenna at 4.8 GHz
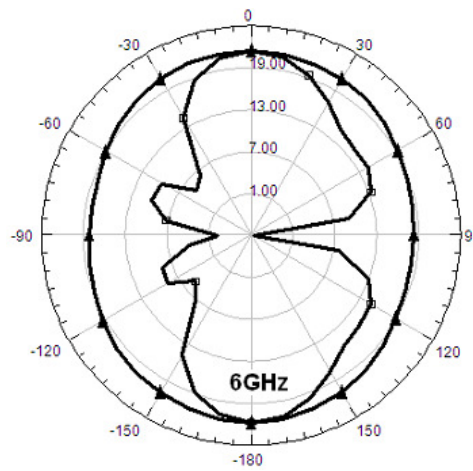

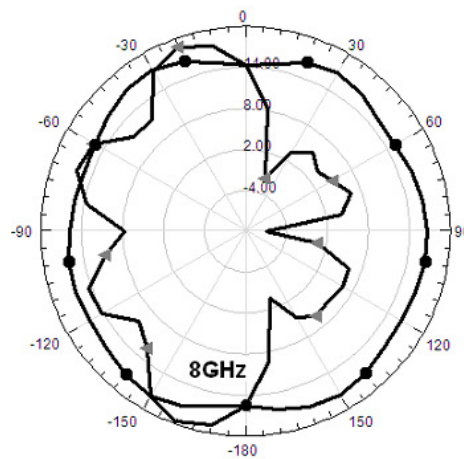Fig. 12. Simulated E and H-plane radiation pattern of proposed antenna at 6.0 GHz

Fig. 13. Simulated E and H-plane radiation pattern of proposed antenna at 8 GHz

VI.   GROUP DELAY AND PHASE VARIATION

The studies of group delay and phase variation are important parameters for UWB system. The group delay has been measured by putting two identical antennas face to face at 30 cm distance in far field region. The experimental group delay versus frequency is shown in Fig. 14. The group delay is less than 1.5 ns in the operating frequency band with two identical antennas. Actually, it will be half of the calculated group delay using two antennas i.e 0.75 ns. It is observed that group delay is almost constant throughout the band. It means variation in the phase is negligible. This indicates the phase linearity. This phase linearity of antenna is important in UWB system to transmit/receive the high data rate pulse without distortion.
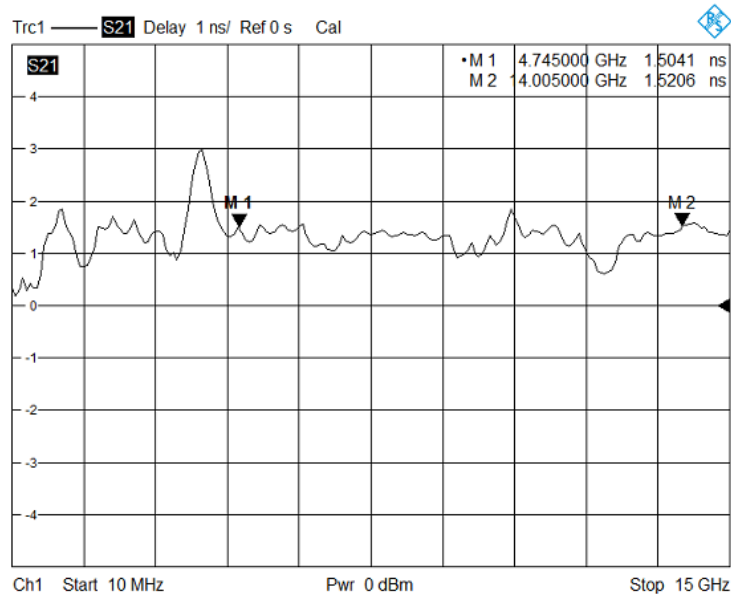

Fig. 14. Experimental group delay of proposed antenna by using two identical antennas at 30 cm

VII.   BACKSCATTERING OF PROPOSED ANTENNA

The study of backscattering is important because antenna contributing significantly in the total RCS of low observable platforms. The RCS of fractal antenna is dependent on the short circuit, open circuit and matched load termination. The short circuit and open circuit termination gives antenna mode scattering. The structural mode scattering can be calculated with matched load termination. The simulated results of monostatic RCS for open, short and matched load termination are shown in Fig. 15. It is observed at higher frequency, the monostatic RCS reduces because the size of object become more than the wavelength. Similarly, at lower frequency the RCS is maximum because object size is less that the operating wavelength.
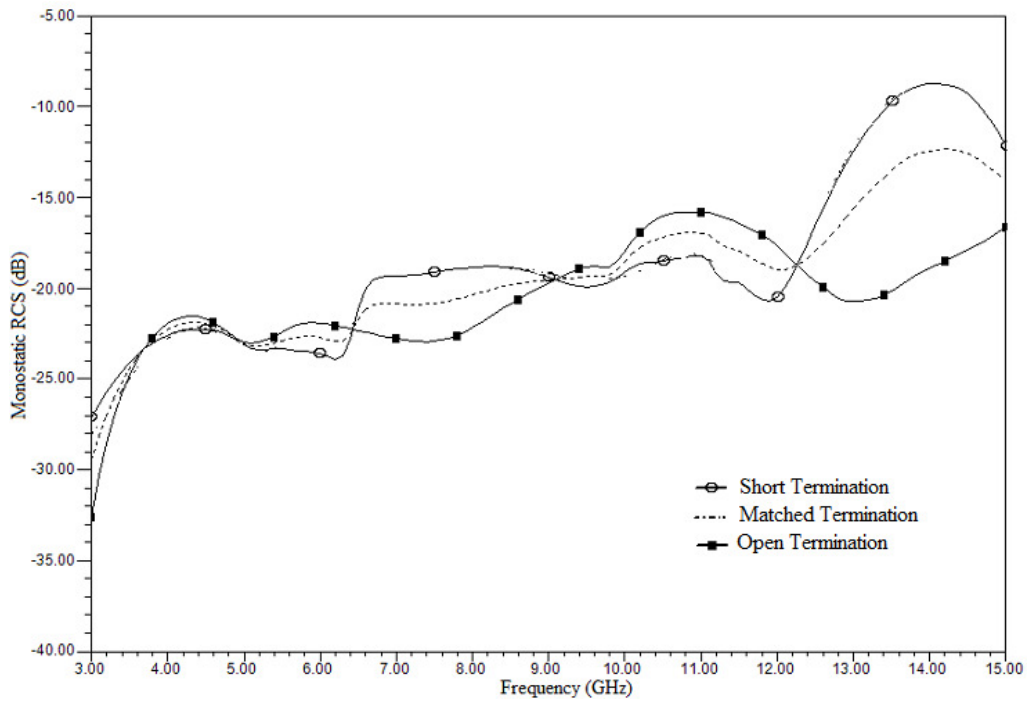
Fig. 15. Simulated results of short, open and matched load termination

The total RCS (σ) of an antenna are divided into two part i.e. RCS of structural mode (σ_s) and antenna mode (σ_a). They are related to each other by $\sigma = \left| \sqrt{(\sigma_s)} + \sqrt{(\sigma_a)}e^{j\Phi} \right|^2$ where Φ is the phase difference between these two modes [13]. The antenna scattering can be calculated for the proposed antenna by using the model proposed in [14]. The antenna scattering for antenna mode and scattering mode can be calculated using following expression

$$\sqrt{\sigma} = \sqrt{\sigma_s} + \sqrt{\sigma_a}e^{j\phi} \tag{1}$$

Where, σ = total RCS of Antenna

σ_s = RCS of Structural Mode

σ_a = RCS of Antenna Mode

For Open Circuit termination,

$$\sqrt{\sigma_o} = \sqrt{\sigma_s} + \sqrt{\sigma_a}e^{j\phi} \tag{2}$$

For Short Circuit termination,

$$\sqrt{\sigma_{sh}} = \sqrt{\sigma_s} + \sqrt{\sigma_a}e^{j(\phi+\pi)}$$

$$\sqrt{\sigma_{sh}} = \sqrt{\sigma_s} - \sqrt{\sigma_a}e^{j\phi} \tag{3}$$

From equations (2) and (3), the structural mode and antenna mode scattering can be calculated

$$\sigma_s = \left| \frac{(\sqrt{\sigma_0} + \sqrt{\sigma_{sh}})}{2} \right|^2 \qquad (4)$$

For antenna mode scattering

$$\sigma_a = \left| \frac{\sqrt{\sigma_0} - \sqrt{\sigma_{sh}}}{2} \right|^2 \qquad (5)$$

In conclusion, the RCS of Structural Mode is the RCS of matched load termination and can also be calculated from equation (4). It is verified from equation (4) and matched load termination. The antenna mode scattering can be calculated from equation (5) using the RCS of open and short Circuit termination. The monostatic RCS with open and short termination is calculated using HFSS. The calculated monostatic RCS for each iteration is shown in Fig. 16. It is observed the monostatic RCS of proposed antenna (3rd iterative antenna) is greatly reduces above 13 GHz. This reduction of RCS is justified from experimental reflection coefficient which becomes poor above 13 GHz. The monostatic RCS is also calculated with respect to aspect angle. The antenna mode scattering RCS with respect to aspect angle can be calculated from monostatic RCS with short and open circuit termination as shown in Fig. 17 at 5 GHz. It is observed monostatic RCS for antenna mode scattering versus aspect angle varies as aspect angle vary.
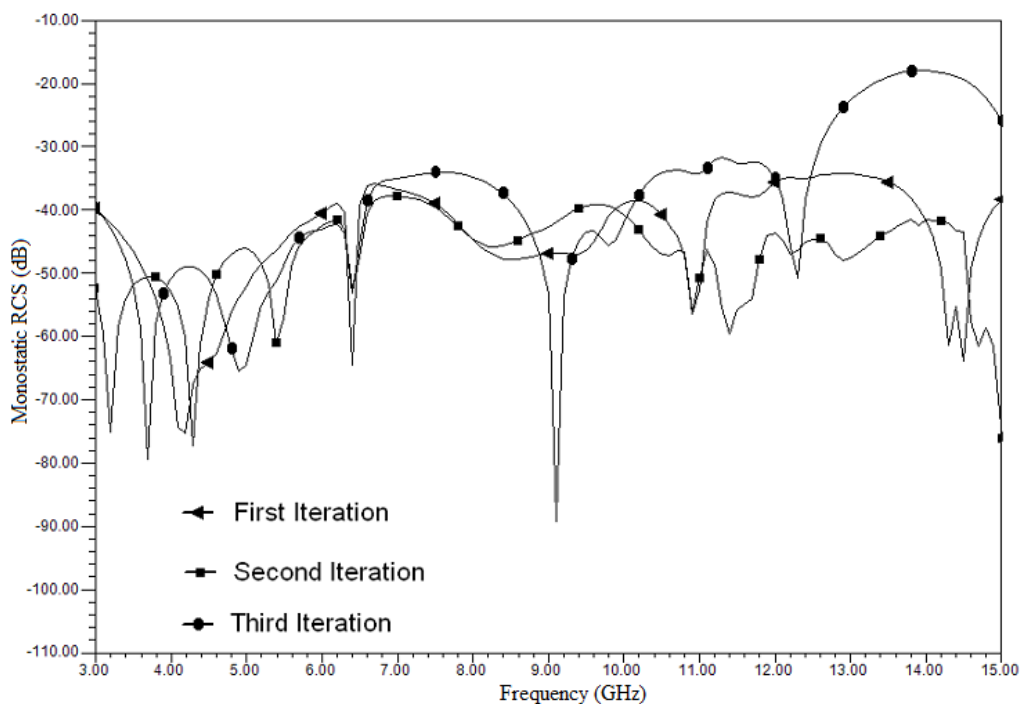

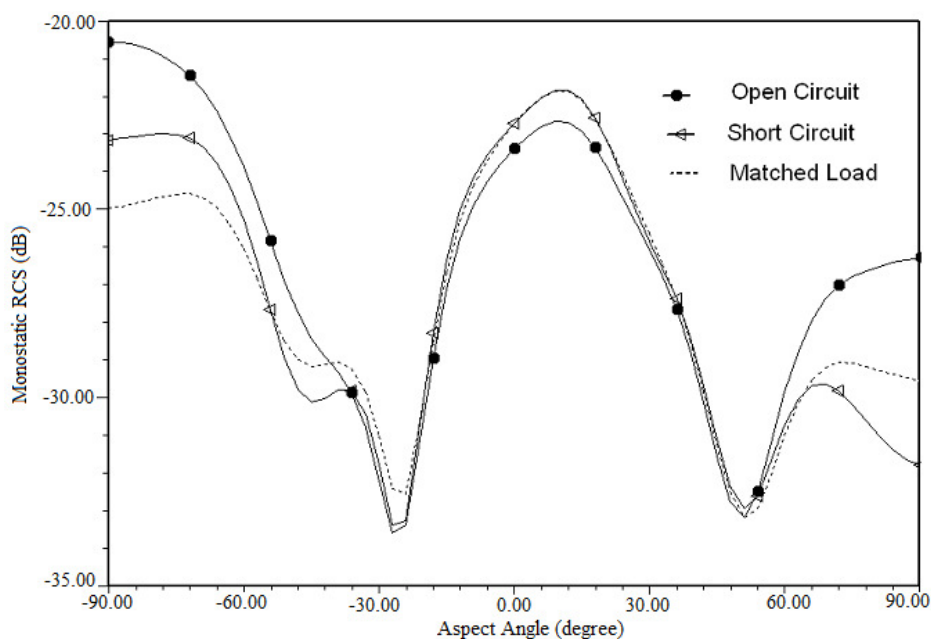Fig. 16. Simulated results of antenna mode scattering for each iteration

Fig. 17. Simulated results with short, open and matched termination versus aspect angle

VIII.   CONCLUSIONS

The proposed tree–type fractal antenna has designed and implemented experimentally. The antenna exhibits 96.297% impedance bandwidth. To achieve UWB characteristics from 5.825 GHz - 10.6 GHz for DS-CDMA system, the effects of various design parameters have been studied thoroughly. The simulated results are found in good agreement with experimental results. The radiation pattern of the antenna is omni-directional in H-plane and bidirectional in E-plane. The group delay of this antenna is less than 0.75 ns. The phase variation is almost negligible throughout the band. The backscattering of this antenna is good through the operating band. This makes the antenna strong candidate for secure and military applications. This antenna is simple to fabrication, compact in size, easy to integrate with the device and MIC/MMIC circuits. Such type of antenna is useful for UWB DS-CDMA system, microwave imaging and vehicular radar.

ACKNOWLEDGEMENT

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