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Full Length Article

Design and investigation of sectoral circular disc monopole fractal antenna and its backscattering

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ABSTRACT

This article presents the design of sectoral circular disc fractal antenna. The proposed antenna has been excited using CPW – feed. The measured result of this antenna offers the ultra wideband characteristics from 3.265 GHz to 15.0 GHz. The measured and simulated results are compared and found in good agreement. The impedance match of the antenna throughout the band is improved by incorporating the rectangular slots in the ground plane. The measured radiation patterns of this antenna are nearly omni-directional in H-plane and bidirectional in E-plane. The backscattering of antenna is also discussed and calculated for antenna mode and structural mode scattering. This type of antenna is useful for UWB system, microwave imaging and vehicular radar, precision positioning location.

1. Introduction

With the tremendous advancement in wireless communication systems, there is an increasing demand for miniature, low-cost and easy-to-fabricate ultra wideband antennas. The ultra wideband (UWB) spectral range declared in February 2002 by the FCC is from 3.1 GHz to 10.6 GHz [1]. The UWB system has the advantages of transmitting high data rate with low power consumption. The UWB system requires an UWB antenna of small size. It is difficult to design an antenna of compact size with the characteristics of omni-directional radiation patterns, constant group delay and phase linearity. In the open literature, many researchers have reported UWB monopole antennas designed on both non-planar and planar structures. A non-planar UWB antenna has been reported in [2] while an UWB planar monopole antenna with direct probe feed reported in [3]. However, these antennas exhibit UWB characteristics with a bigger overall size and cannot be easily integrated with MIC/MMIC devices. Some researchers have reported UWB antennas with partial ground plane microstrip feed [4,5] and with coplanar waveguide (CPW) – feed [6,7]. The CPW-feed has many advantages in comparison with partial ground microstrip feed such as no double side printing, no alignment problem and low losses at higher frequencies. A CPW-feed is also advantageous for wide bandwidth and good radiation patterns and easily integrated with MIC/MMICs.

The miniaturization of antennas along with bandwidth enhancements are the two main challenges in UWB antenna design. Recently, fractal geometries have been reported as a promising research area in the design of UWB compact antennas and also advantageous for good impedance matching. Fractal geometries are characterized by self-similarity and space filling properties. These properties of fractal can be used in the design of various type of antennas and microwave circuits. Self-similarity offers the multiband properties or UWB feature of an antenna while spacing filling properties make the antenna/circuit miniaturized. The multi frequency properties of fractals when used as radiating structures were first reported in [8]. Fractals might also join some of the early designs based on self scaling properties however they are of bigger size [9]. Puente et al. first reported the behaviour of a fractal multiband antenna i.e. Sierpinski monopole [10]. Some steps further in the field of multiband fractal antennas were published in [11–13]. Fractal antennas with multiband properties have also been reported in [14]. The multiband resonances generated using the defected ground structure (DGS) and DGS effects on size reduction of antenna and Mutual coupling of arrays is reported in [15]. But multiband exhibits by DGS are narrow bandwidth and complex to adjust the bands into the useful applications. The bandwidth enhancement of antenna by employing the fractal geometry with gap coupling has also been shown [16]. The proposed antenna is coaxially feed and bandwidth has been enhanced by merging the multiple resonances but size of antenna

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is bigger than the reported monopole antenna. Present author [17] has reported monopole antenna to achieve the UWB and dual polarization by implementing slot in patch and ground plane. Some planar monopole fractal antennas using partial microstrip feed and CPW – feed for UWB bandwidth were reported in [18–21]. Currently, fractal geometry is also being combined with Metamaterial (MTM) and has become a hot topic in antenna and microwave circuits research. For instance, fractal perturbation in CSRRs results in a significant lower resonance [22,23], multiband behaviour [24], and broadband performance [25]. Others researchers also introduced the Hilbert curve in artificial magnetic materials [26], and some authors even exploited fractal concept for elevation of pass band performance in UWB filter [27].

In this paper, fractal geometry on circular disc sectoral monopole antenna has been exploited to achieve the ultra wide bandwidth. Antenna with fractal geometry is advantageous for good impedance matching and good RCS also. The RCS of UWB fractal antenna is necessary to study because antenna scattering is the main contribution to the total radar cross section (RCS) of low-observable platforms. The antenna scattering is related with its feed port, which affects the design of antenna with low RCS and good radiation characteristic simultaneously [28–30]. Therefore, scattering behaviour of antennas is important for defence applications. In fact, antenna scattering can be a source of electromagnetic compatibility problems and can cause interference with other systems on the same platform. Wide usages of fractal antennas make sense in the RCS study and its reduction for antenna designer. The RCS reduction of fractal antenna in narrow band has been reported in [31]. But RCS reduction of multiband or UWB fractal antenna has not been reported in the open literature.

This paper presents the design of UWB fractal monopole antenna followed by a discussion on its backscattering properties. The proposed fractal antenna is excited with CPW – feed and studied with respect to the various design parameters and their effect on its impedance bandwidth. The proposed antenna is also validated experimentally. This antenna is characterized in terms of impedance bandwidth, radiation patterns, group delay and backscattering.

2. Fractal geometry of the proposed antenna

The proposed antenna has been designed for UWB characteristics. The antenna is made using an iterative structure as shown in Fig. 1. In the zeroth iteration, a cylinder of radius 15 mm is taken

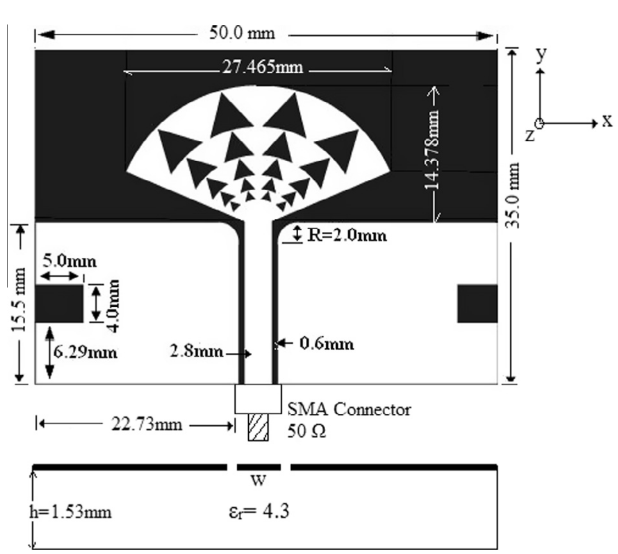

Fig. 1. Proposed fractal antenna with CPW – feed.

with the angle 120°. In the first iteration, four equilateral triangles of side length 5 mm are inserted and subtracted from the zeroth iteration. This becomes the first iteration of the antenna. For the second iteration, four equilateral triangles with side length of 3.175 mm are inserted in the second iterative structure and subtracted. This is called the second iteration. For the third iteration, four equilateral triangles of side length 2.0161 mm are inserted and subtracted from the second iteration. This is called the third iteration. For the fourth iteration, again four equilateral triangles with side length of 1.28 mm are inserted and **s**ubtracted from the third iteration. This becomes the fourth iteration of antenna. For the fifth iteration, four equivalent triangles with side length of 0.81294 mm are inserted and subtracted from the fourth iteration. This becomes the fifth iteration of the antenna and the structure of the final proposed antenna. The same process can not be repeated to the infinite iteration because of fabrication constraints. Here, the final antenna structure is taken with five iterations. Four equilateral triangles are present in each iteration and each of them is placed with 30° difference. The first equilateral triangle is rotated by 30°, the second is rotated by 60°, the third is rotated by 90°, and the fourth is rotated by 120°. These equilateral triangles are inscribed into the cylinder in each iteration. The radii of the cylinders in various iterations are 15.0 mm, 10.654 mm, 7.44 mm, 5.258 mm, 3.753 mm, and 2.73 mm respectively in the decreasing order of the iteration. The central metal parts of the equilateral triangles are removed to form the fractal geometry.

This final proposed antenna has been fed with CPW-feed as shown in Fig. 1 and it has been designed on a substrate of dielectric constant $\varepsilon_r = 4.3$ and thickness 1.53 mm. The size of the antenna structure is 32.5 mm × 37.46 mm. The width of the CPW-feed has been taken $W = 2.8$ mm and spacing between feed and ground is 0.6 mm. This makes the feed line's characteristic impedance $Z_0 = 50\ \Omega$. Thus, it can be connected with a 50 Ω SMA connector directly. The length and the width of the ground planes for the CPW – feed are optimized at 15.5 mm and 22.73 mm respectively. The overall dimension of the substrate is 35.0 mm × 50.0 mm. The proposed antenna is shown in Fig. 1 with optimized dimensions.

3. Simulated results

The proposed antenna has been simulated for each of the design parameters which affect the performance of the antenna. The gap between the patch and the ground plane, the gap between the ground and the feed line, the length and width of the ground plane, all are critical parameters which have an influence on the antenna bandwidth. This is because the current distribution is at the edges of the patch and along the upper edges of the ground plane as shown in Fig. 2. So, the gap between the patch and the ground plane is critical to achieve UWB characteristics. The length of the ground plane is also important for monopole antenna. It should be around quarter wavelength $\lambda/4$. To accommodate the effect of substrate and fractal geometry, the length of the ground has to be optimized. The ground width of the proposed antenna has also been optimized for optimum performance. The gap between the feed and the ground is optimized for proper input impedance matching throughout the band.

3.1. Effect of gap between the patch and ground plane

The proposed antenna has been simulated for various gap between the patch and the ground plane. The simulated results of gap from 0.1 mm to 0.5 mm with the step of 0.1 mm are shown in Fig. 3. It is observed from the simulated results that as the gap decreases from 0.5 mm to 0.3 mm, the impedance matching improves. But a good impedance matching throughout the band

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