A Staircase-Shaped DGS Structure Monopole Antenna for UWB Operations

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Abstract. This paper presents a novel, physically compact, miniaturized, ultra-wideband (UWB) monopole antenna design, which utilizes a defected ground structure (DGS). The defected ground design is realized as a spiral staircase-shaped pattern, and the optimized antenna volume is $26 \times 25 \times 1.6$ mm^3. The resultant antenna operates over the full UWB frequency range from 3.1 GHz to 10.6 GHz, with predicted gains in the range 0.1 dBi to 3.36 dBi across the band.

Keywords: Defected ground structure (DGS) · Ultra-wideband (UWB) · Metamaterial (MTM) antenna · Monopole antenna

1 Introduction

UWB continues to receive widespread attention because of it's immunity to multipath interference, and the ever increasing demand for larger bandwidths and higher data rates. Applications that can benefit from ultra-wideband technology include broadband wireless communication systems, peer-to-peer ultra-fast communications and short range communication systems and sensor networks.

There are several well established techniques for achieving ultra-wideband antenna characteristics. These are now routinely supplemented by the use of techniques based on artificial metamaterials, with specific electromagnetic (constituitive) parameters. Examples include composite righthand/lefthand (CRLH antennas, metamaterial loaded antenna structures, and metasurfaces or electromagnetic bandgap structures (EBG) [1]. EBG approaches date back to the late 1980 s through the work of Yablonovitch and Pendry [2].

EBG structures can be classified into four distinct categories; defected ground structure (DGS), photonic band-gap structure (PBG), high impedance electromagnetic surfaces (HIS) and artificial magnetic conductors (AMC) [3, 4]. The stop-band characteristics of EBG and DGS structures are be used for wide range of antenna applications such as miniaturization, gain enhancement, and promote stable radiation patterns. A

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major feature of EBG/DGS antennas is in establishing large bandwidths, and miniaturisation [5, 6] through the modification and suppression of surface waves. Various compact shapes of monopole antennas with defected ground structure (DGS) have been reported in for UWB applications [7, 8]. However, due to small antenna sizes, the gain in the lower band is always lower than the upper band [8]. In [8] the bandwidth is wide because of the CPW feeding - this feeding enhances bandwidth but not the gain. In this paper a monopole antenna, with a novel defected ground structure, is designed for small size, with positive gain and stable radiation pattern performance across the full UWB service band.

2 Antenna Design and Optimization

The geometrical configuration of the defected ground structure (DGS) is shown in Fig. 1, and the proposed antenna is shown in Fig. 2. The antenna model was simulated using HFSS. The substrate is FR4, with relative permittivity of 4.4, a loss tangent of 0.02, and a thickness 1.6 mm. The front side of the substrate is patterned with monopole and the back side is patterned with the DGS. The cloud shape monopole antenna is chosen for its novelty and a triangular patch is cut on top of the antenna to reduce a footprint without affecting the characteristic of the antenna, which gives rise to wider bandwidth and stable radiation pattern.

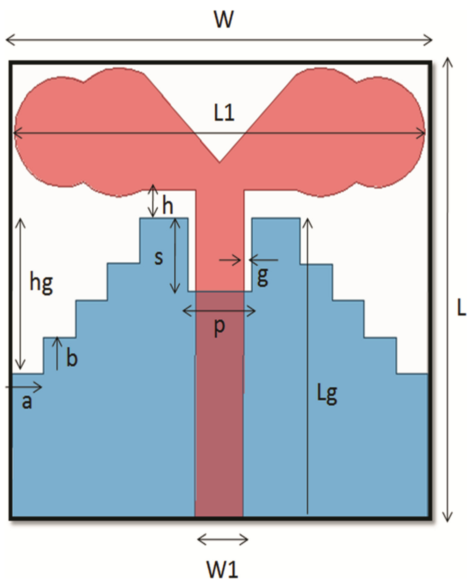


Fig. 1. Geometry of proposed DGS monopole antenna

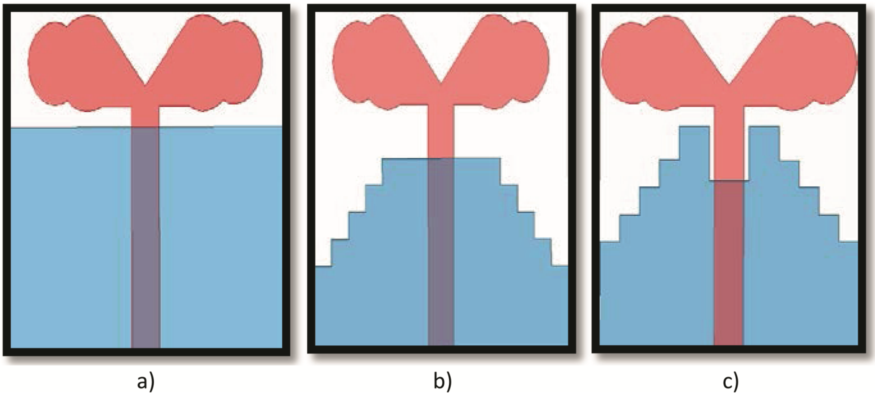


Fig. 2. (a) Simple ground monopole (b) DGS monopole (c) Front (pink) & Back (blue) of modified DGS monopole (Color figure online)

The construction of the defected ground structure was inspired from the arrangement of spiral staircase inside the ancient Mayan "El Caracol" observatory, which will further enhance the bandwidth and radiation pattern. Initially only a three quarter simple and plain ground is etched at the back of the substrate (Fig. 2a), and then the sides of the ground are carved in stairs on both sides, which gives rise to resonances from 3.1 to 6 GHz and 9 GHz and above (Fig. 2b). The middle of the DGS is then modified by cutting a square shape of size (s × p) i.e. (4.1 × 4) mm which produces the UWB frequency response from 3.1 to 10.6 GHz (Fig. 2c). The antenna is fed by a 50 Ω micro-strip line of width 3 mm. The antenna volume is 26 × 25 × 1.6 mm^3. The optimized parameters of the DGS and UWB antenna (shown in Fig. 1) are given in Table 1. The simulated reflection coefficients for the three antenna variants are shown in Fig. 3. Initially, there is no radiation with the plane ground plane. For the defected structure, radiation from 3.1 GHz to 6 GHz and then from 9 GHz can be observed. Finally in the modified DGS, a square patch is carved in the middle of the upper part of the DGS, a continuous full band UWB frequency response is obtained.

Table 1. The optimized parameter of the propose UWB antenna

Parameter	Value mm	Parameter	Value mm
L	25	h	1.5
W	26	hg	8.5
L1	25.6	g	0.6
Lg	16.5	s	4.1
a	2	p	4
b	2	w1	3

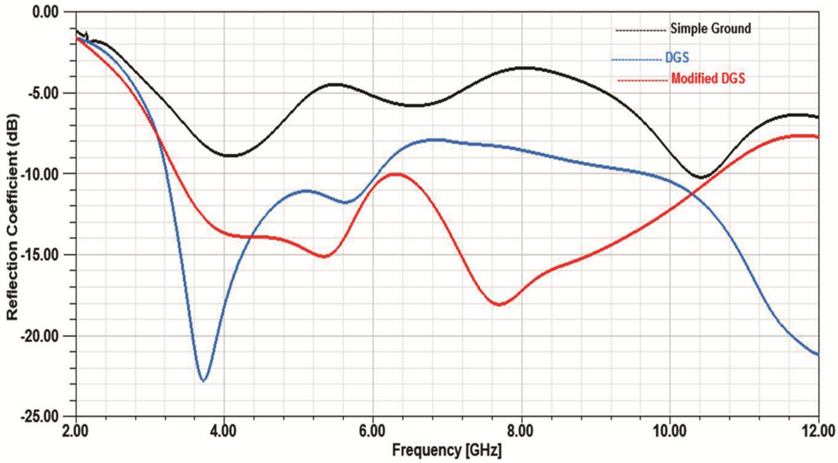


Fig. 3. Reflection coefficient of the monopole antenna with simple plain ground, DGS and Modified DGS.

3 Discussion of Parametric Performance Analysis

Figure 4 shows the comparison of simulated return loss (S_{11}) of the monopole antenna for different spacing sizes, “h”, of the defected ground structure (DGS). The structure parameter “h” is the gap between the ground and the upper part of the monopole. Both parts are on opposite sides of the substrate as shown in Fig. 1. The different “h” values used are 1.2 mm, 1.5 mm, 2 mm and 2.5 mm. The graph indicates that the best results are observed for “h” equal to 1.5 mm in the frequency range from 3.1 to 10.6 GHz. For this graph the

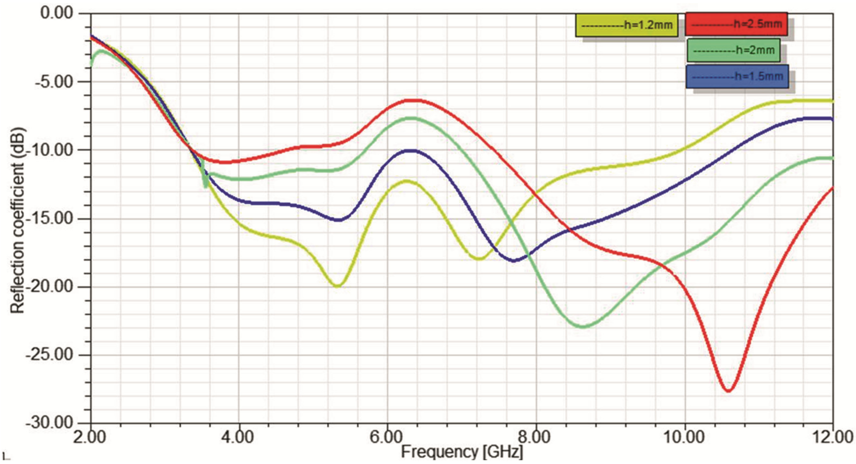


Fig. 4. Reflection coefficient of UWB antenna for different “h”

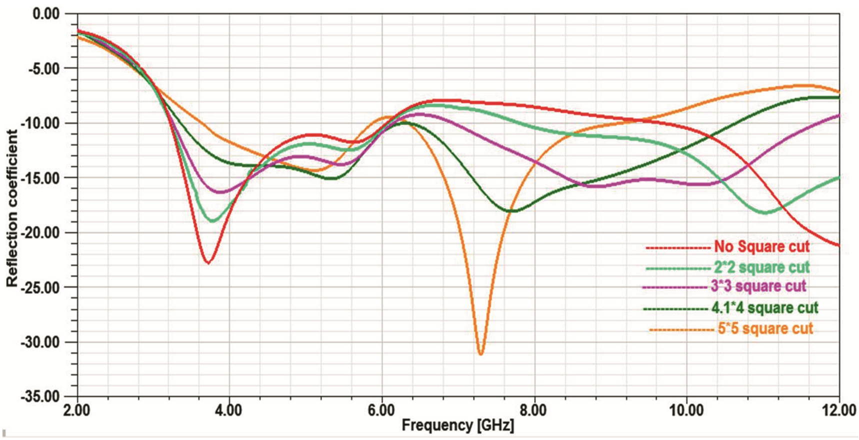
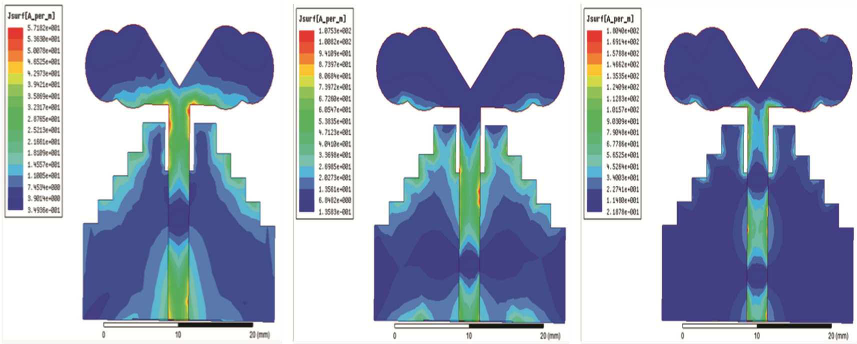


Fig. 5. Reflection coefficient of UWB antenna for different s × p

square shaped cut in the middle of the ground is maintained at 4.1 mm × 4 mm, this removes any discontinuity in the frequency range from 6 to 7 GHz.



a) b) c)

Fig. 6. Current distribution at different frequencies (a) 3.2 GHz (b) 7 GHz (c) 10 GHz

Figure 5, shows the parameter study for the DGS monopole antenna for different "s × p" sizes. Here, "s × p" is the square shaped cut in the middle of the defected ground. Initially a DGS is simulated without any square cut in the middle. Afterwards, four different square cuts of 2 mm × 2 mm, 3 mm × 3 mm, 4.1 mm × 4 mm and 5 mm × 5 mm are sequentially introduced in the middle of the ground. The graph clearly illustrates that the best results are observed for "s × p" at 4.1 mm × 4 mm in the frequency range between 3.1 to 10.6 GHz. From this graph, the gap between the ground and monopole antenna is kept at h = 1.5 mm, which will remove any discontinuity in the frequency range from 6 GHz and above.

Figure 6 shows current distribution at three different frequencies of 3.2 GHz, 7 GHz and 10 GHz. Figure 7 shows the antenna gain across the full UWB frequency band from

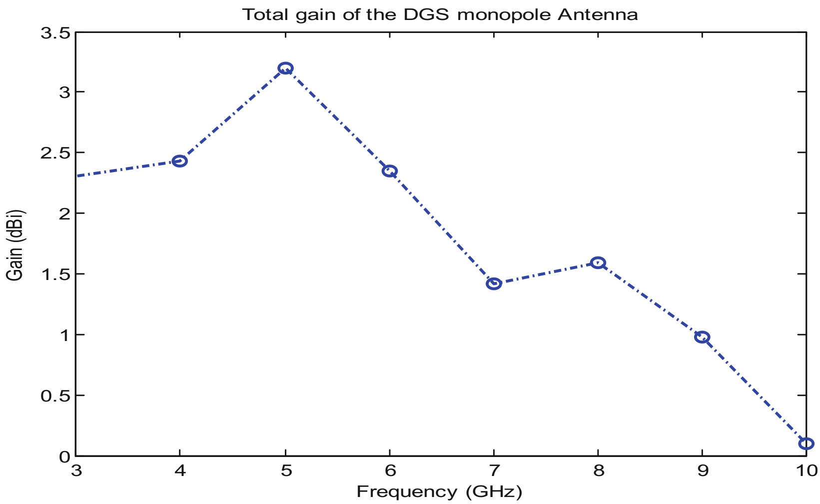
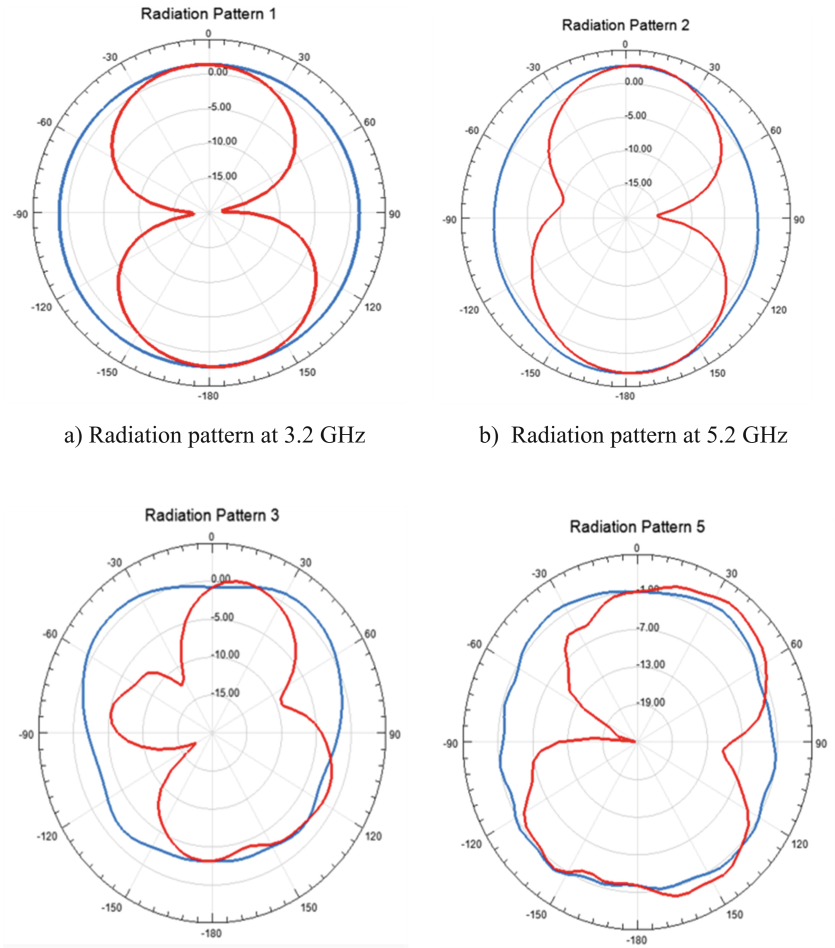


Fig. 7. Total Gain of DGS monopole antenna across the UWB

3.1 to 10.6 GHz. The total gain throughout the whole bandwidth is positive and varies from 0.1 dBi to 3.36 dBi. In most cases e.g. [8] the gain at the lower frequency band has negative values as it is often difficult to control the gain for smaller antenna sizes. In this design a positive gain is not only observable at lower band frequencies, but throughout the band, whilst making the antenna smaller at the same time. The antenna gain at the higher frequencies is smaller as compared to the lower frequencies, as this phenomenon is observed in DGS [8] and MTM antennas [9]. As in DGS and MTM antennas, the resonance is because of the defected ground structure and metamaterial unit cell respectively rather than the antenna alone itself; these antennas can't withhold a stable gain throughout the bandwidth. The peak gain of 3.36 dBi is observed at 5.2 GHz (see Fig. 7). The far fields patterns of the proposed antenna are illustrated in Fig. 8 for different frequencies. The radiations patterns were quite stable over a wide bandwidth.



a) Radiation pattern at 3.2 GHz

b) Radiation pattern at 5.2 GHz

c) Radiation pattern at 7 GHz

d) Radiation pattern at 10 GHz

Fig. 8. Simulated E-Plane (Red) and H-Plane (Blue) at (a) 3.2 GHz, (b) 5.2 GHz, (c) 7 GHz. (d) 10 GHz (Color figure online)

4 Conclusion

A miniature monopole antenna, with a novel defected ground structure, has been presented for WLAN 5.2/5.8 GHz and full-band UWB operations. The simulation model was analysed using HFSS, and predicts a working bandwidth operating over the full UWB range from 3.1 GHz to 10.6 GHz. This broad banding is a function of the defected ground structure, which also contributes to the gains observed from 0.1 dBi to 3.36 dBi across the range, and associated pattern stability.

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