Slotted ultra wideband antenna for bandwidth enhancement

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1. Introduction

In choosing an antenna topology for ultra wideband (UWB) design, several factors must be taken into account including physical profile, compatibility, impedance bandwidth, radiation efficiency, and radiation pattern. The main challenge in UWB antenna design is achieving the very broad bandwidth with high radiation efficiency and small in size. Accordingly, many techniques to broaden the impedance bandwidth of small antennas and to optimize the characteristics of broadband antennas have been widely investigated in many published papers as listed in references. Some examples of the techniques used to improve the impedance bandwidth of the planar monopole antenna include the use of beveling technique (Z.N. Chen[(a)] et al., 2006), (Giuseppe R. & Max J. Ammann, 2006), (M.C. Fabres[(a)] et al.,2005), semi-circular base (X.N. Qiu et al., 2005), cutting notches at bottom (Seok H. Choi, et al., 2004), (H. Ghannoum et al., 2006), an offset feeding (Z.N. Chen[(a)] et al., 2006), (Giuseppe R. & Max J. Ammann, 2006), (M. J. Ammann & Z. N. Chen, 2004), a shorting pin (Z.N. Chen[(a)] et al., 2006), (E. Lee et al., 1999), and a dual/triple feed (Z.N. Chen[(a)] et al., 2006), (S. Boris et al., 2005), (K.L. Wong et al., 2005), (H. Ghannoum et al., 2006), (E. Antonio-Daviu et al., 2003), magnetic coupling (N. Behdad & K. Sarabandi, 2005), folded-plate (D. Valderas et al.,2006), (Z.N. Chen et al., 2003), hidden stripline feed (E. Gueguen et al., 2005). The radiators may be slotted to improve the impedance matching, especially at higher frequency (Z.N. Chen[(a)] et al., 2006), (Z.N. Chen[(b)] et al., 2006). Planar monopole antennas are good candidates owing to their wide impedance bandwidth, omni-directional radiation pattern, compact and simple structure, low cost and ease of construction. Further detail on various bandwidth enhancement techniques will be discussed in section 2.

2. Various Bandwidth Enhancements

In order to fulfill the UWB antenna requirements, various bandwidth enhancement techniques for planar monopole antennas have been developed during last two decades. The recent trends in improving the impedance bandwidth of small antennas can be broadly divided into the following categories (T. Huynh & K. F. Lee, 1995), (Z.N. Chen[(a)] et al., 2006), (L. Jianxin, 2006), the first category is the leading of all categories in numbers and varieties. By varying the physical dimensions of the antenna, the frequency and bandwidth characteristics of the resulting UWB pulse could be adjusted (R. J. Fontana, 2004).

2.1 Various Geometry and Perturbations

Planar monopoles with a huge number of different geometries have been numerically characterized (Z.N. Chen[(a)] et al.,2006). Many techniques to broaden the impedance bandwidth of planar monopole antennas and to optimize the characteristics of these antennas have been widely investigated. Among all these techniques, the beveling technique was reported to yield maximum bandwidth. Various geometries and perturbations are used to introduce multiple resonances as well as input impedance matching. The input impedance is also extremely dependent on the feeding gap configuration (M.C. Fabres[(b)] et al., 2005). An example of beveling technique most currently used in literature review is shown in Figure 1.

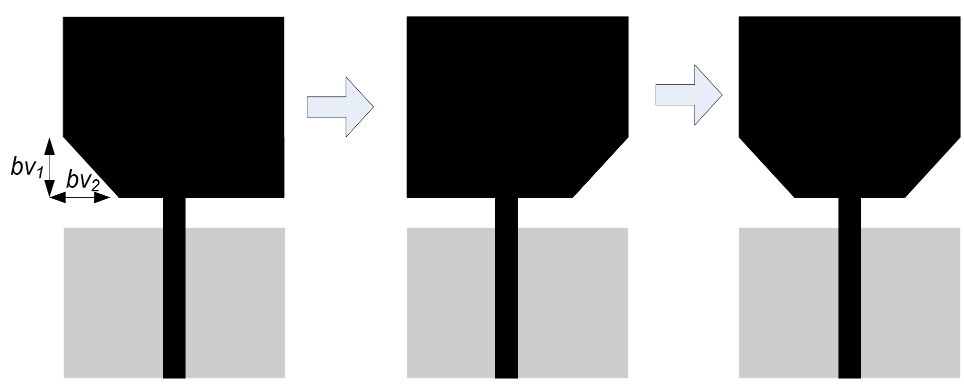


Fig. 1. An example of beveling technique

Beveling the bottom edge of the radiating element has been demonstrated to shift upward significantly the upper edge frequency when properly designed (Giuseppe R. & Max J. Ammann, 2006), (Z.N. Chen[(b)] et al.,2006), (M. J. Ammann & Z. N. Chen, 2003), (M. J. Ammann, 2001). The optimization of the shape of the planar antenna especially the shape of the bottom portion of the antenna, improve the impedance bandwidth by achieving smooth impedance transition (Z.N. Chen[(a)] et al., 2006). In fact, this part of the radiator results to be very critical for governing the capacitive coupling with the ground plane. Any reshaping of this area strongly affects the current path (Giuseppe R. & Max J. Ammann, 2006). The election and beveling angle is critical, as it determines the matching of the mode.

The patch radiator may be slotted to improve the impedance matching, especially at higher frequency. The slots cut from the radiators change the current distribution at the radiators so that the impedance at the input point and current path change (Z.N. Chen[(a)]et al., 2006). A notch is cut from radiator to reduce the size of the planar antenna (Z.N. Chen[(b)] et al., 2006).

Adding a strip asymmetrically at the top of the radiator can also reduce the height of the antenna and improve impedance matching (A. Chai et al., 2005). An offset feeding point has been used in order to excite more modes and consequently improving the impedance bandwidth (M. J. Ammann & Z. N. Chen, 2004). By optimizing the location of the feed point, the impedance bandwidth of the antenna will be further widened because the input impedance is varied with the location of the feed point.

Moreover, other strategies to improve the impedance bandwidth which do not involve a modification of the geometry of the planar antenna have been investigated. Basically, these strategies consist of adding a shorting post to the structure or using two feeding points to excite the antenna (M.C. Fabres(b) et al., 2005). A shorting pin is also used to reduce the height of the antenna (E. Lee et al.,1999). In (Giuseppe R. & Max J. Ammann, 2006), the shorting pin inserted to the antenna that provides a broad bandwidth has been investigated. A dual feed structure greatly enhanced the bandwidth particularly at higher frequencies (E. Antonio-Daviu et al., 2003). By means of electromagnetic coupling (EMC) between the radiator and feeding strip, good impedance matching can be achieved over a broad bandwidth (Z.N. Chen(b) et al., 2003).

The use of double feeding configuration to the antenna structure is to enforce the vertical current mode, whereas it prevents other modes such as horizontal and asymmetrical current modes from being excited, which degrade the polarization properties and the impedance bandwidth performance of the antenna (H. Ghannoum et al., 2006), (Christophe Roblin et al., 2004), (E. Antonino-Daviu et al., 2003), (Eva Antonino et al., 2004). The double feeding gives a significant improvement of the vertical current distribution resulting in better matching notably over the upper-band part (S. Boris et al., 2005). The matching of this upper frequency band is mainly governed by two parameters: the distance between the two monopole ports and the height between the monopole and the ground plane (H. Ghannoum et al., 2006). In (E. Antonino-Daviu et al., 2003), a square monopole antenna with a double feed has been proposed. This feed configuration has shown the improvement on radiation pattern and impedance bandwidth. This is due to a pure and intense vertical current distribution generated in the whole structure.

The hidden feed-line technique on printed circular dipole antenna has been investigated in (E. Gueguen et al., 2005). The specific feeding has shown remove any radiation pattern disturbance generally met with this kind of antenna when fed with a coaxial or a microstrip line. It was also shown a wide frequency bandwidth.

Due to the radiation from planar antenna may not be omni-directional at all operating frequencies because they are not structurally rotationally symmetrical. Roll monopoles is a choice to feature broad impedance bandwidth with omni-directional characteristics (Z.N. Chen(a) et al., 2003). With the roll structure, the antenna becomes more compact and rotationally symmetrical in the horizontal plane. However, the roll monopoles are not easy to fabricate with high accuracy (Z.N. Chen(a) et al., 2006). The folded antenna was also presented in (Daniel Valderas et al., 2006) in order to improve radiation pattern maintaining the broadband behavior. In (Daniel Valderas et al., 2006), the antenna was analyzed employing transmission line model (TLM).

In (A.A. Eldek, 2006), various combinations of bandwidth enhancement techniques was successfully applied in UWB antenna design such as adding slit in one side of the monopole, tapered transition between the monopole and the feed line, and adding notched ground plane.

2.2 Genetic Algorithm (GA)

Optimization of patch geometry is an ideal technique to have single or more optimized figures of merit like, impedance bandwidth. The GA has been successfully applied by a number of researchers to improve the impedance bandwidth (Z.N. Chen et al., 2004), (A. J. Kerkhoff, 2001), (R. Holtzman et al., 2001), (A. J. Kerkhoff et al., 2004), (S. Xiao et al., 2003), (H. Choo & H. Ling, 2003). The optimized shape however is too much irregular and unconventional and this can only be fabricated using the pattern produced in true scale by the GA code.

Electromagnetic optimization problems generally involve a large number of parameters. The parameters can be either continuous, discrete, or both, and often include constraints in allowable values. The goal of the optimization is to find a solution that represents a global maximum or minimum. For example, the application of GA optimization is used to solve the problem of design a broadband patch antenna (Z.N. Chen et al., 2004). Parameters that are usually included in this type of optimization problem include the location of the feed probe, the width and length of the patch, and the height of the patch above the ground plane. In addition, it may be desirable to include constraints on the available dielectric materials, both in terms of thickness and dielectric constants; tolerance limits on the patch size and probe location; constraints on the weight of the final design; and possibly even cost constraints for the final production model. Given the large number of parameters, and the unavoidable mixture of discrete and continuous parameters involved in this problem, it is virtually impossible to use traditional optimization methods. GA optimizers, on the other hand, can readily handle such a disparate set of optimization parameters (Z.N. Chen et al., 2004).

The use of the GA approach in the design of UWB antennas has been proposed in (A. J. Kerkhoff, 2001), (R. Holtzman et al., 2001). The planar fully-metal monopole (PFMM) of bow tie (BT) and reverse bow tie (RBT) have been demonstrated in (A. J. Kerkhoff, 2001), (A. J. Kerkhoff et al., 2004) have an ultra wide bandwidth. The element height, the feed height, and the element flare angle were the parameters that used in optimization. The height essentially determines the operating mode and the lower frequency limit of the antenna, while the flare angle and the feed height control the variation of the input impedance over frequency, the high frequency impedance value, as well as the resonance bandwidth (A. J. Kerkhoff, 2001). In this paper, the GA was used to determine the optimal dimensions of the selected element shape in order to fulfill the given bandwidth requirement. As a result, the RBT antenna can achieve a much wider impedance bandwidth than the BT with significantly reduced sizes.

In (R. Holtzman et al., 2001), the semi-conical UWB antenna was optimized by using the Green's Function Method (GFM) Absorbing Boundary Condition (ABC) with GA. The goal of this optimization is to have significant reduction in the size of the white space, due to the unique capability of the GFM to model arbitrarily shaped boundaries in close proximity to the antenna. The white space is defined as the region between the antenna and the absorbing boundary.

The GA optimizer is also used to reconfigure the radiation characteristics of antenna over an extremely wide-band (S. Xiao et al., 2003). The design results indicate that the antenna can obtain the required goals over an ultra-wide band through reconfiguring the states of the switch array installed in shared aperture when it operates with the higher order modes (S.

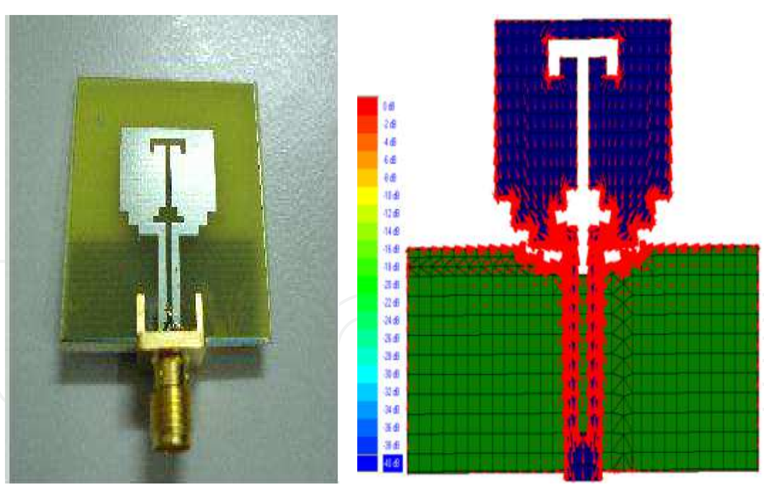
Xiao et al., 2003). Optimization of broadband and dual-band microstrip antennas on a high-dielectric substrate by using GA was also proposed in (H. Choo & H. Ling, 2003).

2.3 Resonance Overlapping

Normally, the bandwidth of a resonant antenna is not very broad because it has only one resonance. But if there are two or more resonant parts available with each one operating at its own resonance, the overlapping of these multiple resonances may lead to multi-band or broadband performance.
Theoretically, an ultra wide bandwidth can be obtained if there are a sufficient number of resonant parts and their resonances can overlap each other well. However, in practice, it is more difficult to achieve impedance matching over the entire frequency range when there are more resonant parts. Also, it will make the antenna structure more complicated and more expensive to fabricate. Besides, it is more difficult to achieve constant radiation properties since there are more different radiating elements.

3. Slotted UWB Antenna Design and Development

From various bandwidth enhancement techniques, there are three techniques adopted for this proposed UWB antennas design. The three techniques are the use of slots, truncation ground plane, and cutting notches at the bottom which can lead to a good impedance bandwidth. By selecting these parameters, the proposed antenna can be tuned to operate in UWB frequency range. The performance optimization is done by studying their current distribution. The photograph and current distribution behavior of proposed slotted UWB antenna is shown in Figure 2.



(a) (b)

Fig. 2. (a) Photograph, (b) current distribution with slot

The geometry of antenna originates from conventional rectangular monopole and is realized by adding T slot for both patch and feeding strip. This geometry is taken as initial geometry due to the flexibility of this geometry to be modified. The T slot cutting on patch and feeding strip has disturbed the current direction thus provide a broad bandwidth. This is due to the geometry of an antenna implies the current courses, as shown in Figure 2(b), and make it possible to identify active and neutral zones in the antenna. Therefore, it will be possible to fix which elements will act on each characteristic. The active zone is the matching and radiator zone. Zone closed to feeding point is the active zone. As shown in Figure 2(b), much current density occurs closed to the feeding edge, while at the top of antenna; the current levels are not too strong. The neutral zones where geometry modifications are useless because neither the radiation pattern nor the matching bandwidth is much influenced.

To better control an antenna behavior, it is necessary to identify neutral zones. The neutral zone can be used to simplify the antenna structure and integrate other function of the systems such as antenna circuits. This investigation has been proposed in (Pele I. et al., (2004), but not much explanation given particularly determine the neutral zone.

The antenna has a compact dimension of 30 mm x 30 mm (W_{sub} x L_{sub}), designed on FR4 substrate with thickness of 1.6 mm and relative dielectric constant (ε_r) of 4.7. The radiator is fed by a microstrip line of 3 mm width (w_f). On the front surface of the substrate, a rectangular patch with size of 15 mm x 12 mm (w x l) is printed. The two notches size of 1.5 mm x 12 mm (w_1 x l_1) and 1 mm x 9 mm (w_2 x l_2) are at the two lower corners of radiating patch. The distance of h between the rectangular patch to ground plane printed on the back surface substrate is 1 mm, and the length (l_{grd}) of truncated ground plane of 11.5 mm. The excitation is a 50 Ω microstrip line printed on the partial grounded substrate. The slot size of w_s, w_{s1}, w_{s2}, w_{s3}, l_{s1}, l_{s2}, l_{s3} are 1, 5, 3, 6, 11, 7, 2 mm, respectively.

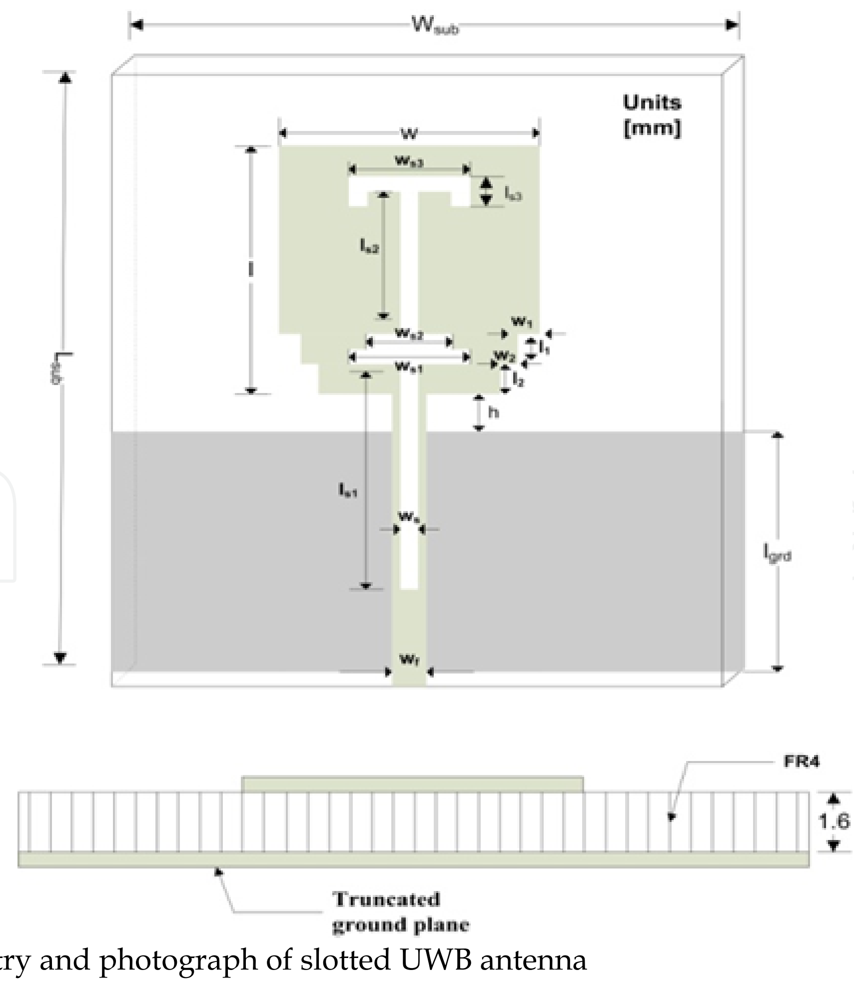


Fig. 3. Geometry and photograph of slotted UWB antenna

Figure 3 shows the geometry of proposed UWB antenna. The slot shapes are designed very carefully by studying the current flow distribution. The discontinuity occurred from cutting notches at the bottom side of a rectangular antenna has enforced the excitation of vertical current mode in the structure. The T slot on the feeding strip produces more vertical current thus improve the matching impedance performance at higher frequencies. The length of the T slot on the feeding strip is designed approximately equal to at 10.5 GHz. While the T slot cutting on the patch provides return loss improvement at 5.2 GHz. Thus, the slot wideband behavior is due to the fact that the current along the edges of the slot introduce the same resonance frequencies, which, in conjunction with resonance of the main patch, produce an overall broadband frequency response characteristic. The effect of T slots to the return loss of antenna is shown in Figure 4.

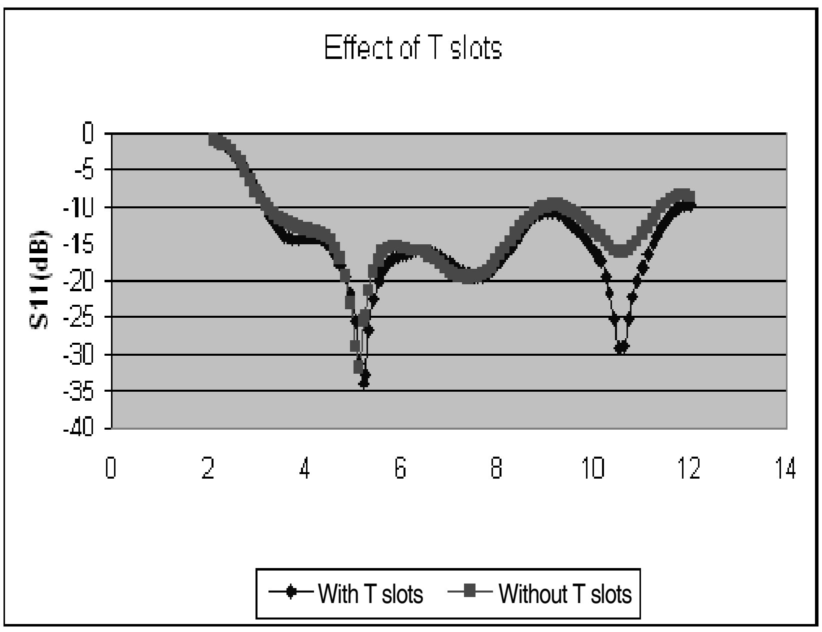
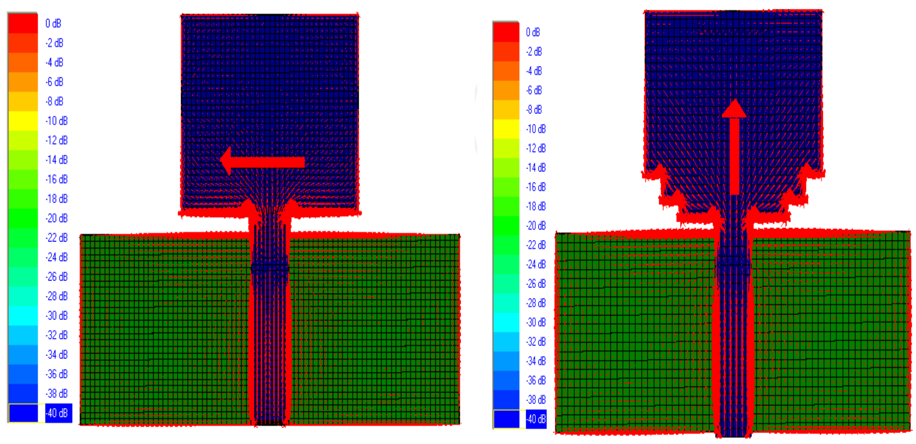


Fig. 4. The effect of T slots to the return loss of antenna

Figure 4 shows the effect of T slots to the antenna performance. From the graph, at upper frequency of 10.5 GHz, the $|S_{11}|$ reaches -30 dB. The bandwidth enhancement is due to much more vertical electrical current achieved in the patch through the T slots resulting in much regular distribution of the magnetic current in the slots. The use of slot embedded on the microstrip patch shows as the most successful technique utilized a coupled resonator approach, in which the microstrip patch acts as one of the resonator and slot as the second resonator near its resonance. In this case, the bandwidth broadening comes from the patch and T-slots, coupled together to form two resonances.

Matching bandwidth is due to the shape of the antenna closed to the feeding point, where currents are strongest. The field supported by these currents would be mainly confined between the bottom part of the rectangular antenna and the ground plane; this is due to the small distance, a small fraction of wavelength, of this edge to the ground plane (D. Valderas et al., 2006). Thereby, this part acts as a matching element.

The study of the current flow on a planar monopole antenna reveals that it is mostly concentrated in the vertical and horizontal edges, as shown in Figure 5. It is observed that the horizontal currents distributions are focused on the bottom edge of rectangular patch. Besides, the horizontal component is also greater than the vertical on this part of the antenna. From Figure 5, it shows that two types current distribution modes occurred on patch radiator and feeding strip such as vertical current mode and horizontal current mode.



(a) (b)

Fig. 5. Simulated current distribution (a) rectangular, (b) rectangular with two notches at the bottom

Cutting notches at the bottom techniques are aimed to change the distance between the lower part of the planar monopole antenna and the ground plane. The simulated return loss, as shown in Figure 6, covers 3.17 GHz to 11.5 GHz of frequency ranges. The slot also appears to introduce a capacitive reactance which counteracts the inductive reactance of the feed.

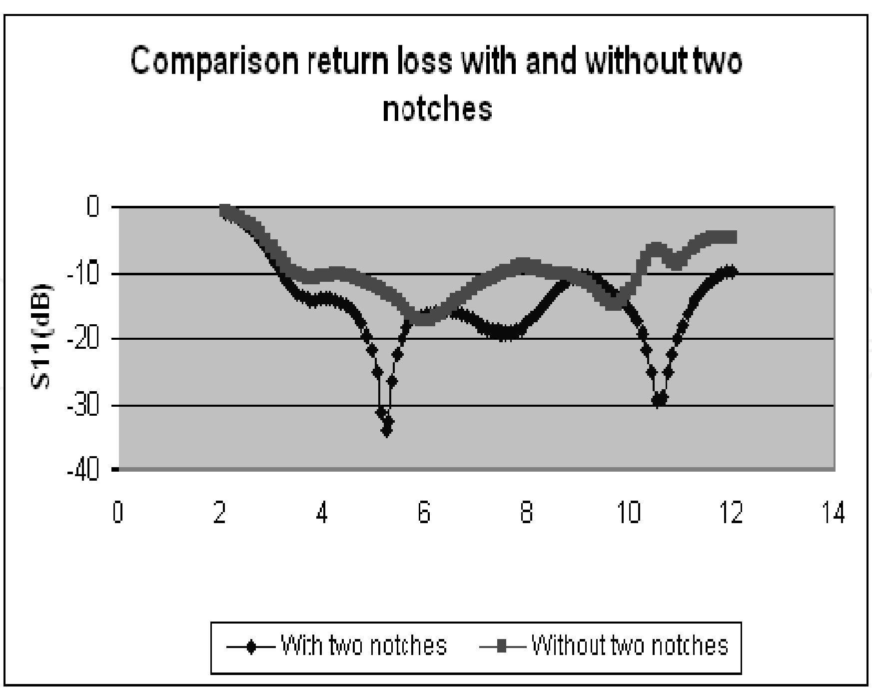


Fig. 6. Comparison of return loss for antenna with and without two notches at the bottom

Figure 6 shows the simulated return loss for both antennas with and without two notches cutting at the bottom edges. Figure 6 shows that the return loss performance of antenna without two notches at the bottom starts degrading its performance at 7.5 GHz, this is due to more horizontal current mode occurs in the whole structure which degrade the polarization properties and the impedance bandwidth performance of the antenna, as shown in Figure 5. In order to modify the equivalent characteristic impedance on the antenna, the distance of the bottom edge to the ground plane and the bottom profile of the monopole should be varied. By varying the edges closed to the feeding point means modifying the current path on the antenna.

The simulated input impedance for antenna with one notch, two notches, and three notches cutting at the bottom edges are also performed and shown in Figure 7. It shows that the loops around matching impedance (50 ohm), which is located at the centre of smith chart. It also shows that the one step and three steps notches cutting at the bottom give more capacitive to the antenna than the two steps notches especially at higher frequency ranges. The ground plane as an impedance matching circuit and also it tunes the resonant frequencies.

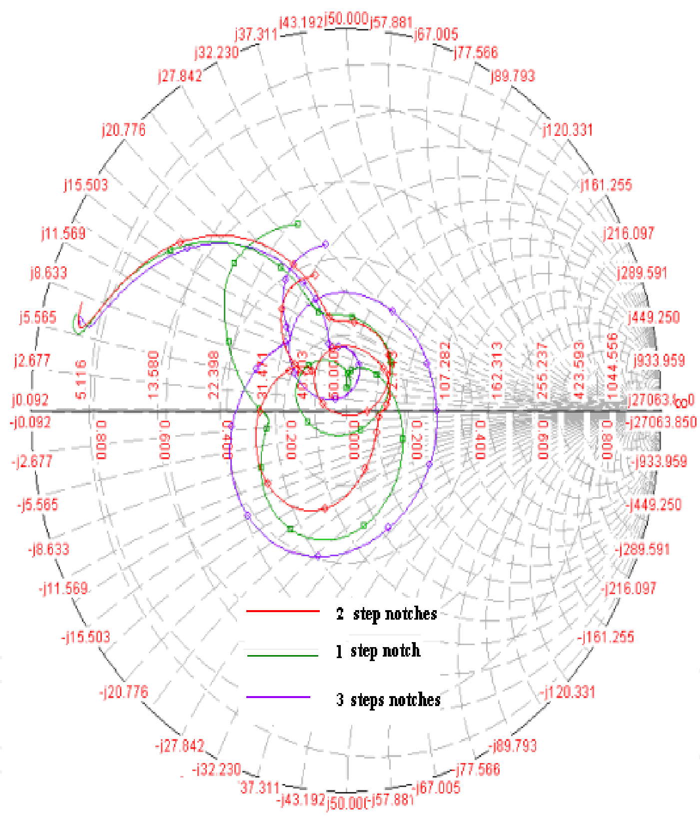


Fig. 7. Simulated input impedance for various notches

Figure 8 shows the simulated current distribution of the proposed antenna at three different frequencies. It shows that the current density decreasing by increasing the frequency. Most vertical electrical current is distributed near to T slot edges rather than distributed on the antenna surface.

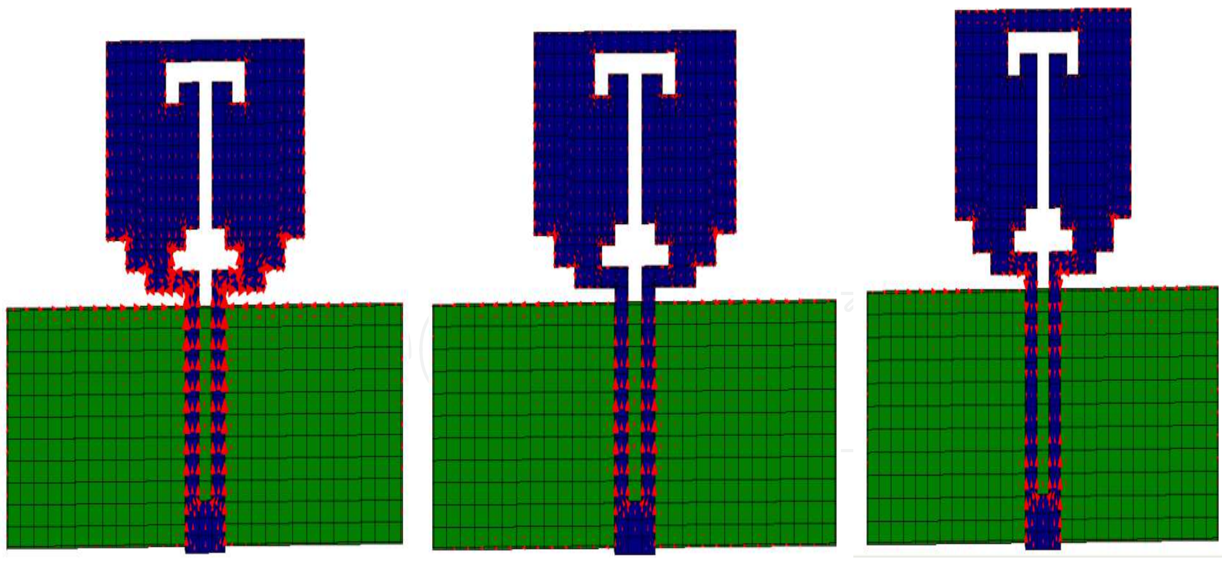


Fig. 8. Simulated current distribution at (a) 3GHz, (b) 6.5 GHz, (c) 10.5 GHz

To validate the simulation results, an antenna prototype was fabricated and tested. In this prototype, measurements are done by using a coaxial port which is soldered at the bottom edge of microstrip line. However, some differences in the simulated and measured results are expected, since in the simulation model discrete and not coaxial port is used. In reality the coaxial cable has a considerable effect, especially the length of its inner conductor, which is connected to the input of the antenna, creating an additional inductance.

The simulated and measured return losses are plotted in Figure 9. The resonance frequencies are shifted from the simulated result but they are still covering the UWB bandwidth requirement. The return loss curves of frequency ranges above 10.5 GHz are getting worst. In addition, since the antenna is fed by microstrip line, misalignment can result because etching is required on both sides of the dielectric substrate. The alignment eroror results degradation to the antenna performance.

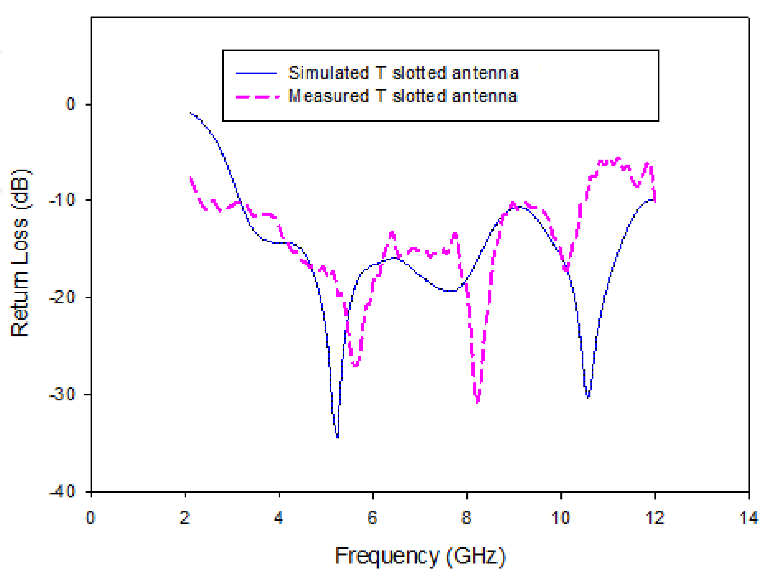


Fig. 9. The simulated and measured return loss

Once the resonance frequencies were identified, principal radiation patterns were taken to characterize the operational performance of antenna. These measurements were obtained using indoor anechoic chamber room. Several requirements are needed to take into consideration during the measurement process. Obtaining true patterns depends primarily on accurately positioning the probe, accurately measuring the field, and eliminating distortions in the field introduced by the room, track, or probe itself. The room reflections must be lower than the basic side-lobe level, the probe itself must have low reflections and accurate position.

The measured radiation patterns were plotted into horizontal (H) and vertical (V) cuts. The H-cut is cut for the azimuth plane with fixed elevation angle at 0^0 and vary the azimuth angle. The V-cut is cut for the elevation plane with fixed azimuth angle at 0^0 and vary the elevation angle.

The existing chamber employed the spherical near field measurement as shown in Figure 10. By definition, near field tests are done by sampling the field very close to the antenna on a known surface. From the phase and amplitude data collected, the far field pattern must be computed in much the same fashion that theoretical patterns are computed from theoretical field distributions. The transformation used in the computation depends on the shape of the surface over which the measurements are taken with the scanning probe (Gary E. Evans, 1990).

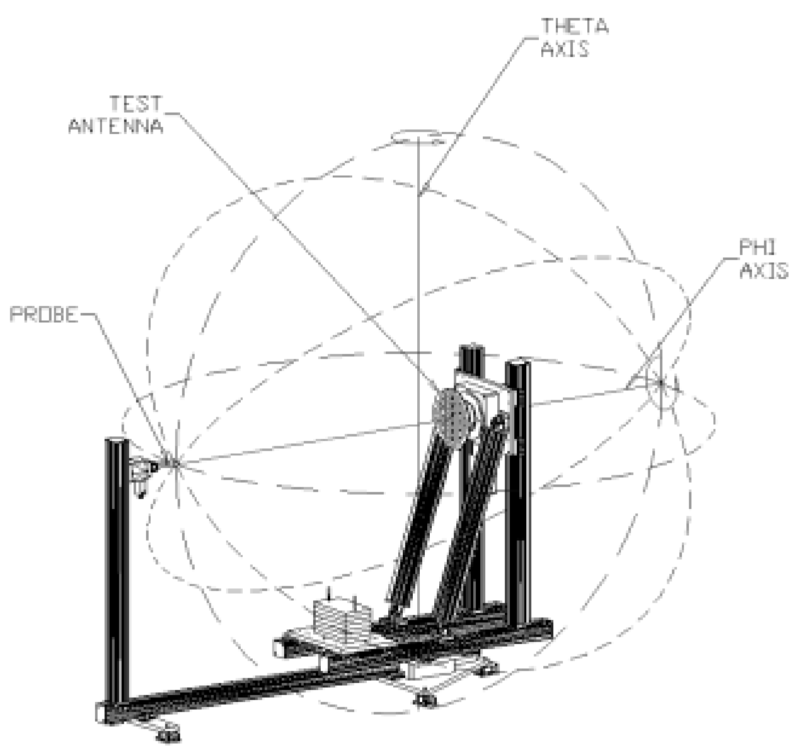
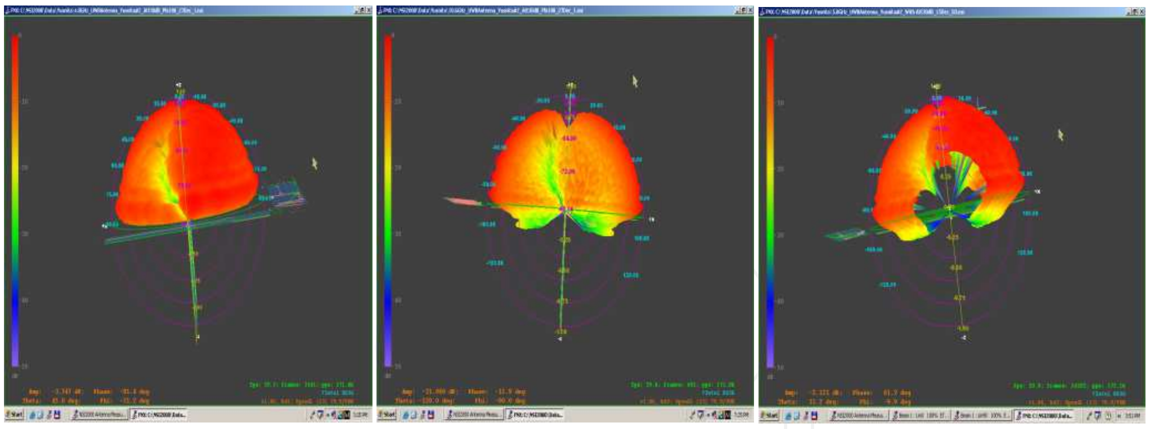


Fig. 10. Coordinate system for typical spherical near-field rotator system (G. Hindman & A.C. Newell, 2004)



(a) (b) (c)

Fig. 11. Measured Radiation Pattern at (a) 4GHz, (b) 5.8GHz, (c)10.6 GHz

The elevation patterns for the antennas are simulated at the H-plane (φ = 0^0, yz-plane) and E-plane (φ = 90^0, xy-plane). The E-plane pattern is the radiation pattern measured in a plane containing feed, and the H-plane pattern is the radiation pattern in a plane orthogonal to the E-plane. The measured 3D radiation patterns of the antenna are shown in Figure 11 at frequencies 4 GHz, 5.8 GHz, and 10.6 GHz. The radiation patterns are nearly omni-directional.

4. Conclusion

In this chapter, various bandwidth enhancement techniques have been presented. The T slotted antenna has been designed and developed. Three bandwidth enhancement techniques were adopted in order to produce a small slotted UWB antenna. This proposed antenna uses two notches, T slot and a partial ground plane. An experimental prototype has been fabricated and tested. It shows that the measured return loss covering the UWB bandwidth requirements of 3.1 GHz – 10.6 GHz with respect to -10 dB. The measured radiation patterns of this prototype are also presented at frequencies 4, 5.8, and 10.6 GHz, respectively.

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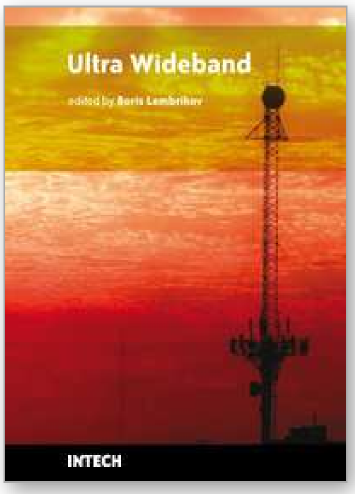

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