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Design of CPW -Fed Fourth Iterative UWB Fractal Antenna

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Abstract **-This paper presents the fourth iterative UBW Fractal antenna. The UBW fractal antenna has been designed on substrate ε_r = 4.3, thickness h = 1.53 mm with 40 mm radius. This fractal antenna offers the excellent ultra wide bandwidth from 0.88 GHz to 15 GHz corresponding to 177.83 %. The impedance bandwidth of this antenna is 14.12 GHz. The experimental radiation pattern of antenna has been observed nearly omni-directional in azimuth plane. The proposed antenna has been analyzed theoretically and experimentally with respect to design parameters. The simulated results are in good agreement with the experimental results. This type of antenna is useful for UWB wireless communication, microwave imaging and positioning systems.**

Index Terms – **Fractal Antenna, Ultra wide band, resonant Frequency and Impedance Band width**

I. INTRODUCTION

There has been an ever-growing demand of Ultra wide band radio system, which is revolutionizing the major advances in wireless communication, networking, radar, imaging and positioning systems [1]. The antenna is an important element of UWB system. The antenna should possess the small size, conformal, low cost, ultra wide band and ease of fabrication. Microstrip – like antenna is one of them. The limitations of the conventional microstrip antenna are its narrow bandwidth, efficiency, and size [2-3]. The microstrip antenna is an efficient radiator around half wavelength long. As the size of the antenna becomes less than λ/2, the radiation resistance, gain and bandwidth of the antennas deteriorate. Fractal geometry is a very good solution for this problem [4]. These structures recognized by their self-similarity, space filling properties and fractional dimensions. In the recent years, geometrical properties of self-similarity and space filling nature has motivated antenna research to meet the target of multi-band , wideband and miniaturization [5-9]. The fractal antennas based on self - similarity properties have been reported by many authors [5-7] for multi-bands and ultra wide band characteristics. Whereas, antennas based on space filling property lead curves that electrically long but fit into a compact physical size. This property leads to the miniaturization of antennas [8-9].

This paper presents UWB fractal antenna. The new printed-circuit antenna in coplanar technology [10] offers excellent ultra wide bandwidth with compact size. The radiation pattern of antenna is nearly omni-directional. This antenna can be useful for UWB applications, microwave imaging and radar applications.

II. ANTENNA GEOMETRY

The simple conventional circular patch antenna has been shown in Fig. 1. The solid circular patch antenna has been designed on FR4 substrate with ε_r = 4.3, h = 1.53 mm, radius 40 mm. This is called the initiator or zeroth iteration. The first iteration of fractal antenna has been constructed by inscribed the square patch of dimension 56.08 x 56.08 mm inside the circle and subtracted it from circle. The 1st iterative inscribed square circular fractal antenna is shown in Fig. 1a. The 2nd iteration has been achieved by making the circle of radius 28.32 mm and an inscribed square of dimension 40.05 x 40.05 mm has been subtracted from this inner one circle as shown in Fig. 1b. The 3rd iteration is constructed by making the metallic circle of 20.05 mm radius inside the square touching the metallic part of its and subtracting an inscribed square of dimension 28.32 x 28.32 mm. In the fourth iteration, a circle of radius 14.16 mm is made and an inscribed square of dimension 20.025 x 20.025 mm is subtracted and this process can be repeated upto infinite iteration. Practically infinite iterative structure is not possible because of fabrication constraints. The fourth iterative fractal antenna has been finalized to design on the same substrate dielectric constant and thickness as conventional microstrip patch shown in Fig. 2. This antenna has been fed with the coplanar feed.

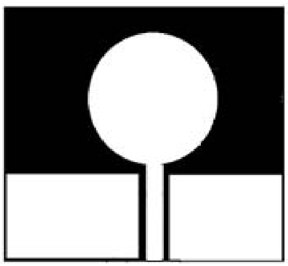

Fig. 1. Zeroth iteration

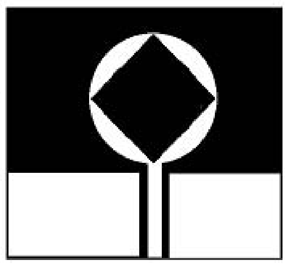

Fig. 1a. 1st iteration

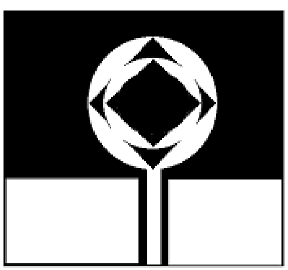

Fig. 1b. 2nd iteration

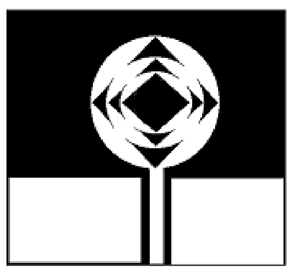

Fig. 1c. 3rd iteration of Circular Fractal Patch

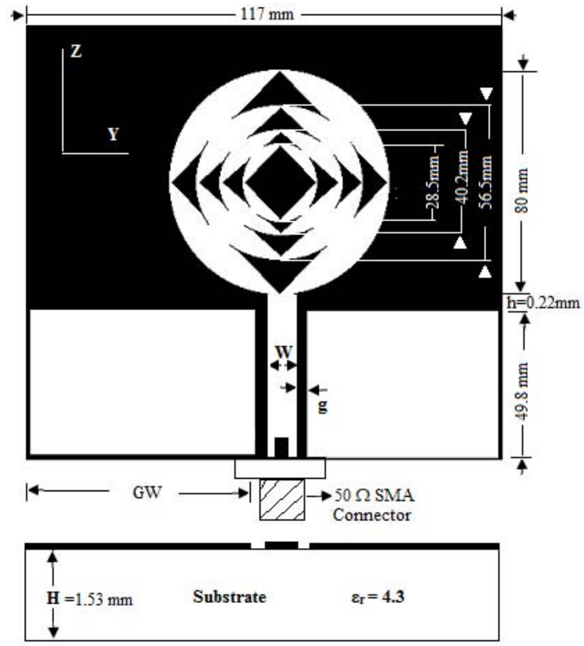

Fig. 2. 4th iterative Circular Fractal antenna with CPW-Fed

III. DESIGN OF CIRCULAR MICROSTRIP ANTENNA

The design expression of simple circular Microstrip patch antenna for calculating the resonant frequency is given below;

$$f_r = 1.841 v_o / 2\pi r_{eff}\sqrt{\epsilon_{eff}} \qquad (1)$$

where v_o is the velocity of light. The effective radius r_{eff} can be calculated by following expression

$$r_{eff} = r_o[1+2h/\pi r_0 \epsilon_r\{\ln(r_0 /2h)+(1.41\,\epsilon_r +1.77) +h/ r_0 (0.268\,\epsilon_r +1.65)]^{1/2} \qquad (2)$$

The dimension of the solid circular patch is taken as a radius 40 mm as shown in Fig. 1. This patch has been designed on FR4 substrate dielectric constant $\epsilon_r = 4.3$ and thickness h = 1.53 mm. This simple monopole antenna has been fabricated. The resonant frequency of the monopole antenna with CPW –Fed patch has been studied for various diameter, which approximately corresponds to the quarter wavelength at resonant frequency.

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IV. DESIGN OF FRACTAL ANTENNA

The final structure of the fractal antenna of fourth order iteration is shown in Fig. 2. The antenna is fed with CPW- fed. The advantages of coplanar feed over conventional microstrip feed lines are lower dispersion characteristics at higher frequencies, broader impedance bandwidth, unipolar configuration and ease of integration with active devices as it does not require backing ground plane. In the Coplanar technology, no via is required for ground purpose. So, this technique is less costly than microstrip feed. In CPW – fed, the 50 Ω impedance is achieved by adjusting the width (w) of the inner conductor and the gap width (g) between the ground plane and the inner conductor. It is also relevant to the relative permittivity and the thickness of the substrate. In this paper, the Teflon substrate with thickness of 1.53 mm and relative permittivity of $\varepsilon_r = 4.3$ is used. The width of coplanar line, gap between ground plane and feed line, gap between ground plane and radiating patch, width and length of ground plane effects the lower end frequency and as well as ultra wide bandwidth. These parameters have been optimized using 3D electromagnetic Software.

In the proposed, new 4^{th} iterative circular fractal antenna, the self - similarity and space filling fractal properties has been used to design the fractal antenna. Fractal antenna has been truncated with the finite iteration. The 4^{th} iterative fractal antenna has been designed on the same substrate and dimension of the simple patch. It is seen that effect of fractal geometry shifts the resonant frequency because of removal of metallization. It is because the current is mainly distributed along the circumference of the antenna as shown in Fig. 3. This results low current density in the middle area of the circular fractal antenna. So, the current will not be affected if the middle area of the circular shaped antenna is slotted. This increases the effective path of the surface current will become longer. In other sense, the first resonance frequency will be shifted lower side and the size of the antenna will be reduced. To achieve the UWB characteristic, the fractal structure has been added to increase the resonance frequency in high frequencies by adding four resonance elements with the self-similarity and space filling property.

The simulation is performed using 3-D electromagnetic simulator which utilizes the Finite Difference and Time Domain (FDTD) method. A prototype of the proposed fourth iterative fractal monopole antenna with optimal design, r=40 mm, h=0.22 mm and substrate width =117 mm, W=3.2 mm and g=0.5 mm as shown in Fig. 2 has been fabricated.

V. SIMULATION AND EFFECT OF DESIGN PARAMETERS

It is noticed in simulations that the operating bandwidth of the proposed antenna is heavily dependent on the gap between ground plane and patch h, Number of iteration, diameter of the disc r and ground length. So these parameters should be optimized for maximum bandwidth for the antenna design. First, fractal antenna has been simulated for each iteration. It is clear from the Fig. 4, as the iteration increases the first resonant frequency shifted towards lower side. It is also found that as the number of iteration increases, the lower-edge of the impedance bandwidth is moved to the low frequency and the level of the impedance matching over the operating frequency band is improved. The fourth iterative fractal antenna gives the impedance matching in UWB characteristic. The simulated results of each iteration i.e. return loss Vs frequency has been shown in Fig. 4.

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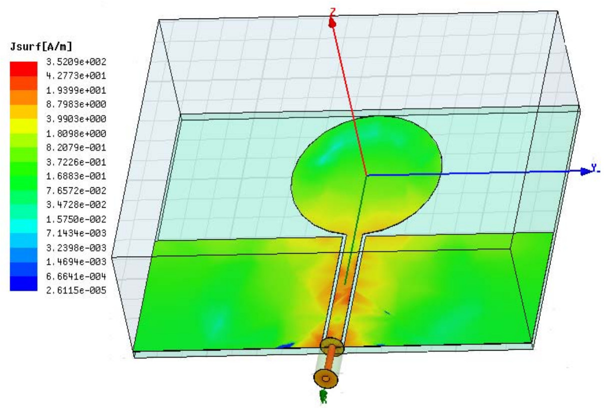

Fig. 3. Current Distribution on the monopole Patch Antenna

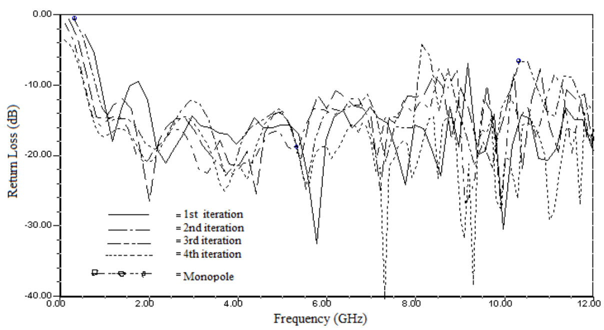

Fig. 4. Simulated results with respect to each iteration

As shown in Fig. 3 , the current is mainly distributed along the edge of the fractal antenna disc. This is the reason why the first resonant frequency is associated with the diameter of the circular disc. On the ground plane, the current is mainly distributed on the upper edge along the x-direction, which explains why the performance of the antenna is critically dependent on of h gap between ground plane and patch. The parameter h is very critical parameter for proper coupling from feed line to patch which effect the UWB characteristic. The proposed fractal monopole antenna has been simulated for various values of gap. The simulated results have been shown in Fig. 5. It has been observed from graph that gap (h) between ground and patch effects the lower end frequency and bandwidth. The fourth iterative fractal antenna has been simulated for optimal value of gap as shown in Fig. 5. The fourth iterative proposed fractal antenna has been fabricated with gap h=0.22 mm, 50 Ω feed with W=3.2 mm and g=0.5 mm.

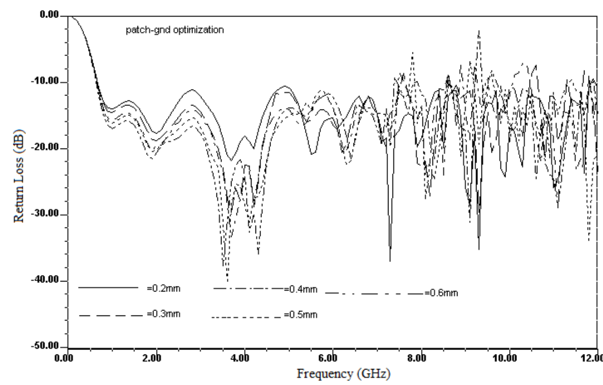

Fig. 5. Simulated result of fractal antenna with respect to gap between ground plane and patch

Here the effect of the dimension of the disc is analyzed. It is observed that the first resonant frequency decreases with the increase of the diameter of the disc. The relationships between the diameters and the first resonances are shown in Fig. 6. The first resonant frequency is determined by the diameter of the disc, which approximately corresponds to the quarter wavelength at this frequency. So the lower end frequency of the operating bandwidth of the antenna is directly determined by the diameter of the disc. Fig. 6 shows the simulated return loss curves for different dimensions of the circular disc monopole antenna with their respective optimal designs (r =40 mm, h= 0.22mm, r=25mm, h= 0.3, r =15 mm, h=0.35 mm, r = 10mm, h= 0.4mm and r =7.5 mm with h=0.42mm). The first resonant frequency of 40 radius circular disc monopole antenna is around 1.15 GHz.

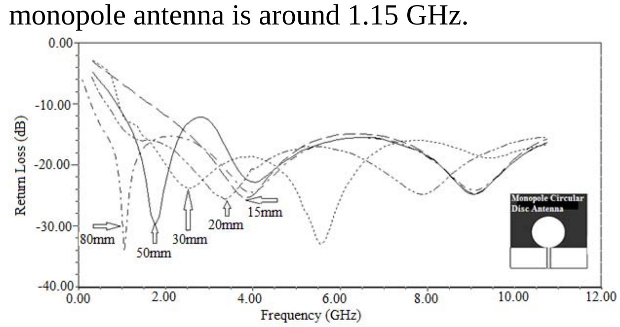

Fig. 6. Simulated result of monopole antenna with various diameter of circular disc.

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VI. DISCUSSION EXPERIMENTAL RESULTS

The fourth iterative fractal antenna has been designed and fabricated on FR4 substrate with the dielectric constant ε_r = 4.3 and h =1.53 mm. The fourth iterative fractal antenna has been fed with CPW- fed. In CPW - fed, the 50 Ω impedance is achieved by taking the width *w* =3.2 mm of the inner conductor and the gap width g = 0.5 mm between the ground plane and the inner conductor. The gap between fractal antenna and ground has been taken 0.22 mm. The antenna has been designed and fabricated.

The circular disc monopole antenna and proposed four iterative fractal antennas have been tested on vector network analyzer ZVA40. The first resonant frequency of conventional solid circular disc monopole of r = 40mm was experimentally measured around 1.1 GHz. The experimental results i.e. return loss versus frequency has been shown in Fig. 7.

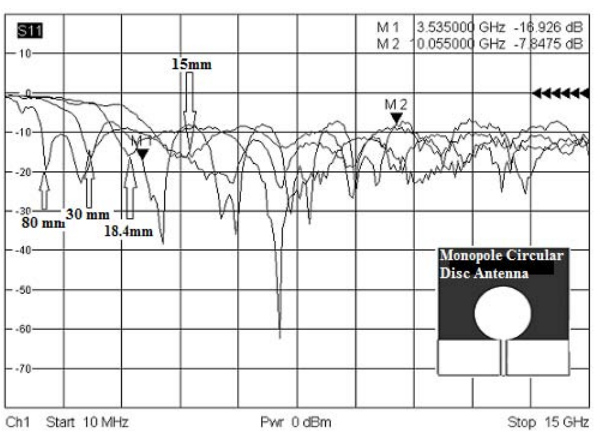

Fig. 7. Experimental result of monopole antenna with various diameter of circular disc.

In Fig.7, the relation between the various diameter of circular disc monopole antenna and their first resonant frequencies have been shown experimentally . This graph reveals as diameter of the disc increases the first resonant frequency reduces to lower frequency side.

The fractal geometry has been incorporated in the solid simple circular patch with four iterations. The photograph of this fourth iterative antenna is shown in Fig. 8. This antenna offers the excellent ultra wide bandwidth from 0.88 GHz to 15 GHz. The impedance bandwidth of this antenna is 14.12 GHz which corresponds to 177.83 %. Fig. 9 shows the experimental and simulated return loss versus frequency of proposed fourth iterative circular fractal antennas. It has been observed that the lower end resonant frequency of the fractal antenna is shifted at 0.88 GHz in comparison to conventional simple circular disc monopole antenna 1.1 GHz. It indicates the size reduction of antenna by the application of fractal feature.

Fig. 8. Photograph of Fourth Iterative Monopole Fractal Antenna

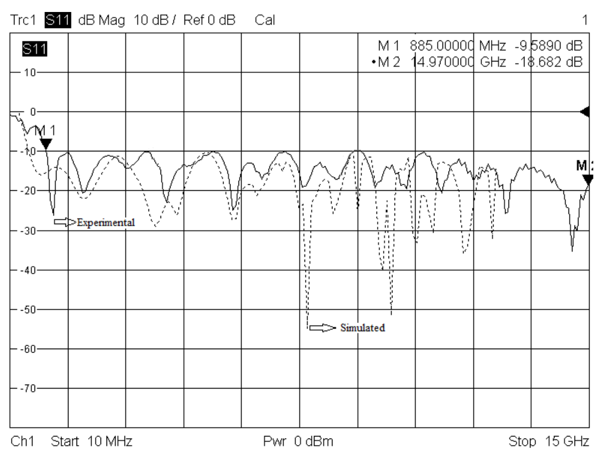

Fig. 9. Experimental and simulated results of fractal antenna

The experimental results of fractal antenna with respect to each iteration has been shown in Fig. 10. It is observed as the iteration increases the first resonant frequency shifted to lower frequency side and matching improved at the higher frequency. The fourth iterative structure gives the UWB characteristics of fractal antenna. The experimental results are in good agreement with the simulated results. The impedance behavior of this fractal with respect to frequency exhibits clearly the good matching of antenna from 0.88 GHz to 15 GHz or beyond as shown in Fig. 11.

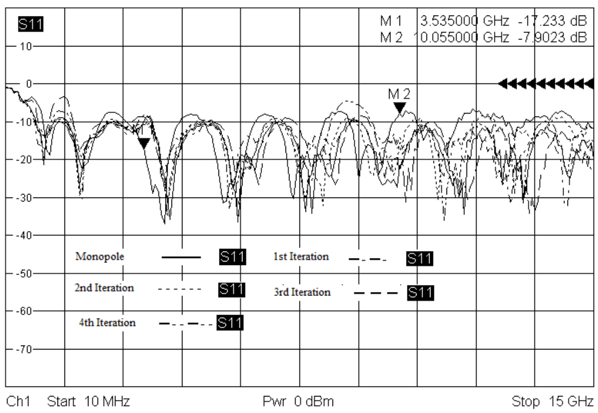

Fig. 10. Experimental results of fractal antenna with respect to iteration

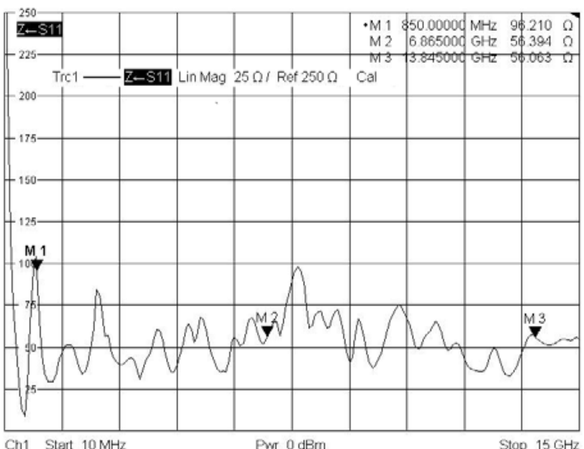

Fig. 11. Experimental impedance of 4^{th} Iterative circular fractal antenna

It is observed that simulated and measured results are slightly varies. This may be due to the tolerance in manufacturing, uncertainty of the thickness and/or the dielectric constant of the substrate and lower quality of SMA connector (VSWR = 1.3). The differences between simulated and experimental value may also be caused by the soldering effects of an SMA connector, which have been neglected in our simulations.

The radiation pattern of this antenna has been measured in house anechoic chamber. The radiation pattern has been measured at the selective frequencies at 1.023 GHz, 2.05 GHz, 3.25 GHz, 7.8 GHz and 10.43 GHz respectively. The radiation pattern is nearly omni-directional as shown in Fig. 12-14. At higher frequency, the ripple in radiation pattern increases because of edges reflection. The gain of antenna is less than 5 dBi. The cross polarization of antenna is shown in Fig. 15 and 16. The experimental cross to co polarization ratio is better than 16 dB at lower frequency but reduces as frequency increases**.**

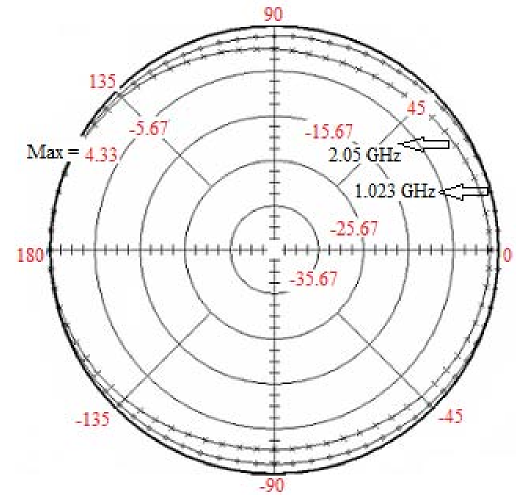

Fig. 12. Experimental radiation pattern of fractal antenna at frequency at 1.023-1.683 GHz

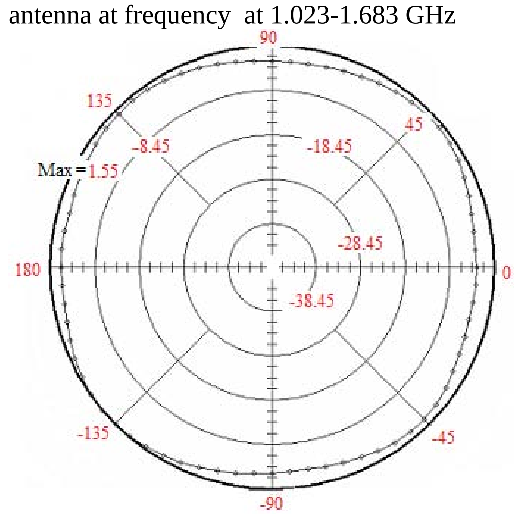

Fig. 13. Experimental radiation pattern of fractal antenna at frequency 3.25GHz

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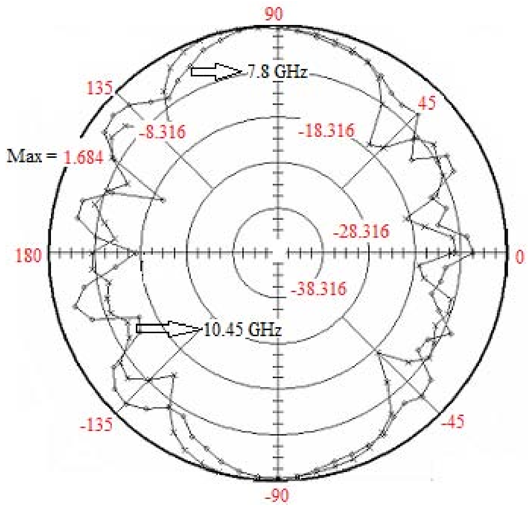

Fig. 14. Experimental radiation pattern of fractal antenna at frequency 7.8-10.43 GHz

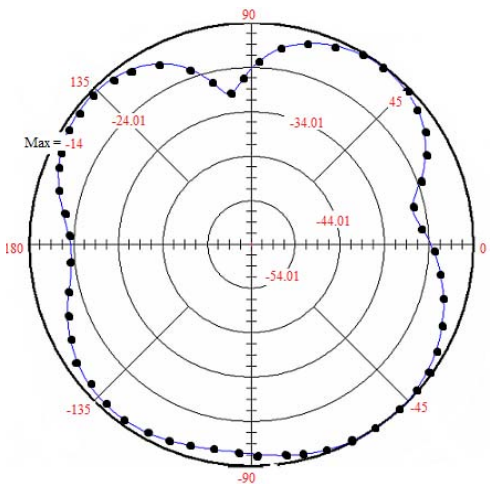

Fig. 15. Cross polarization of fractal antenna at frequency 1.05 GHz

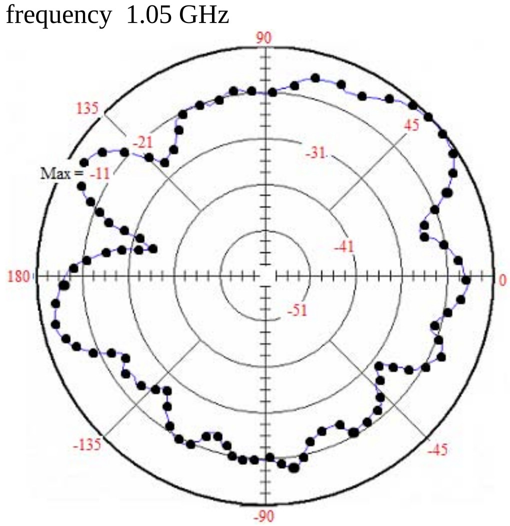

Fig. 16. Cross Polarization of fractal antenna at frequency at 5.78 GHz

To get insight a short-range UWB communication system, a stable group delay performance is a primary requirement. If not, the impact on the signal transmission will be significant, especially on the received waveforms. To measure, two identical antennas are fabricated and setup as depicted in Figure 17, via a vector network analyzer. Since the output power of this VNA is relatively small, the distance between the two proposed fractal antennas was around 50 mm. Maximum measured group delay of the antenna from 3.0 GHz to 16 GHz is around 0.50 ns. Therefore, it is expected that pulse transmitted or received by the antenna will not distort seriously and will retain its shape in this frequency range. This indicates that the proposed antenna has the superior pulse handling capabilities as demanded in modern communication systems. This antenna can be useful for UWB wireless system for transmitting the very high data rate.

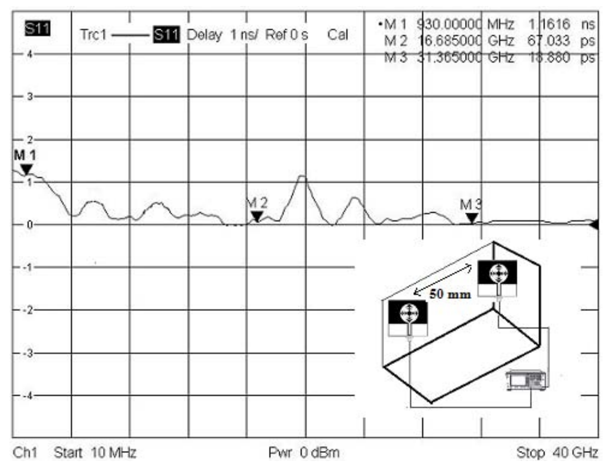

Fig. 17. Group Delay of fourth iterative circular shape fractal antenna

VII. CONCLUSION

The new prototype fourth iterative UWB circular fractal antenna has been studied. This antenna offers the ultra wide bandwidth of 177.83 % and size reduction in comparison to the conventional circular monopole antenna. The experimental impedance bandwidth of antenna is 14.12 GHz cover the bands L, S, C, X and above. The group

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delay variation of antenna is around 0.5 ns from 3.0 GHz to 16 GHz. The antenna exhibits the nearly omni – direction radiation pattern in azimuth plane. This fourth iterative fractal antenna has the privilege of size reduction and ultra wide bandwidth. The use of coplanar ground plane makes the design conformal and more suitable for the miniaturized applications. Parametric studies are also presented to show the effects of different parameters on the antenna design. The measurement results have shown a good agreement with the simulation ones. This antenna can be useful for modern UWB wireless communication, positioning Systems, microwave imaging and radar applications.

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