

Ultra-Wide Band (UWB) Ice Cream Cone Antenna for Communication System

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Abstract: The objectives of this paper are to design, fabricate and analyze UWB Ice Cream Cone Antenna. This antenna was fabricated on FR4 substrate. The effect of varying parameter for length of rectangular is studied. This antenna occupies the entire 3.1 GHz to 10.6 GHz spectrum band. The designs are simulated using CST Microwave Studio Simulation and the measurement are successfully achieves UWB spectrum band requirement. The proposed antenna suggested that the return loss must be less than -10 dB and a VSWR of less than 2 throughout the entire band with a lightweight planar profile and omnidirectional radiation pattern. The UWB Ice Cream Cone Antenna is designed, fabricated, measured and managed to cover UWB bandwidth from 3.1-10.1 GHz with the VSWR between 1.18 - 1.7 with a small size of 40 x 25 mm². The sizes of UWB communication devices can be reduced by using the Ice Cream Cone antenna. In the future, the low loss substrates can be used in order to increase the Return Loss of the antenna at higher frequencies for wideband applications.

Key words: Ice Cream Cone Antenna, Ultra Wide-Band, Lightweight, Omnidirectional, Radiation Pattern

INTRODUCTION

Ultra Wide-Band (UWB) wireless communication is a technology to transmit digital data with wide frequency spectrum by a using short-pulse, extremely low powered radio signal and high data rate over a short distance. The capability of implementing UWB is its multi-use system with a minima background noise. The Federal Communication Commission (FCC) has authorized that UWB radio transmission can be legally operated in the range from 3.1 GHz – 10.6 GHz at a limited transmit power -41.3 dBm/ MHz (Guan, Y.C., *et al.*, 2005). The UWB antenna design must operate over 3.1-10.6 GHz frequency range. Therefore, UWB can be achieved in the UWB system due to the large bandwidth; with spanning frequency of 7.5 GHz. The UWB applications require a high radiation efficiency to ensure it can transmit low power spectral density. Hence, the dielectric losses and conductor should be minimized in order to maximize radiation efficiency of UWB, which consists of system immunity from a multipath and non-interfering operation with the existing services.

The UWB concept is attractive because it facilitates optimal sharing of a given bandwidth between different systems and applications. This feature avoids interference of the existing services, while fully utilizing the available spectrum (Rahayu, Y., *et al.*, 2008). A simple structure of microstrips, slot and planar monopole antennas, for example, a triangular with slot fed antenna (Azzeddine D., *et al.*, 2011), a rectangular with T-shaped slot (Satya, K.V and K.G. Anup, 2011), a circular with C-shaped and U-shaped slot (Tan, Z.H., *et al.*, 2011), a bowtie antenna (Yi S., *et al.*, 2011), an elliptical dipole antenna (Nazli. H., *et al.*, 2010), an umbrella antenna (Elsheakh, D.N., *et al.*, 2009), and a square ring monopole antenna (Hongwei D., *et al.*, 2009) are proposed. A microstrip triangular patch antenna is printed on the Rogers-5880 substrate with an optimized size of antenna i.e.78 mm x 34 mm. An excellent result in terms of performance, bandwidth, gain and radiation stability is obtained (Azzeddine D., *et al.*, 2011). This substrate has the thickness of 1.575 mm and relative permittivity of dielectric constant (ϵ_r), 2.2. These antennas show a gain that ranges from 2.5-10.5 dBi, a good performance in terms of bandwidth between 2.8-12 GHz. These antennas also improve the radiation pattern,

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which is at four different frequencies, namely 4 GHz, 6 GHz, 8 GHz, and 10 GHz. The Voltage Standing Wave Ratio (VSWR) is less than 2 over the entire bandwidth ranging from 3-10.6 GHz.

A compact T-shaped slot antenna is proposed for UWB communication (Satya, K.V and K.G. Anup, 2011). The antenna is generated from 2.9-11.7 GHz and S_{11} is < -10 dB. The antenna is fabricated on a FR4 substrate thickness of 0.8mm with relative permittivity of ϵ_r , 4.4. The antenna has a dimension of 28.1 mm x 14.6 mm and shows a stable omnidirectional radiation patterns with-pulse handing capabilities within the UWB bandwidth. The Dual band-notched antenna for UWB application is designed and manufactured (Tan, Z.H., *et al.*, 2011). The antenna operates between 3.2-3.7 GHz and 5.515-5.825 GHz. The proposed antenna is printed on a FR4 substrate with thickness 1.6 mm² and relative permittivity of ϵ_r , 4.4. The total size of the antenna is 30 mm x 35 mm². The impedance bandwidth for VSWR is less than 2 from 2.9-11.4 GHz. The radiation patterns are at 3, 4.5 and 7.5 GHz, which are approximately omnidirectional.

The planar antenna with a bowtie shape is proposed and fabricated on FR4 with relative permittivity of ϵ_r , 4.4 and thickness of 1.6 mm. The simulated and measured result have shown that the designed antenna covers the 3.1–10.6 GHz band allocated to UWB system with a well behaved omnidirectional radiation pattern and linear phase response (Yi S., *et al.*, 2011). The VSWR is less than 2 ranging from 3.1-10.6 GHz. A planar elliptical dipole antenna proposed with 106 mm x 85 mm by using the Roger RT Duroid 5880 substrate. The antenna operates from 1.1 to 11 GHz (Nazli. H., *et al.*, 2011). The gain performance of the antenna is increased by means of elliptical slots in the frequency ranging from 2.7-11 GHz. The standing wave ratio is less than 2 along of operation bandwidth from 1.1 to 11 GHz. The radiation pattern for certain frequencies, for example, 1.1, 3.1, 6.1 and 10.1 GHz, the return loss and the gain performance are presented with 5 dB. The antenna introduces a low-level ringing and a pulse distortion. This antenna is useful for the impulse and UWB communication systems.

An umbrella antenna provides an impedance bandwidth of more than 35 GHz with a return loss of less than -10dB. The spiral artificial magnetic conductor ground plane issued is to improve the bandwidth, reduce size and increase the gain of the antenna (Elsheakh, D.N., *et al.*, 2009). This antenna is printed on the FR4 substrate with relative permittivity of ϵ_r , 4.7 and thickness of 3.2 mm with a dimension 24 mm x12 mm. The antenna gain is calculated at an average of 7dBi. A square ring monopole antenna is proposed. The measured bandwidth of the proposed antenna occupies about 7.69 GHz covering from 3.11-10.8 GHz (Hongwei D., *et al.*, 2009). The objectives of this paper are to design, fabricate and analyze an Ice-Cream Cone antenna with a 15 mm x 8.3 mm diameter using a FR4 substrate with relative permittivity of ϵ_r , 3.5 and thickness of 1.5 mm.

METHODS AND MATERIALS

Antenna Design and Architecture:

An Ice Cream Cone antenna is fabricated on a FR4 substrate with board dimensions of 34 mm x 26 mm. The effect of varying the antenna feed angle as well as the ground plane dimension is studied (Kuldip N.M., *et al.*, 2006). The lower cut off frequency of the frequency band in the-antenna operation-shows an increase in its angle. This antenna shows a VSWR between 1-2 for frequencies ranging from 2-4 GHz and remains above 2 for the rest of the UWB frequency. Therefore, this antenna is considered as a potential UWB candidate, which means that, it can be used both in lower band as well as in the upper band for pulse based UWB technology.

In order to meet the demands of a reduced antenna size, a higher dielectric substrate is required (Kuldip N.M., *et al.*, 2006). By using a substrate with high dielectric constants, it will provide a small antenna size. Therefore, a small size of single antenna is chosen. The chosen antenna is a combination of two patches; a triangle, and semi-circular patches. The triangular patch will produce a higher cross-polarization due to its unsymmetrical geometry. Meanwhile, the semi- circular patches will expense of the bandwidth and gain. Later, ice-cream cone antennas are fabricated on a 0.831 mm thickness of a Roger RT Duroid 5880 substrate with a dielectric constant of 3.38 and the areas of dielectric substrate are both 15 mm × 13.5 mm. The VSWR is less than 2. The Ice Cream Cone antenna has a higher gain at 3 GHz but lower gain when it is between 6-8 GHz.

In this paper, the Ice Cream Cone antenna design will use high dielectric constants such as FR4 with relative permittivity of ϵ_r = 4.7 and thickness of 1.6 mm to get a smaller antenna size. An analysis and a comparison between the simulation and measurement results are conducted to investigate the effect of parameter for length by rectangular on antenna performance. The dimension of patch is treated as a circular patch element by the actual radius, a_e is given in (Balanis C.A., 1982) where f_r is the resonant frequency, v_o is the free space speed of light.

$$a_e = \alpha \left\{ 1 + \frac{2h}{\pi \epsilon_r a} \left[\ln \left(\frac{\pi a}{2h} \right) + 1.7726 \right] \right\}^{1/2} \quad (1)$$

$$a = \frac{F}{\left\{ 1 + \frac{2h}{\pi \epsilon_r F} \left[\ln \left(\frac{\pi F}{2h} \right) + 1.7726 \right] \right\}^{1/2}} \quad (2)$$

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon_r}} \quad (3)$$

$$(f_r)_{110} = \frac{1.8412 \nu_0}{2\pi a_e \sqrt{\epsilon_r}} \quad (4)$$

The length of triangular patch element can be determined (Rajesh, K.V., *et al.*, 2006). a_1 is the side length of the triangular.

$$a_1 = \frac{2c}{3f_r \sqrt{\epsilon_r}} \quad (5)$$

$$f_r = \frac{2c}{3a \sqrt{\epsilon_r}} \quad (6)$$

The calculation value is used in the CST Microwave Studio Simulation Software. The parameter design adjusted by the parametric method is used to achieve the UWB spectrum band requirement that operates between 3.1 to 10.6 GHz. Figure 1 shows the geometry of the Ice Cream Cone antenna. The antenna is fabricated on a thin FR4 substrate of thickness 1.6 mm with relative permittivity of ϵ_r , 4.4. Referring to Figures 2 (a) and (b), it shows that Antenna A has a dimension board of 50 mm x 30 mm while Antenna B has a dimension of 40 mm x 25 mm. The antenna plate is fed by a 50 Ω microstrip feed line of 2.863 mm for the proposed antenna. This patch is directly matched connected to the SMA connected.

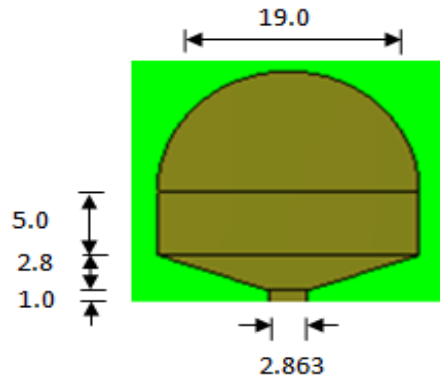
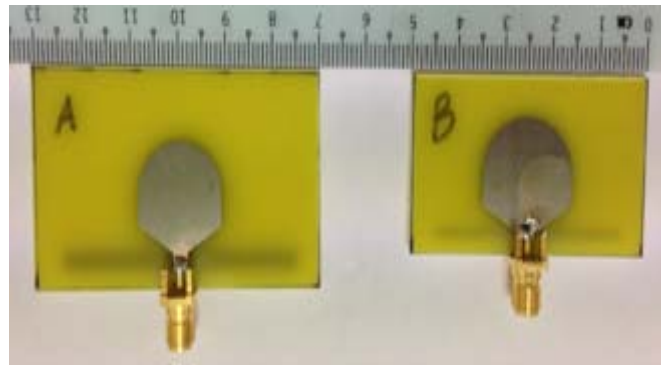


Fig. 1: Geometry of the proposed antenna length of rectangular, $W_r = 19.0$ mm



(a)

(b)

Fig. 2: Ice Cream Cone antenna design (a) Antenna A: 50 mm x 30 mm (b) Antenna B: 40 mm x 25 mm

RESULTS AND DISCUSSION

Figure 3 shows the simulated Return Loss, S_{11} in dB of Ice Cream Cone antenna for Antenna B. From the simulation, the antenna achieves the target of UWB operation ranges between 3.1-10.1 GHz with a very broad bandwidth as the resonance occurs near 3.8 GHz and 7 GHz. The designs are simulated by using the CST Microwave Studio Simulation. The results show that the antenna operates between 3.1 to 10.9 GHz. The best Return Loss, S_{11} for this antenna is obtained when it reaches the length of rectangular antenna which is at 19 mm.

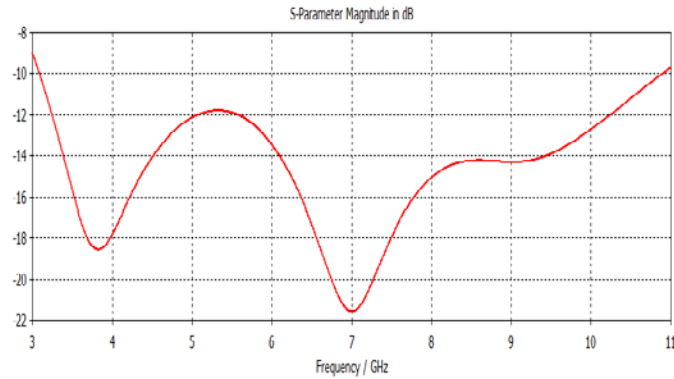
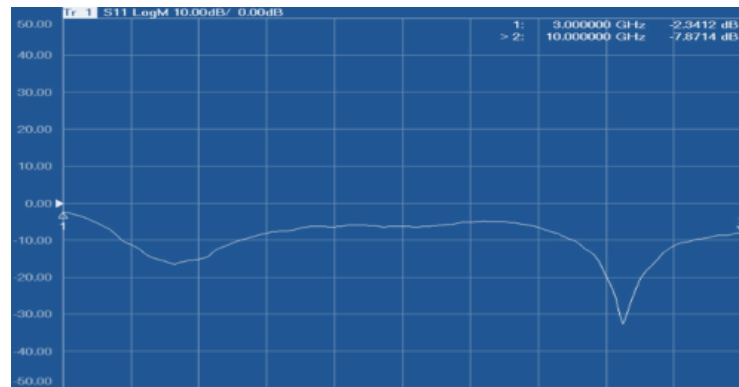
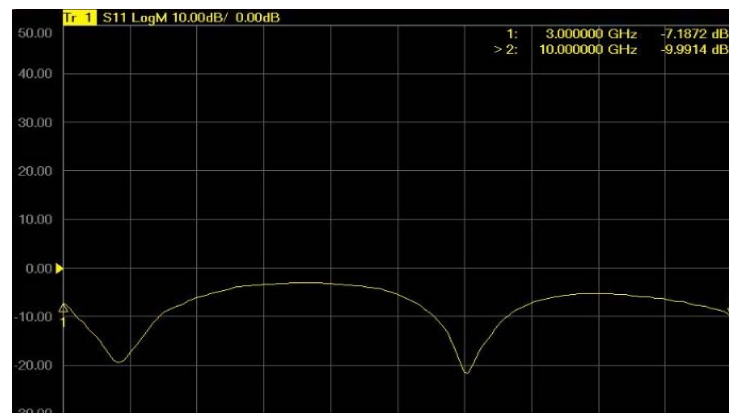


Fig. 3: Simulation results on Return Loss, S_{11} in dB of Ice Cream Cone antenna for Antenna B

Figure 4 shows the antenna measurement using the Vector Network Analyzer. From the graph, it is observed that the overall antennae performance is below -7dB and the resonance is at 8.6 GHz. This result is due to the soldering the connector to the antenna feed lines.



(a)



(b)

Fig. 4: Return Loss, S_{11} measurement in dB for Ice Cream Cone (a) Antenna A (b) Antenna B

Figures 5 (a) and (b) show that the simulated VSWR of both Antenna A and B vary between 1.1-2 for the frequency band and from 3.1 to 10.9 GHz. The VSWR has improved at a higher frequency of the antenna UWB

frequency band for Antenna B as illustrated in Figure 5 (b). The radiation pattern analysis is shown in Figure 6. It shows the simulated 180° planar (phi) and conical (theta) cut radiation patterns at 7 GHz for Antenna B. Figure 7 shows simulated 270° planar (phi) and conical (theta) cut radiation patterns at 7 GHz for Antenna B. From the radiation pattern, it is clearly shows that the proposed antenna B is omnidirectional in azimuth plane and has maximum between 180° - 270° . The efficiency of the antenna is the product of the reflection and radiation efficiency. It has been observed that the directivity is almost same as the antenna gained across the band of operation. The antenna gain is the highest at 7 GHz.

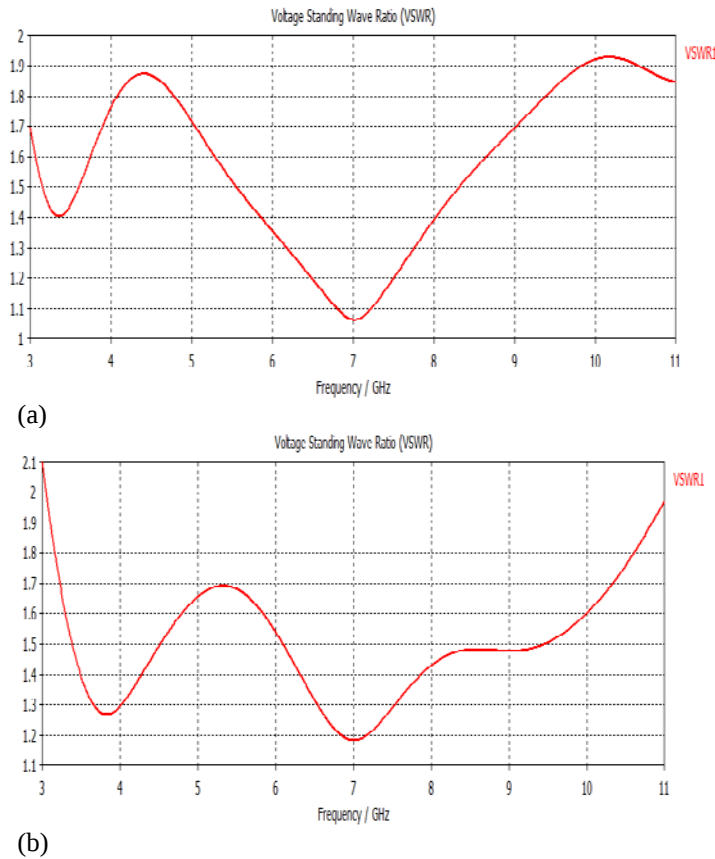


Fig. 5: Simulated VSWR of Ice Cream Cone antenna (a) Antenna A (b) Antenna B

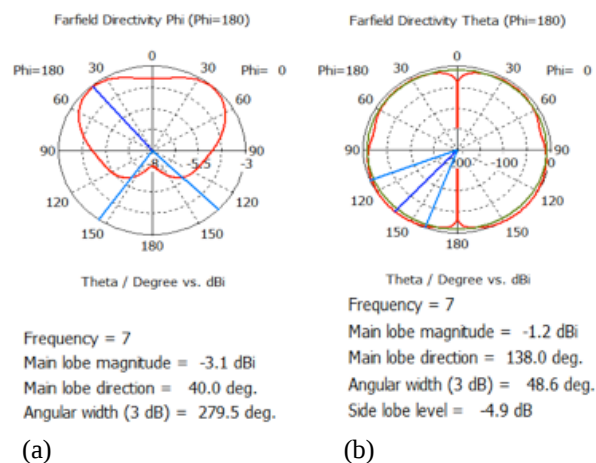


Fig. 6: Simulated radiation of antenna B at 7 GHz (a) Phi cuts for 180° (b) Theta cut for 180°

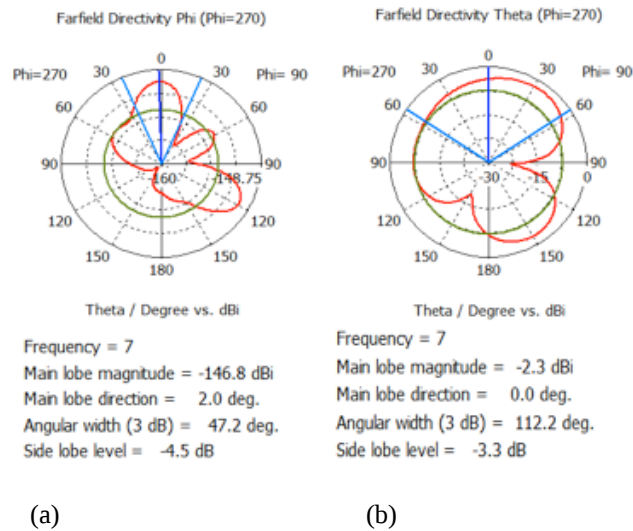


Fig. 7: Simulated radiation of antenna B at 7 GHz (a) Phi cuts for 270° (b) Theta cut for 270°

Figure 8 shows the S-parameter simulations of the Ice Cream Cone B for different length, W_r by rectangular is simulated by using the CST Microwave Studio Simulation. The most effective response for the antenna is at $W_r = 19$ mm. The most challenging task in designing the antenna is to sufficiently match to its input transmission line that is approximately 10 % or less of the incident signal which is lost due to the reflection. The impedance bandwidth measurements include the characteristic of VSWR and return loss.

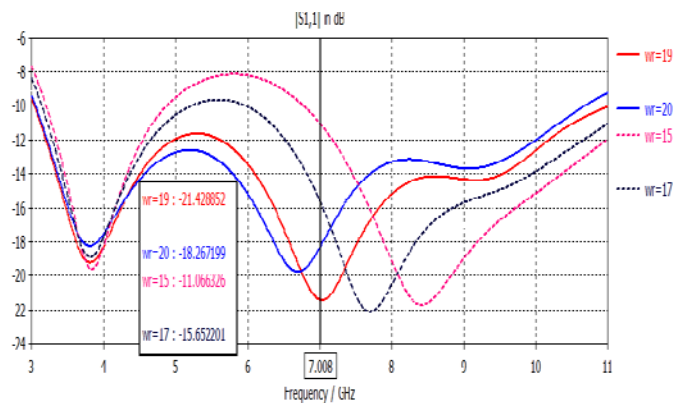


Fig. 8: S-parameter (S_{11}) simulations of the Ice Cream Cone B for different length, W_r by rectangular

Table 1 shows the simulated S_{11} and VSWR for different length by rectangular. It is observed that the lower cut off frequency of the frequency band of the operation antenna is increased with a decrease in parameter for length by rectangular. It also displays the VSWR decrease with decreases in length by rectangular.

Table 1: Comparison different length, W_r of the rectangular at frequency 7 GHz

Length (mm)	S_{11} (dB)	VSWR
19	-21.429	1.185
20	-18.257	1.278
17	-15.652	1.395
15	-11.066	1.776

Figure 9 shows the impedance matching for the antenna design at the frequency of 7 GHz. Table 2 shows several settings of height of rectangular (t_r) height of feed line (h_f) and length of feed line (w_f) at frequency 7 GHz to maintain the input transmission line at 50 Ω . The matching network and the feeding strip can be etched on the same plane. A good impedance match is indicated by return loss greater than 10 dB and VSWR less than 2. The simulation result shows that varying parameter for length by rectangular has a relation effect on the antenna performance depending on the rectangular height (t_r) and feed structure.

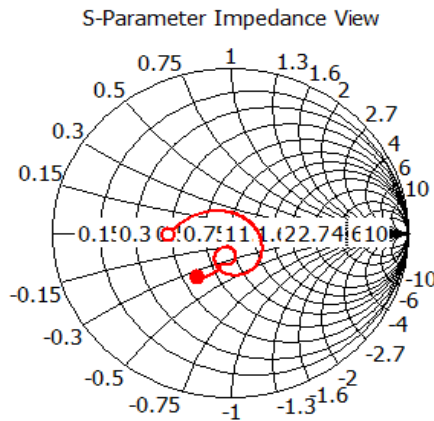


Fig. 9: The impedance matching for the antenna design

Table 2: Comparison different height of rectangular (tr) height of feed line (hf) and length of feed line (wf) at frequency 7 GHz

Line Impedance (Ω)	tr (mm)	hf (mm)	wf (mm)
50	5	3	2.7075
50	5	1	2.707
50	7	1	2.7
50	5	3	2.7

Conclusion:

Printing a semicircle on the top rectangular element and a triangle etched from the ground respectively creates an Ice Cream Cone antenna. A planar UWB antenna fed by coaxial was proposed, designed, fabricated and measured. This antenna was simulated using CST Microwave Studio Simulation and the measurement achieved the UWB spectrum band requirement, which operates between 3.1-10.9 GHz. The proposed antenna was printed on a FR4 substrate with thickness 1.6 mm² and relative permittivity of ϵ_r , 4.7. The total board dimension of the antenna is 40 mm x 25 mm. The impedance bandwidth for VSWR is lower, less than 2 ranging from 3.1-10.9 GHz. The radiation patterns at 3.1-10.9 GHz are capable to achieve broadband and omnidirectional in azimuth plane and has a maximum beam width between 180°-270° at a frequency of 7 GHz. The Ice Cream Cone Antenna can be used for UWB communication and in future, an array of Ice Cream Cone Antenna can be developed further to enhance the UWB communication system.

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