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A Low Profile Cross Strip 3D Monocone Antenna for UWB Applications

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Abstract—Based on the principle of discone antenna a new UWB monocone antenna is presented. Instead of using traditional cone geometry as a radiator for discone, planar vertical cross strips of aluminum are used as an antenna radiator. This results in wide impedance characteristic and miniaturization of antenna. The simulated model has broadband impedance bandwidth 18 : 1 form 550 MHz to 18 GHz with Omni directional radiation pattern. The two different antenna models are presented in this paper. Design softwares CST Microwave Studio, HFSS and Solid works are used for designing and parametric analysis of antenna. Size reduction up to 45 percent is achieved as compared to tradition discone antenna. The N type panel mount connector is used for antenna feeding. As a result of a low profile structure, antenna can be easily mounted for portable application. The antenna radiation pattern is measured in anechoic test chamber. The measured results of antenna are found to be in good agreement with simulation results. The features make the antenna highly suitable for UWB applications.

1. INTRODUCTION

With the rapid development in manufacture of electronic technology, wideband and miniaturized antennas have achieved a lot of importance. Especially, UWB antenna technology has gained much attention for indoor wireless radio, imaging and radar applications. Wideband antennas with omnidirectional radiation pattern have numerous industrial and military uses. These proposed monopole antennas having omnidirectional radiation pattern and broad impedance bandwidth are heavily investigated. Monopole antennas are generally categorized into two types i) planar monopoles. ii) Three-dimensional monopoles. However, wide varieties of monopole antennas in different shapes and sizes are available, such as circular, elliptical, trapezoidal and square monopole antennas [1–6]. Antennas, such as skirt monopole and discone antennas, are very common for their wide impedance bandwidth.

UWB applications antennas are required to have wide impedance bandwidth and linear constant gain pattern over the operational bandwidth. Among the available antenna designs, such as bicone antenna, log periodic antennas, and double rigid waveguide horn antennas, discone antenna is more widely used and preferred for UWB applications. The biconical antenna requires infinite dimensions for outstanding UWB performance, normally having size of cone equal to half of wavelength at cut off frequency. On the other hand, horn and log periodic antennas antennas have directional radiation pattern. In comparison to the mentioned antennas, discone antenna has compact size and tilted radiation pattern due to asymmetric structure [7–11].

Antenna is a RF front-end element and plays a very vital role in all of the wireless communication devices. The antenna performance is greatly dependent on antenna size and geometry. The antenna parameters, such as antenna input impedance, gain, and radiation efficiency, are seriously degraded

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as a result of antenna miniaturization. Therefore, for many practical applications, tradeoff is adopted among different antenna parameters, such as size, impedance, and bandwidth. The common methods of miniaturization of antenna are loading antenna, adding broadband impedance network, optimization of antenna, etc. [12]. Various designs and techniques are developed for UWB antennas [13–17].

The discone antenna is constructed by using cone and disk. Generally, discone antenna is less sensitive in terms of pattern and impedance with respect to frequency variation. The performance of discone antenna as function of frequency is very much similar to high pass filter [18]. The efficiency of discone antenna reduces significantly below the cutoff frequency. Usually at cutoff frequency, antenna cone has a length of $\lambda/4$ wavelength.

Based on the concept of discone antenna [19–22], in this paper UWB novel antenna is presented. The antenna parameters, such as ground plane, height and geometry of planar vertical strips, are optimized to obtain wide impedance bandwidth. The antenna has an omnidirectional radiation pattern which provides user freedom to transmit or receive in every direction.

2. BANDWIDTH CLASSIFICATION OF MONOPOLE ANTENNAS

2.1. Monopole Antenna of Various Diameter

The basic monopole antennas usually do not have wide resonating impedance bandwidth. It is a well-known factor that increasing the diameter of monopole antenna results in increase in its impedance bandwidth [2]. There are different criteria for characterizing the bandwidth of any antenna, i.e., impedance bandwidth, pattern bandwidth, polarization bandwidth: i) impedance bandwidth is antenna bandwidth bounded to certain impedance level usually 50 Ohm, ii) pattern bandwidth is used to describe the stability of antenna radiation pattern with respect to resonating frequency, and iii) polarization bandwidth is frequency band over which the antennas operational bandwidth is restricted to certain polarization type. The bandwidth is often expressed in terms of fractional bandwidth (FBW).

$$FBW = \frac{F_H - f_L}{f_c} \tag{1}$$

Its value varies from 0 to 2, and it is often expressed in term of percentage. For a simple wire monopole antenna, the fractional bandwidth is about 10% or 1.11 : 1.

2.2. Monocone Antenna

The classical antenna that increases the bandwidth of monopole antenna is conical monopole or monocone antenna. As a result of broadband impedance characteristics, its performance does not degrade abruptly with small variation in the antenna structure. The monocone or discone antenna is evolved from biconical antenna, having broadband impedance bandwidth due to its special geometry [29]. The equivalent circuit of discone antenna is shown in Figure 1. The antenna reactor section contains the capacitance between the disk and the cone. The input impedance of antenna by

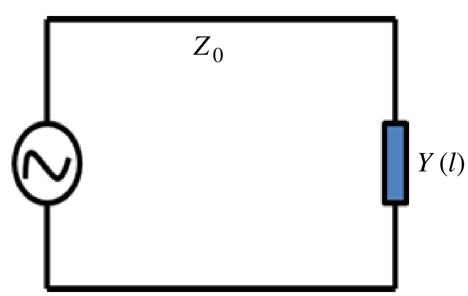


Figure 1. Equivalent circuit.

transmission line theory is given below

$$Z_{in} = Z_0 \frac{Z(l)\cos(k_0 l) + jZ_0 \sin(k_0 l)}{Z_0(l)\cos(k_0 l) + jZ(l)\sin(k_0 l)} \quad (2)$$

$$k_0 = \text{wavenumber of free space}$$

$$k_0 = \omega\sqrt{u_0\omega_0} \quad (3)$$

$$Y(l) = G + jX \quad (4)$$

$$Z_0 = \text{Characteristic impedance of antenna}$$

where $Z\ (l)$ is terminal impedance of antenna in Equations (2) and (5). For a discone antenna, input impedance is defined as a function of its electrical length, i.e., kl. The speed of change in the input impedance is mainly governed by terminal admittance $Y(l)$

$$Y(l) = \frac{1}{Z(l)} \quad (5)$$

2.3. Modified Monocone Antenna

A most common technique for increasing the bandwidth of a conical antenna is to make the antenna have a bulbous or a spherical surface [23]. In many other research articles, such as in [24], the bandwidth of monocone antenna is enhanced by merging a cone with circular cylinder at junction location [25]. For monocone, antenna characteristic impedance is usually lower than dipole antenna with the disk and cone acting as two separate monopoles. The input impedance of two monopoles behaves differently, with the frequency monopoles playing a complementary role in antenna wide band operation. In this research paper, a different approach for increasing the bandwidth of monocone antenna has been investigated. Instead of using traditional monocone structure, planar vertical strips with tapered side arms are used. The antenna design parameters are optimized to get the best impedance performance. The distance between the antenna radiator and ground plane is very critical and is required to optimize for broadband impedance response.

3. PLANAR VERTICAL CROSS STRIPS MONOCONE ANTENNA GEOMETRY

The proposed planar vertical cross strips monocone antenna is designed for UWB applications. The geometry of proposed antenna with single planar vertical strip is shown in Figure 2. Dimensions regarding different design parameters of antenna are given in Table 1.

Table 1. Table for dimensions.

Variable	Length	Variable	Length
x_1	20.0 mm	y_1	10.0 mm
x_2	20.0 mm	y_2	30.0 mm
x_3	36.0 mm	y_3	40.0 mm
x_4	28.0 mm	y_4	112.0 mm
I_rad	5.5 mm	O_rad	57.0 mm
Feed Gap		2.2 mm	

The dimensions of ground plane and other antenna parameters are given in Table 1. The designed antenna has small profile geometry compared to conventional discone antenna. At lower resonating frequency of 700 MHz, the cone diameter of discone antenna radiator is found to be 200 mm, whereas the designed antenna radiator maximum width is 80 mm.

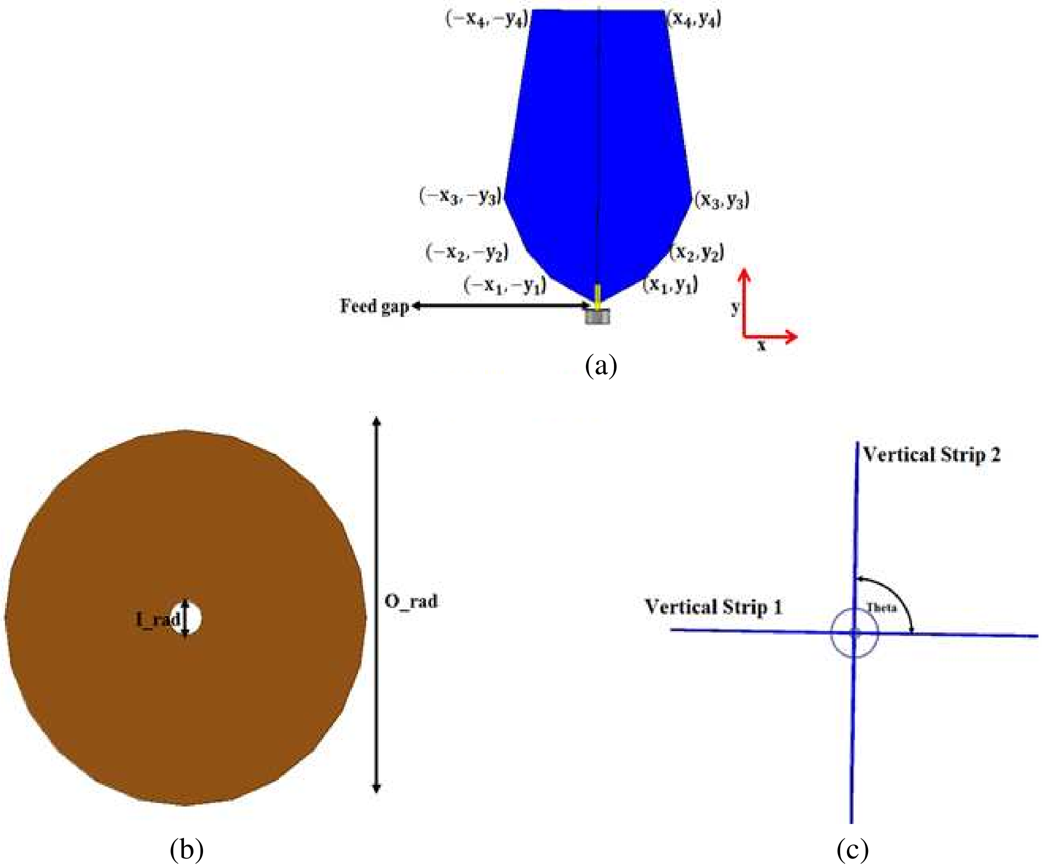


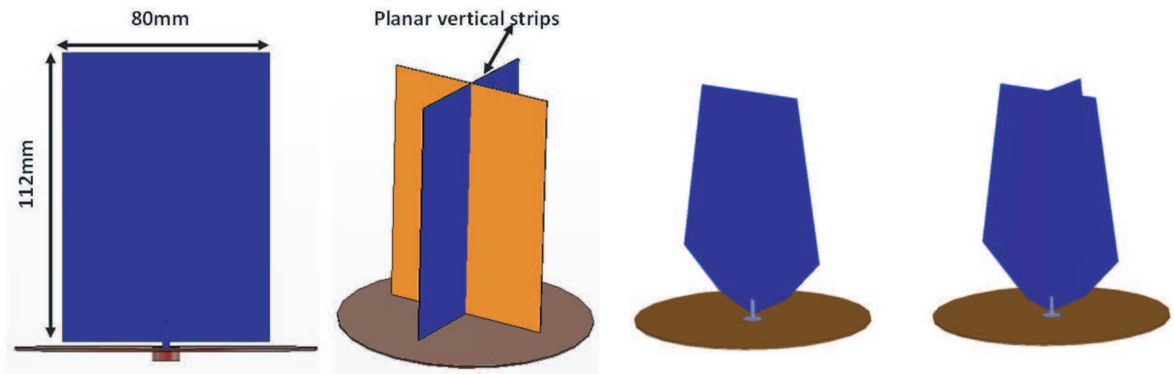
Figure 2. Geometry of proposed antenna. (a) Antenna radiator. (b) Ground plane. (c) Top view of modified planar cross vertical strips monocone antenna.

3.1. Simulated Results

The antenna is designed and simulated by HFSS 13 and CST Microwave Studio 2012 using transient analysis. Software tool Ansoft HFSS is used for designing and simulating antenna geometry and radiation pattern whereas CST Microwave Studio is used for parametric analysis of proposed antenna. The initial designing of the antenna is started by taking the consideration of planar monopole antenna. The different antenna parameters mentioned in Table 1 are optimized for the best output performance.

The proposed antenna is divided into two phases. In the first phase, the antenna with single rectangular vertical strip and double rectangular vertical cross strip is design and simulated as shown in Figures 3(a), (b). The simulated S parameters for antenna with single and double cross vertical rectangular strips are depicted in Figure 5. The antenna with a single rectangular vertical strip has only one resonance frequency of 810 MHz with the impedance bandwidth of 880 MHz below −10 dB return loss. By using antenna with double rectangular vertical strips, the number of resonance frequencies increases to three at 820 MHz with the bandwidth of 270 MHz, at 4.2 GHz with the impedance bandwidth of 960 MHz and at 8.10 GHz with the impedance bandwidth of 360 MHz respectively. The antenna S parameters in both of the cases do not have UWB behavior due to a small gap between the antenna ground plane and outer ends of vertical cross plates, which results in high inductance behavior at higher frequencies as shown in Figure 6.

In the second phase, the antennas with modified single planar vertical strip and modified two planar cross vertical strips at 90 degree orientation are designed and simulated as illustrated in Figures 3(c), (d). The simulated antenna's S parameters of both designed models are shown in Figure 7. In the first stage, the antenna with one planar vertical cross strip is optimized for the best impedance bandwidth performance. The high inductive effect of the antenna at upper frequencies is removed by truncating



(a) (b) (c) (d)

Figure 3. Simulated antenna (using HFSS) model phase 1 is shown in section (a), (b) and simulated antenna model phase 2 is shown in section (c), (d). (a) Antenna with single rectangular vertical strip. (b) Antenna with double rectangular vertical cross strips. (c) Antenna with modified single planar vertical strip. (d) Antenna with modified single planar cross vertical strip.

Figure 4. Fabricated antennas.

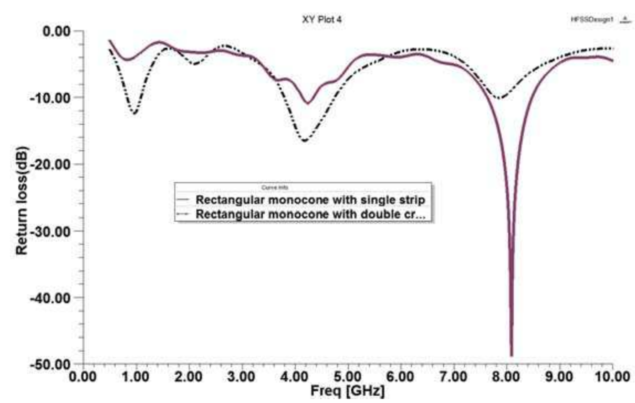


Figure 5. Simulated S parameters (using HFSS) for rectangular monocone antenna with single strip and double strips.

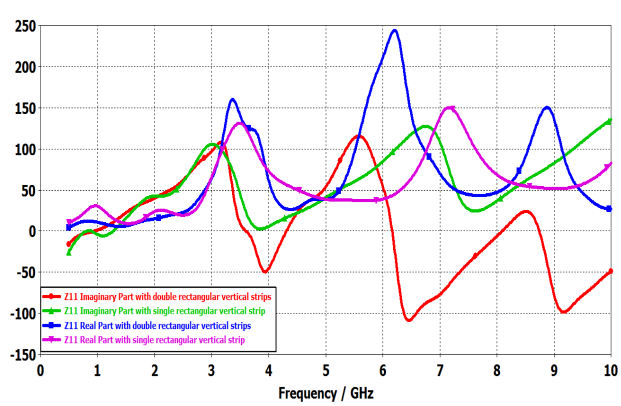


Figure 6. Real and imaginary input impedance plots for single rectangular vertical strip and double rectangular vertical strips (using CST).

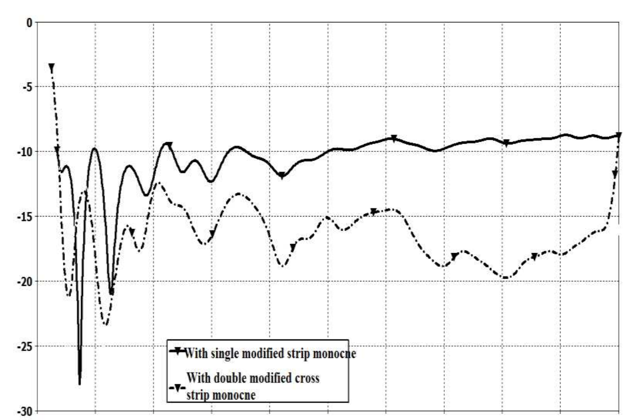


Figure 7. Simulated S parameters for rectangular monocone antenna with single strip and double strips.

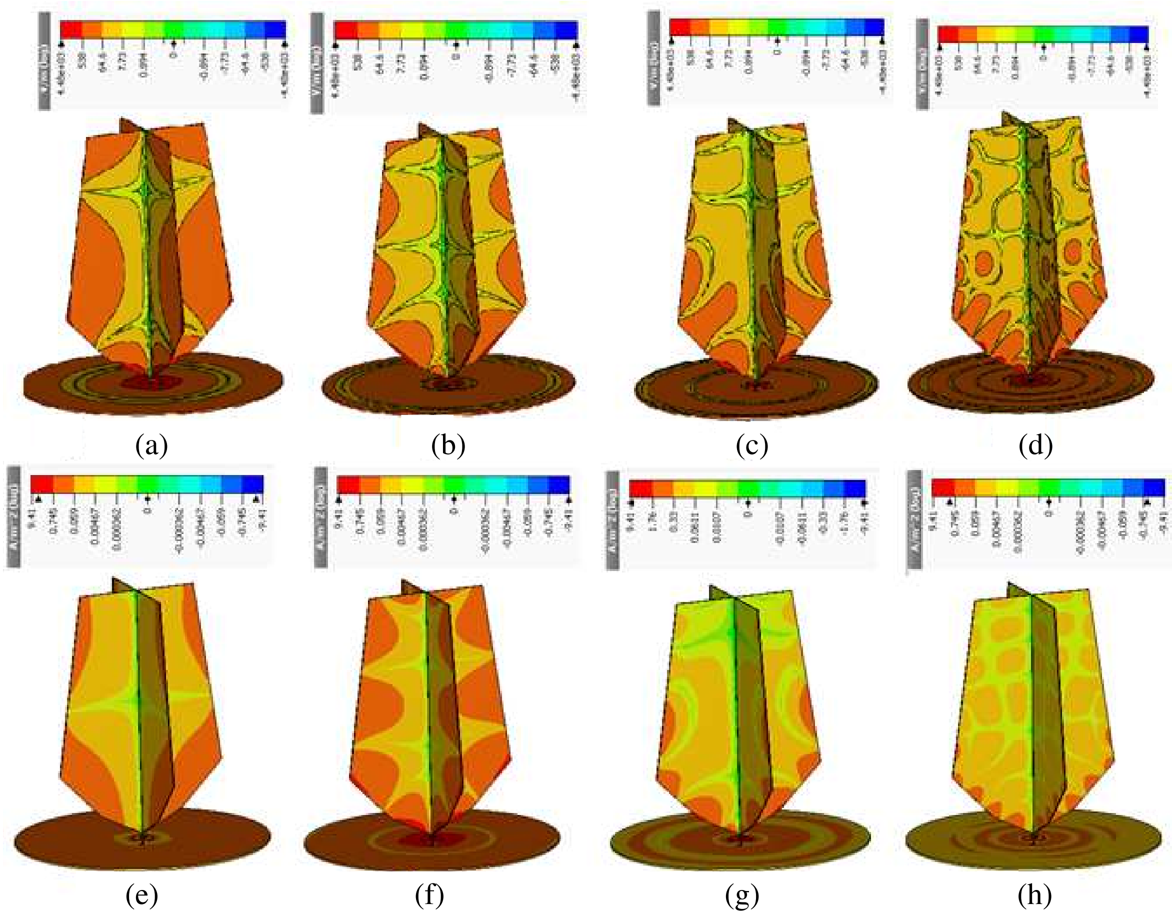


Figure 8. Simulated Current density and E field plots. (a) Current density @ 4 GHz. (b) Current density @ 8 GHz. (c) Current density @ 12 GHz. (d) Current density @ 16 GHz. (e) Electric field @ 4. (f) Electric field @ 4. (g) E field @ 12 GHz. (h) E field @ 16.

the lower end corners of the vertical rectangular strip as illustrated in Figure 9 in the form of amplitude impedance plot. Bandwidth of 10 : 1 from 570 to 10 GHz is achieved by performing the optimization on single modified planar vertical strip which is further enhanced by up to 18 GHz using two modified planar cross vertical strips. The simulated S parameters are shown in Figure 7.

The simulated antenna is fabricated by using aluminum sheet of 0.5 mm thickness. A photograph of the fabricated antenna is shown in Figure 4.

For the designed antenna, the electric field and current density plots at phase = 0 are shown in Figure 8.

From the current density plots, it is observed that at higher frequencies, i.e., 15 GHz and 18 GHz, the antenna has high back lobe radiation as compared to low frequencies. Figure 7(a) at 4 GHz and Figure 7(b) at 8 GHz show high current density and electric fields along the vertical cross strips, thus the antenna has good omnidirectional radiation pattern with very small energy concentrated in the antenna back lobes. However, Figures 8(c), (d) and (i) at 12 GHz and 16 GHz show low current density and E field strength along the vertical cross strips of designed antenna. Low current densities along the vertical cross strips of antenna at higher frequencies result in higher back lobe radiation which can be clearly seen from antenna measured and simulated radiation pattern at these frequencies.

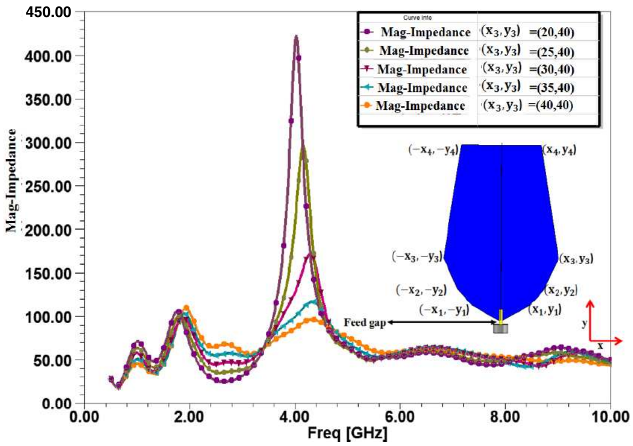


Figure 9. Magnitude impedance plot of modified double planar vertical strip antenna for parametric analysis of variable x_3 (using CST).

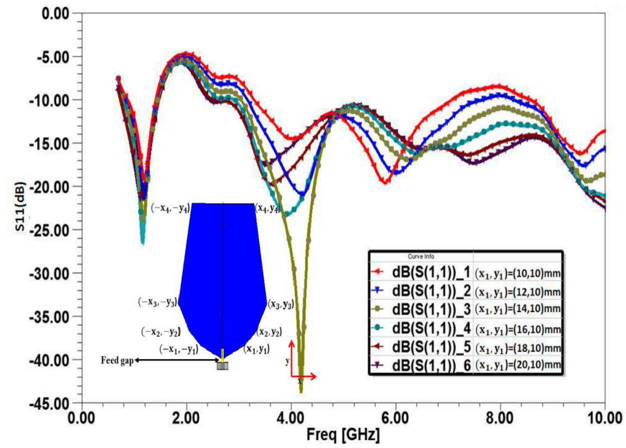


Figure 10. S parameter plot of double planar vertical strip antenna for parametric analysis of variable x_1 (using CST).

4. PARAMETRIC ANALYSIS

In-depth analysis of antenna parametric analysis of different design parameters is carried out. The antenna input impedance plays a very important role concerning the antenna performance bandwidth. The parametric analysis of antenna input impedance with respect to antenna geometry parameter x_3 is illustrated in Figure 9. The design parameter x_3 has significant effect on the antenna input magnitude impedance. Varying parameter x_3 from 20 mm to 40 mm, the antenna input impedance reduces from 450 Ohm to 80 Ohm as shown in Figure 9.

It is a well-known factor that increasing the diameter of monopole antenna results in increase in its impedance bandwidth [2]. The larger the width of antenna radiator is, the wider the antenna impedance bandwidth is. The parametric analysis of antenna S parameters with respect to antenna geometry parameter x_3 is illustrated in Figure 10. Significant improvement in antenna impedance bandwidth performance is observed by varying the antenna parameter x_1 from 10 mm to 20 mm. The antenna bandwidth improves up to 7 GHz by varying the parameter x_1 from 10 mm to 20 mm.

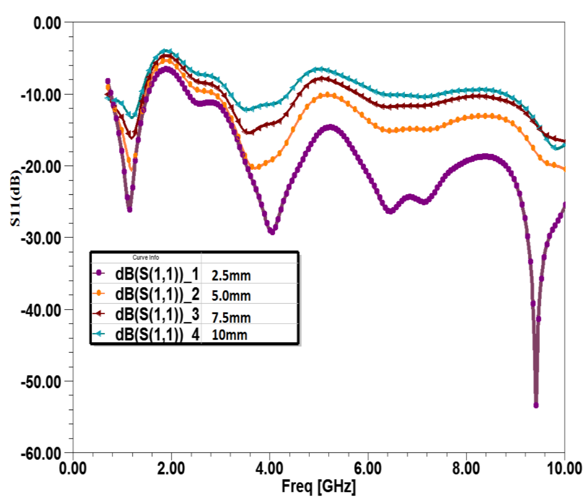


Figure 11. S parameter plot for parametric analysis of feed gap distance of double planar vertical strip antenna. (Using CST).

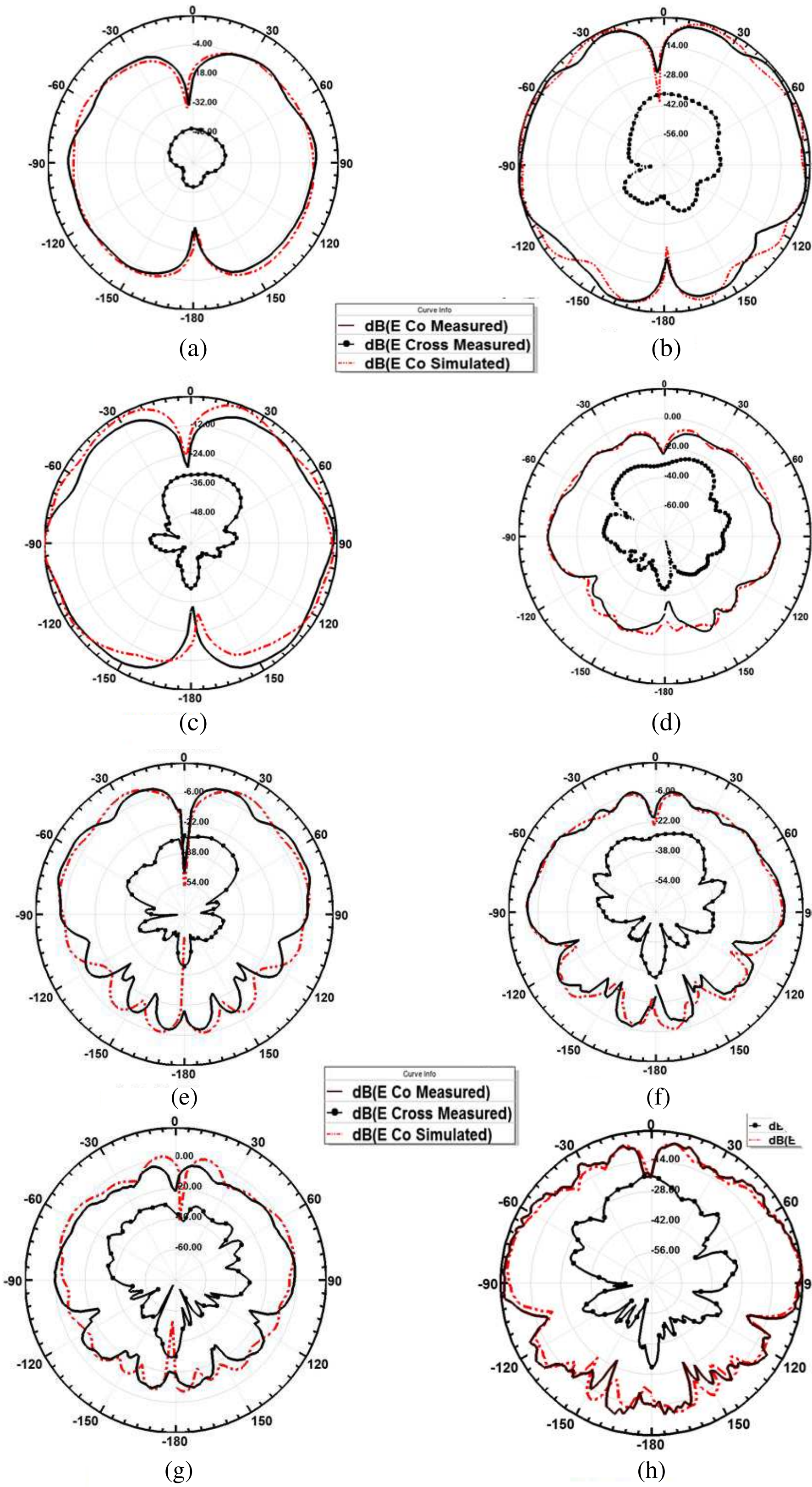


Figure 12. Antenna E plane measured and simulated radiation patterns in yz plane. (a) At 2 GHz. (b) At 4 GHz. (c) At 6 GHz. (d) At 8 GHz. (e) At 10 GHz. (f) At 12 GHz. (g) At 15 GHz. (h) At 18 GHz.

For designing any type of antenna, the antenna feed gap is a very critical parameter for antenna bandwidth performance consideration. The parametric study of an antenna's feed gap distance is illustrated in Figure 11. Decreasing the antenna feed gap between antenna radiator and ground plane reduces high inductance effect which usually occurs at higher frequencies in antennas, hence improving the antenna impedance bandwidth. There is significant improvement in S parameters results by varying the antenna feed gag from 10 mm to 2.5 mm as shown in Figure 11. The S parameters response improves up to -10 dB throughout the bandwidth from 2 GHz to 10 GHz.

4.1. Measured Result and Discussion

The two-dimension polar plots of the antenna's measured and simulated radiation patterns at different frequencies are illustrated in Figure 12. The antenna radiation pattern remains omnidirectional on most of the impedance bandwidth. However, on higher frequencies, i.e., 15 GHz, 18 GHz, the antenna radiation pattern becomes distorted due to high back lobe radiation. The E plane cross measured on most of the frequencies is also found below -25 dB which is acceptable.

For validity of the above discussed results, the simulated antenna model is tested. The return loss of the antenna is measured with an Agilent E8362B network analyzer. The comparison between simulated and measured antenna results is shown in Figure 13.

The comparison between simulated and measured S parameter results is shown in Figure 13. The figure clearly indicates the wideband impedance nature of the antenna and outstanding resemblance with the simulated one. The finite size of ground plane permits re-radiation in lower-half space effectively, reducing the gain at horizon [8]. The antenna's total simulated efficiency is found above 90% in most of the impedance bandwidth as shown in Figure 14.

4.2. Time Domain Analysis

For ensuring effective data transmission and utilization of UWB frequency band, it is necessary that the proposed antenna should have linear transmission phase response. As the transmission in UWB is in the pulse form, it is necessary that the antenna should have constant group delay throughout the bandwidth [26–28]. In this regard, group delay is useful information of time distortion. It is usually calculated by differentiation phase with respect to frequency. If group delay exceeds more than 1 ns variation, the phases are no more linear in far field and causes serious problem for UWB application. The measured group delay of antenna with a variation between -1 ns and 1 ns is shown in Figure 15.

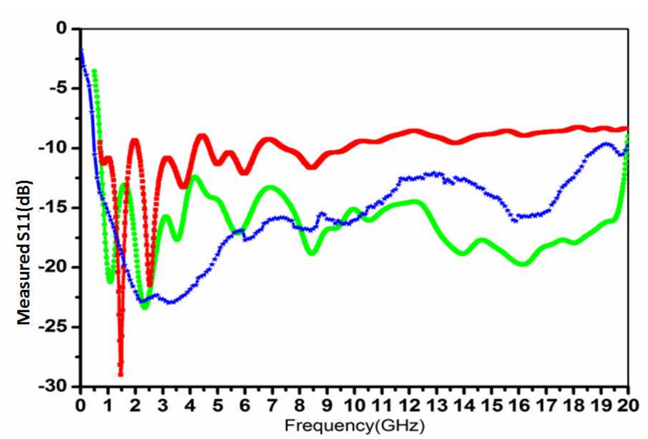


Figure 13. Red curve represents the antenna's simulated result with modified single planar vertical strip monocone antenna. Green curve represents the simulated result with modified double planar vertical strip monocone antenna, and blue curve represents the measured result for the modified double planar vertical strip monocone antenna.

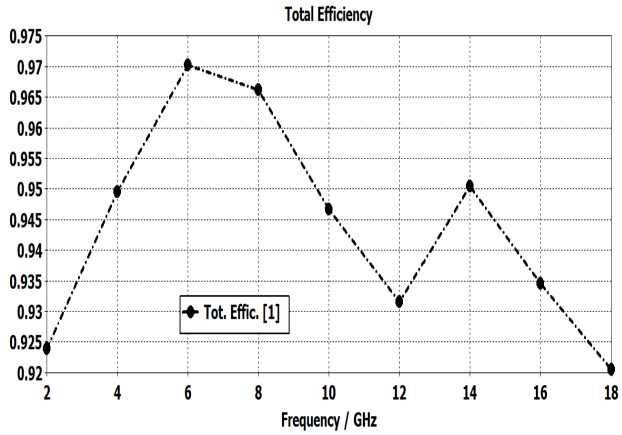


Figure 14. Total efficiency of simulated antenna.

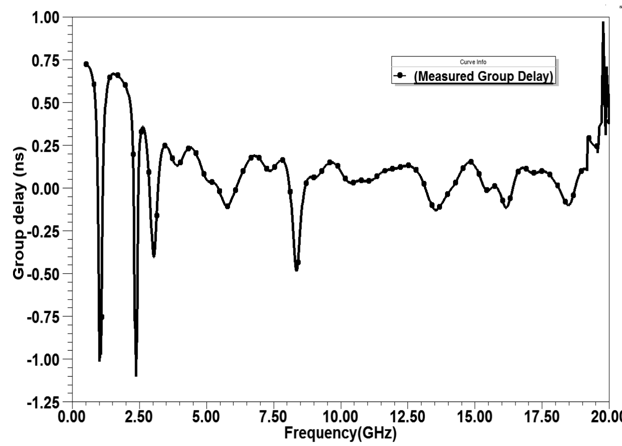


Figure 15. Measured group delay of fabricated antenna.

5. CONCLUSION

A UWB monocone antenna is investigated and presented in this paper. The designed antenna has a broad impedance bandwidth of 18 : 1 from 550 MHz to 18 GHz. In contrast to discone antenna, two planar vertical strips are used as an antenna radiator, which results in wide impedance bandwidth and size reduction of the antenna. In comparison to traditional discone antenna radiator, the diameter of the designed antenna radiator is 90 mm, i.e., 45% smaller than cone diameter at lower frequency of 0.7 GHz. The proposed antenna provides stable radiation pattern with reduced cross polarization throughout the UWB frequency band. The average efficiency of antenna remains 90% throughout the bandwidth. The features of low profile and small size make the antenna more feasible for potable applications. The antenna's omnidirectional radiation pattern makes it suitable for UHF, GSM, WLAN, and many other wireless applications.

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