Modified L-Shaped CPW - Feed for UWB Fractal Antenna

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Abstract - This paper presents the ultra wide band antenna with L-shape CPW – feed. The fractal antenna has been fabricated on FR4 substrate $\varepsilon_r = 4.3$ with thickness $h = 1.53$ mm. The circular disc fractal monopole antenna has been constructed with scale factor of 0.5 by incorporating equilateral triangle in solid circle of $18.2$ mm diameter. The experimental results of this antenna exhibits the ultra wide band characteristic from $2.465$ to $15.0$ GHz. Measured impedance bandwidth is achieved $12.535$ GHz corresponds to $143.54$ %. Using L - shape ground, good improvement in the gain is achieved. The experimental radiation pattern exhibits the directionality indicates the gain improvement. The space filling property, which is able to add more electrical length in less volume, can be utilized to miniaturize antennas [11-12]. These planar fractal antennas exhibit radiation patterns similar as quasi-omnidirectional radiators. This feature is desirable for UWB communication systems, whereas it is a strong limitation in the case of radar and satellite applications because of limited gain. A gain enhancement technique is required for UWB fractal antenna to employ it in radar applications.

Index Terms – Antenna, Resonant frequency, Fractal antenna and CPW – Fed, UWB

I. INTRODUCTION

Ultra wide band (UWB) communication have attracted great interest lately being one of the most promising technologies for short range mobile systems. UWB system use short duration pulses of some sub nanoseconds to transmit coded signal [1]. UWB technology seems adequate to numerous potential applications such as radars, ground penetration radars, through the wall or medical imaging, precision location systems and other military communications setup. In UWB system, antenna is the key component with its all desired feature for UWB system. Recently, UWB antenna research tends to focus on planar monopole antennas as they are more practical in terms of simple structure, light weight, manufacturing and integration with the entire system. Several printed planar monopole and fractal monopole antennas have been reported for UWB applications [2-8]. The fractal antenna has been realized so far with multi frequency feature and miniaturization of antenna. Self – similar object look “roughly” the same at any scale is useful for multi band and UWB behavior [9-10]. The space filling property, which is able to add more electrical length in less volume, can be utilized to miniaturize antennas [11-12]. These planar fractal antennas exhibit radiation patterns similar as quasi-omnidirectional radiators. This feature is desirable for UWB communication systems, whereas it is a strong limitation in the case of radar and satellite applications because of limited gain. A gain enhancement technique is used in[13] by employ an additional corner partial microstrip ground plane as a reflector. As it is understood, the gain of fractal antenna is less then the gain of conventional planar monopole antennas. So enhancement in the directionality of fractal antenna is essential because incorporation of fractal geometry in antenna reduces the size of antenna. So, a gain enhancement technique is required for UWB fractal antenna to employ it in radar applications.

A very few efforts have been made to increase directionality of printed UWB fractal antenna. In this, ground plane of the antenna is carefully designed in order to enhance the directionality of the radiator in comparison to conventional printed fractal monopole antenna. This antenna has been characterized in term of impedance bandwidth, radiation pattern and gain.

II. FRACTAL GEOMETRY OF ANTENNA

The simple circular disc monopole antenna has been designed on substrate dielectric constant $\varepsilon_r$. 
= 4.3, thickness h = 1.53 mm and conductor thickness 35 \( \mu \)m, with radius 9.1 mm as shown Fig. 1a. The circular fractal antenna has been designed on the same substrate with same dimension. The fractal antenna has been constructed iteration-wise from the solid circular disc of 18.2 mm diameter. In first iteration, an equilateral triangle of 15.76 mm side length has been subtracted from simple solid circular disc monopole antenna. This is called the first iteration of the antenna as shown in Fig. 1b. In second iteration, a circle of half radius of original circle has been made and an equilateral triangle of 7.88 mm side length has been subtracted. This is called second iteration of the fractal antenna as shown in Fig. 1c. In the third iteration, the equilateral triangle of the side length 3.94 mm have been subtracted from the circle of diameter 4.55 mm. This is called 3\(^{rd}\) iteration as shown in Fig. 1d. Like this, the process can be repeated infinite time. The infinite iterative structure is impossible to fabricate. In this paper, a third iterative fractal antenna has been finalized for study.

![Fractal antenna with iteration-wise](image)

Fig. 1 Fractal antenna with iteration-wise

The proposed geometry of UWB fractal antenna consists of a printed circular disc with 3\(^{rd}\) iteration, and CPW – feed with L- shape ground plane. The disc radiator, which has a radius 9.1 mm is printed in the front of FR4 substrate. The substrate size of antenna is in length 50 mm and the width 51 mm. The ground plane width W1 along x-axis and width W2 along y-axis forms the CPW-fed, whereas the conductor ground plane alongside parallel to x-axis (width W3) acts as a reflector. These are the key element which is introduced to improve directionality. The excitation is launched through a 50 \( \Omega \) coplanar feed line, which has the length of 15 mm and the width W = 3.2 mm and gap between ground and feed 0.5 mm. The critical parameter h = 0.4 mm denotes the gap between the disc radiator and the ground plane.

### III. DESIGN OF CIRCULAR MICROSTRIP ANTENNA

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

\[
f_r = \frac{1.841v_o}{2\pi r_{eff}}\sqrt{\varepsilon_{eff}}
\]

(1)

Where \( v_o \) is the velocity of light. The effective radius \( r_{eff} \) can be calculated by following expression;

\[
r_{eff} = r_o [1 + 2h/r_o e_r \{ln(r_o/2h)\} + (1.41\varepsilon_r + 1.77) + h/r_o (0.268\varepsilon_r + 1.65)]^{1/2}
\]

(2)

Where \( r_o \) is radius of the circular patch, \( \varepsilon_r \) dielectric constant of the substrate and \( h \) the thickness of the substrate.

![L-shape CPW - fed fractal antenna](image)

Fig. 2 L-shape CPW - fed fractal antenna

### IV. MICROSTRIP PATCH TO PLANAR MONOPOLE ANTENNA [14]

The monopole antennas are special cases of the microstrip antennas. The bandwidth of the microstrip antenna increases with an increase in the substrate thickness and with a decrease in the dielectric constant of the substrate. However, an increase in the substrate thickness gives rise to two problems. First, the surface waves gives rise to an increase in the probe inductance and difficult to get good impedance matching. The large inductive input impedance can be taken care of by feeding the patch with a shorter probe of length \( s \), as shown in Figure 3b.
In this case, the patch is fed along the periphery, and an additional perpendicular ground plane is required. If the substrate thickness $h$ is very large, bottom ground plane would have a negligible effect, and hence can be removed. This configuration becomes similar to that of a planar monopole antenna as shown in Figure 3c.

Now, a planar circular disk monopole antenna can be thought of as a version of circular microstrip patch. The approximate resonance frequency is calculated theoretically using the microstrip formulations for the circular microstrip patch as given below

$$f_r = \frac{1.841 \nu_o}{2\pi r_{\text{eff}}} \quad (3)$$

where $r_{\text{eff}}$ is the effective radius and $\nu_o$ is the velocity of the wave in free space and $\varepsilon_{\text{eff}} = 1$.

V. FRACTAL GEOMETRY FOR COMPACT SIZE AND UWB

A circular disc fractal antenna with L-shape CPW-feed for UWB applications has been proposed as shown in Fig. 2. It is understood that current distribution of the proposed antenna is mainly along the circumference of patch. The current density is low in the middle area of the solid circular disc antenna as shown in Fig. 4. Therefore, the current will not be affected if the middle area of the solid circular disc antenna is removed by inscribing equilateral triangle with three iteration. This resulted, the first resonance frequency will decrease and the size of the antenna will reduced. To achieve the UWB characteristic, the fractal structure can be added to resonance frequency in high frequencies by adding resonance elements in as shown in Fig. 1. The other parameters which affects the impedance bandwidth characteristic of antenna are gap between ground plane and radiating patch, width of the ground plane, and length of ground plane, gap between feed and ground plane and diameter of the patch. The L-shape ground effects the gain of antenna. These parameters are crucial and have been optimized for UWB characteristics and validated experimentally.

![Fig. 4 Current distribution on the circular disc monopole Antenna](image)

A. Effect of Ground Length

The proposed fractal antenna has been simulated for various length of the ground plane. The ground plane length is varied from 13 to 17 mm with steps of 1 mm when feed width 3.2 mm, gap between patch and ground 0.4mm, gap between feed and ground 0.5mm, ground width 23.4 mm are fixed. As the length of the ground plane increases, the lower edge of the bandwidth increases slightly, while the upper edge is almost constant. This is clearly observable near the second, third and fourth dips of the return loss characteristics curve as shown in Fig. 5.

![Fig. 5 Effect of various values of ground Length](image)

This result reveals that the antenna bandwidth is not heavily dependent on the length of the ground plane. This is because the current is mainly distributed along the x-direction (along the width of ground plane).

B. Effect of ground Width

The proposed antenna has been simulated for various ground plane width from 18.9 mm to
26.9 mm with step of 2.0 mm when feed width 3.2, gap between patch and ground 0.4mm, gap between feed and ground 0.5mm, ground length 15 mm are fixed. The simulated results are shown in Fig. 6. It can be seen from simulated results that the variation of the ground plane width shifts all the resonance modes across the operating frequency. It is interesting to notice that the -10 dB bandwidth is reduced when the width of the ground is either too wide or too narrow. This corresponds to a decrease or increase of the inductance of the antenna if it is treated as a resonating circuit, which causes the first resonance mode either up-shifted or down-shifted in the spectrum. The optimal width of the ground plane is found to be at W=23.4mm.

![Fig. 6 Effect of various values of ground width](image)

**C. Effect of L-Shape Ground**

The L shape ground in the CPW-feed is incorporated to enhance the gain of antenna. Because this L-shape ground works as a reflector. The effect of L-shape ground on return loss and gain have been simulated. It is observed as the L-shape ground width increases towards the patch, the return loss deteriorates as shown in Fig. 7.

![Fig. 7 Effect of L-shape ground width](image)

The gain of the simple CPW-feed ground plane and L-shape CPW-feed ground plane for ground width 13.1 mm are compared in section VI. It is observed the gain with L-shape ground plane is improved considerably.

**D. Effect of Diameters**

Here, the dimension of the circular disc monopole antenna has been taken 18.2 mm diameter. The first resonant frequency of monopole antenna depends on the diameter of circular disc. Here, circular disc of various diameters have been fabricated and tested. It is observed as the diameter of circular disc increases, the first resonant frequency decreases. The experimental results of various circular disc monopole antennas are shown in Fig. 8.

![Fig. 8 Experimental results of circular disc monopole antenna with various diameters](image)

**VI. EXPERIMENTAL RESULTS AND DISCUSSION**

The proposed fractal antenna has been designed and fabricated with optimized dimension. The measured result of this antenna has been obtained from VNA R & S ZVA40 as shown in Fig. 9. This fractal antenna offers the excellent ultra wide bandwidth from 2.465 GHz to 15 GHz or more. The bandwidth more than 143.54 % is achieved. The antenna is simulated using HFSS. The experimental and simulated results are in good agreement. It is also clear by the application of fractal antenna, the first resonant frequency of fractal antenna is shifted to the 2.465 GHz in comparison to simple circular monopole antenna as in Fig 8 and 9. This indicates the size
reduction of the antenna. The simulated gain of antenna with simple and L-shape ground is shown in Fig. 10. It is observed the gain with L-shape ground plane is improved considerably. The peak gain of the proposed fractal antenna is 7.8 dBi whereas conventional fractal antenna is around 3.6 dBi at 10.5 GHz.

The experimental radiation patterns of this fractal antenna have measured in-house anechoic chamber. The radiation patterns in azimuth plane are measured at selective frequencies 3.085, 4.085, 4.25, 5.423, 9.0, 10.35 and 12.15 GHz as shown in Fig. 11, 12 and 13. The nature of radiation patterns of the antenna is directional in broadside as against to the omni-directional nature of conventional fractal antenna. It is clear that this directionality of radiation patterns is due to L-shape of the ground plane which works as a reflector. Because of this reflector, the gain of the antenna increases in comparison to conventional fractal antenna. Cross polarization of proposed fractal antenna has also been measured at various frequencies 4.32, and 5.45 GHz as shown in Fig.

14. It is observed that cross to co-polarization ratio is better at lower frequency in contrast to higher frequencies. This proposed antenna can be useful for UWB system and radar applications.
CPW-feed circular fractal antenna has been designed and demonstrated experimentally. It is shown that the proposed antenna covers operating ultra wide bandwidth included in FCC-defined band and beyond. It has also been observed that the proposed antenna exhibits the improvement of gain in comparison to conventional monopole and retains their simple and compact structure. Moreover, the proposed printed fractal monopole antenna with special structured ground plane exhibits good properties in terms of bandwidth and radiation patterns. The proposed design is compact, low profile, and offers very large impedance bandwidth required of next generation UWB system. The use of coplanar ground plane makes the design conformal and more suitable for the miniaturized applications. The idea of shaping the radiation patterns of planar fractal antennas through the employment of structured ground plane can be further developed for design of ultra compact, efficient and highly directional antennas for radar and satellite applications as well as for various military and commercial wideband applications.

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Fig. 14 Cross polarization measured at frequencies 4.322 and 5.45 GHz