ON THE DESIGN OF ULTRA WIDE BAND ANTENNA BASED ON FRACTAL GEOMETRY

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ABSTRACT
This paper presents ultra wide band circular fractal antenna. The antenna has been fed with coplanar waveguide (CPW) feed. This fractal antenna has been designed and fabricated on FR4 substrate $\varepsilon_r = 4.3$ and thickness $h = 1.53$ mm with initial diameter of solid circular disc 15 mm. The experimental result of circular fractal antenna exhibits the ultra wide band (UWB) characteristic from 3.295 GHz to 13.365 GHz corresponds 120.88 % impedance bandwidth. The first resonant frequency of fractal antenna shifted to 3.75 GHz in comparison to first resonant frequency 4.31 GHz of conventional simple circular disc monopole antenna. This indicates the size reduction of antenna. The measured radiation pattern of this fractal antenna is nearly omni-directional in azimuth plane throughout the band. This type of antenna can be useful for UWB system and sensing applications.

Keywords: Circular microstrip antenna, Monopole antenna, Multi-band antenna, UWB fractal antenna, multiband, Resonant frequency and CPW-feed.

1. INTRODUCTION

The ultra wideband (UWB) system have become emerging research topic in the field of modern wireless communications since Federal Communication Commission (FCC) band 3-1 to 10.6 GHz declared in Feb. 2006. The UWB system required the UWB antenna of unique features such as transmitting and/or receiving electromagnetic energy in shorter durations and avoiding frequency dispersive and space dispersive [1]. Several schemes have been suggested in recent years for designing the ultra wide band antennas. Some UWB antennas are much more complex than other existing single band, dual band and multi-band antennas. Planar microstrip and fractal antennas have been rapidly developed for multiband and broad band in high data rate systems known as wide band communication systems. A fractal antenna can be designed to receive and transmit over a wide range of frequencies. The applications of fractal shapes are reduced size, multiband and wideband antennas. In open literature several multiband and wide band antennas has been developed [2-5]. Sierpinski gasket and Sierpinski carpet have been reported [2-3]. For wide band applications, several UWB fractal antennas have been reported [4-5]. These antennas have been fed directly with the coaxial probe which required very large ground plane [2-3]. These antennas are also fragile and not suitable to integrate with the Microwave integrated circuits (MIC) and monolithic microwave integrated circuits (MMIC). The J. Liang et. al. [6] has reported the conventional circular disc monopole antenna with CPW-feed. The coplanar waveguide has been reported that offer attractive advantages over conventional Microstrip feed lines as it has lower dispersion characteristics at higher frequencies, broader impedance bandwidth, unipolar configuration and ease of integration with active devices. Recently various UWB fractal antennas have been reported for UWB applications [7-11]. In [7], Crown square microstrip antenna is proposed to reduce the size. The frequency notched ultra-wideband microstrip slot antenna with a fractal tuning stub is proposed to achieve frequency notched function [8-9]. Ding et. al. [10] have proposed a new UWB fractal antenna by adopting the fractal concept on the CPW-fed circular UWB antenna. Ji- Chyun et.al. [11] has reported UWB fractal antenna of bigger in size which is directly fed with coaxial probe and not suitable for integration with MMIC/MICs. In this paper, circular fractal antenna with CPW-Fed is presented for UWB characteristics. This antenna exhibits the properties like miniature size, low resonance, broadband phenomenon and omni-directional radiation pattern. This antenna has advantages such as light weight, low profile, low cost, ease of fabrication, easy to integrate with RF devices and MIC/MMICs. A detail parametric study of antenna has been done with respect to design parameters. The antenna has been characterized experimentally in term of impedance bandwidth, radiation pattern and gain.

2. ANTENNA DESIGN

In this paper, ultra wide band circular fractal antenna has been proposed. The UWB printed circular fractal antenna is useful for wireless communication system for high data rate transmission at low power level. The fractal antenna has been constructed based on Descartes circle theorem [12]. First, monopole antenna with CPW fed of 15 mm diameter has been constructed as shown in the Figure 1a. This is called as 'initiator'or 'zeroth iteration'. The fractal antenna...
resulted from each iteration have been constructed with the help of Descartes circle theorem [12]. The iterative stage of initial dimension has been given in Table 1. In the first iteration, two inner circles have been taken each of radius 3.673 mm. The radii of these inner circles were determined by dividing the radius of original circle by 2. Now these two circles are subtracted from the original circle of radius 7.5 mm. This is called 1st iteration as shown in Figure 1b. In the 2nd iteration, two circles have been taken each of radius 2.45 mm. The radii of these circles were determined by dividing the radius of original circle by 3. Now these two circles are subtracted from the original circle of radius 7.5 mm. This is called 2nd iteration as shown in Figure 1c. In the third iteration, four inner circles have been taken each of radii 1.16 mm. The radius of these circles is determined by dividing the radius of original circle by 6. Now these four circles are subtracted from the original circle of radius 7.5 mm. This is called third iteration as shown in Figure 1d. In the fourth iteration, again four inner circles have been taken each of radius 0.47 mm. The radius of these circles is determined by dividing the radius of original circle by 11. Now these four circles were subtracted from the original circle of radius 7.5 mm. This is called fourth iteration as shown in Figure 1e. In the fifth iteration, again four inner circles have been taken each of radius 0.26 mm. The radius of these circles is determined by dividing the radius of original circle by 14. Now these four circles were subtracted from the original circle of radius 7.5 mm. This is called fifth iteration as shown in Figure 1f. This process can be repeated up to infinite iteration. Practically infinite iterative structure is not possible because of fabrication constraints. The fifth iterative fractal antenna has been finalized to design on the same substrate dielectric constant and thickness as conventional microstrip monopole antenna. This antenna has been fed with the coplanar feed. The CPW-fed and radiating elements both are printed on the top side of a low cost FR-4 substrate with dielectric constant $\varepsilon_r = 4.3$, $h = 1.53$ mm and $\tan \delta = 0.02$.

<table>
<thead>
<tr>
<th>Iteration</th>
<th>No. of circles</th>
<th>Radii</th>
</tr>
</thead>
<tbody>
<tr>
<td>0th</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1st</td>
<td>2</td>
<td>1/2</td>
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<tr>
<td>2nd</td>
<td>2</td>
<td>1/3</td>
</tr>
<tr>
<td>3rd</td>
<td>4</td>
<td>1/6</td>
</tr>
<tr>
<td>4th</td>
<td>4</td>
<td>1/11</td>
</tr>
</tbody>
</table>

### 3. DESIGN OF CIRCULAR MICROSTRIP ANTENNA

The design expression of simple circular microstrip antenna [13] for calculating the resonant frequency is given as

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

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

$$r_{eff} = r_o \left[1 + \frac{2h}{r_o} \left(\ln \left(\frac{r_o}{r_i}\right) + (1.41r_o + 1.77) + \frac{1}{2} \left(0.0283r_o + 1.63\right)\right)\right]^{1/3}$$

Where $r_o$ is radius of the circular patch. The dimension of the simple solid circular patch is taken as radius 7.5 mm. This patch has been designed on FR4 substrate dielectric constant of $\varepsilon_r = 4.3$ and thickness $h = 1.53$ mm. The monopole and fractal monopole antenna has been fed with optimized dimension of CPW - feed. The advantage of coplanar feed is that the feed of the antenna, ground and radiating elements all are printed on the same side of the substrate.

### 4. CPW-FED AND UWB CHARACTERISTIC

The antennas have been fed directly with the coaxial probe need a perpendicular ground plane increases the size [1-2]. They are not convenient for integrating with monolithic microwave integrated circuits (MMIC) and MIC circuits. In this paper, printed circular fractal monopole antennas have been fed by a coplanar waveguide (CPW). It has been found out that CPW - fed offers less dispersion at higher frequency and broader matching, easy fabrication and integration with MIC/MMIC. The CPW-fed antenna not only performs better in respect of bandwidth and but radiation pattern is also good [9]. A simple circular disc monopole antenna with CPW-fed is shown in Figure 1. The current distribution of the proposed antenna is mainly along the circumference of the circular disc. The current density is low in the middle area of the solid circular disc monopole antenna as shown in Figure 2. Therefore, the current will not be affected if the middle area metallization of the solid circular disc monopole antenna is removed by circular or other geometrical pattern. Removing some portion of metallization from solid circular disc increases the effective path of the surface current. In this antenna, the effective length of current path is increased by inscribing circle patterns inside solid.

![Figure 1](image1.png)

**Figure 1** Circular fractal antenna with each iteration
circular disc using Descartes circle theorem. This resulted, the first resonance frequency will be decreased and the size of the antenna will be reduced. To achieve the UWB characteristic, the fractal structure can be added to increase the resonance frequency in high frequencies by adding resonance elements in solid circular disc antenna through various circles patterns based on Descartes circle theorem. In this paper, resonance elements have been added by inscribing circles patterns iterative wise using Descartes circle theorem up to fifth iteration as shown in Figure 1. The proposed fractal antenna structure has been shown in Figure 3 with optimized dimension. The impedance matching has been achieved by adjusting the width $W = 3.2$ mm of the inner conductor and optimizing the gap between the ground plane and feed width to $g = 0.7$ mm i.e. $70 \ \Omega$ for wide bandwidth. To achieve the UWB characteristic, the gap between patch and ground has been optimized to $h = 0.5$ mm. The length of ground plane $GL = 14.17$ mm and width of the ground plane $GW = 19.7$ mm have been taken and optimized.

The proposed circular fractal antenna has been shown in Figure 2. The circular fractal antenna and monopole have been fabricated on substrate $\varepsilon_r = 4.3$, thickness $1.53$ mm and with optimized dimension. The substrate dimension of these antennas has been taken $44$ mm x $40$ mm. The circular disc monopole and circular fractal antennas have been tested using R&S vector analyzer ZVA40. The experimental result of monopole antenna has been shown in Figure 4. The first resonant frequency of this antenna is $4.31$ GHz. The experimental result acquired from vector network analyzer for circular fractal antenna has been shown in Figure 5. This antenna exhibits the excellent ultra wide bandwidth (UWB) characteristics. The impedance bandwidth of this antenna is $10.07$ GHz which corresponds to $120.88$ %. It has been observed that first resonant frequency of circular fractal antenna has shifted to $3.75$ GHz by the application of fractal geometry in comparison to monopole antenna first resonant frequency $4.31$ GHz. This indicates the size reduction of the antenna. The proposed circular fractal antenna with CPW- feed is compact one in comparison to circular fractal antenna reported in [10]. Because antenna reported in [10] was fed directly feed by $50 \ \Omega$ coaxial probe to the driven element with an SMA connector. This need a perpendicular ground plane which increases the size of antenna and not suitable for integrating with monolithic microwave integrated circuits (MMIC). The type of fractal antenna configuration is useful for modern UWB wireless communication system.

5.EXPERIMENTAL RESULTS AND DISCUSSION
5. RADIATION PATTERN

The radiation patterns of circular fractal antenna have been measured in in-house anechoic chamber. The radiation in azimuth as well as elevation plane has been measured at selective frequencies. The radiation patterns in H-plane have been measured at frequencies 4.2 GHz, 7.0 GHz, 8.775 GHz and 10.1 GHz as shown in Figure 6. The radiation patterns in E-plane have also been measured at frequencies 6.6 GHz, 8.325 GHz and 9.525 GHz as shown in Figure 7. The nature of H-plane radiation pattern is nearly omni-directional. The radiation pattern in H-plane and E-plane is more stable throughout the band in comparison to reported [10]. The radiation pattern nature in E-plane is like monopole radiation pattern. The radiation pattern of circular fractal antenna in [10] is having increasing number of lobes as frequency increases; while side lobe in the proposed fractal is less than [10]. The radiation pattern in H-plane is more stable. The variation is around 3 dBi up to frequency 10.6 GHz; while the variation in [14] is around -18 dBi up to 7.0 GHz. In E-plane side lobe is less in proposed case. The measured gain of this antenna is less than 5 dBi up to the frequency 13.36 GHz.

6. CONCLUSION

The circular fractal antenna with ultra-wideband characteristics has been successfully implemented and demonstrated. The proposed fractal antenna has been designed with fifth iteration. It is observed as iterations increases, first resonant frequency shifts to the lower frequency side, thus yielding size reduction of the antenna. The measurement results exhibits the excellent UWB characteristics in the wide range from 3.295 GHz to 13.365 GHz corresponds 120.88 % impedance bandwidth and good
Radiation pattern. The measured radiation of proposed antenna in azimuth plane is omnidirectional and stable throughout the band. The gain of this antenna is less than 5 dBi. The proposed fractal antenna is simple to design and easy to fabricate and integrate with MMIC devices. The antennas of this type can be useful for 4th generation wireless applications.

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