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A Compact UWB Microstrip Antenna with Modified Ground Plane for Bandwidth Enhancement

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ABSTRACT
This paper presents a bandwidth enhancing technique using a modified ground plane with diagonal edges, L-shaped slot and parasitic patches with main patch for the design of compact antennas. The proposed low-cost, compact-size rectangular patch antenna on 4.7 cm × 3.6 cm printed circuit board (FR-4) is designed and validated through simulations and experiments. Results show that the ground plane with L-shaped slot in presence of the diagonal cuts at the top corners and the rectangular parasitic patches can increase the bandwidth. Return losses of −23.6 dB and −29.7 dB for the first and second resonant frequencies, respectively, can be achieved when the depth of the diagonal cut is 3 mm, the dimension of each rectangular parasitic patch is 10 mm×3.5 mm, and the L-shaped slot size is 7.5 mm ×2.5mm, providing a 41.27% wider bandwidth than Federal Communication Commission's(FCC) standard.

General Terms
Designing of Microstrip Antenna.

Keywords
monopole antenna, quarter wavelength slot, parasitic patches, Ultra Wide Band.

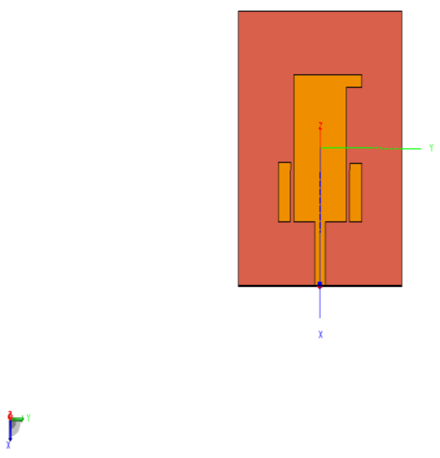
1. INTRODUCTION
Although microstrip antennas have many attractive advantages, it has a narrow bandwidth. Maximum achievable data rate or capacity is related to the bandwidth and the signal-to-noise ratio through Shannon-Nyquist criterion [1, 2]:

$$C = Blog_2(1+\text{SNR})$$

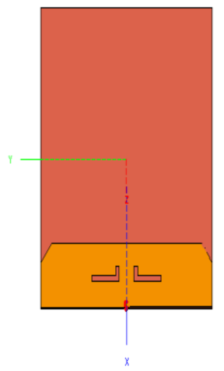
Where C is the maximum transmit data rate, B is for the channel bandwidth and SNR is the signal-to-noise ratio. From the above equation we can enhanced the transmit data rate by increasing either the bandwidth occupation or the transmission power. Many techniques have been used to enhance the bandwidth. Among these techniques are using thick foam or air substrates. Other techniques for enhancing the bandwidth of a single-layer single-patch microstrip antenna include the designs with a three-dimensional microstrip transition feed, a gap coupled feed , a capacitive coupled feed, an optimally designed impedance matching network , a chip-resistor loading , an integrated reactive loading[1]. etc. In addition the up-to-date applications require smaller antenna size in order to meet the miniaturization requirements of RF units .Many techniques have been used to obtain compact microstrip antenna, for example, adopting short-circuit pin (via holes), high dielectric constant substrate, and slots loaded on the patch.[2] However, the above methods for size reduction and extending the bandwidth emphasize microstrip antenna with thick substrates (from 3% to 12% of working wavelength). Little research has been done to enhance the bandwidth and reduce the patch size with a thin substrate (less than 1% of working wavelength) whereas developing ultralow-profile microstrip antenna with enhanced bandwidth and reduced size is very challenging in future integrated RF communication systems.

In this paper, we report a technique to enhance the bandwidth with rectangular patch antenna. The rectangular patch antenna with a 50-Ω microstrip feed line is fabricated on the FR4 substrate.To improve the bandwidth, we modified the original ground plane to be L -shaped with diagonal cuts at the top corners and rectangular parasitic patches with extra strip along with main patch. Applications of corner cut technique have been previously employed to improve the impedance bandwidth for microstrip patch antennas [3–7]. The simulation results of our proposed antenna are compared with the measured ones. The organization of the paper is as follows. The detail of the antenna design is in Section 2 . Preliminary results from simulations are described in Section 3. In section 4 discussion on the experimental results and conclusion in Section 5.

2. ANTENNA DESIGN
The geometries of the antennas in our study are shown in Figure 1. Microstrip antenna offers many advantages, such as being compact, economical, and light weight. On the other hand, it has some disadvantages such as lower bandwidth. Our main objective for the paper is to modify the physical structure and incorporate the techniques to enhance the bandwidth. We also analysis the parametric studies to achieve the optimum values of return loss and bandwidth.



(a)



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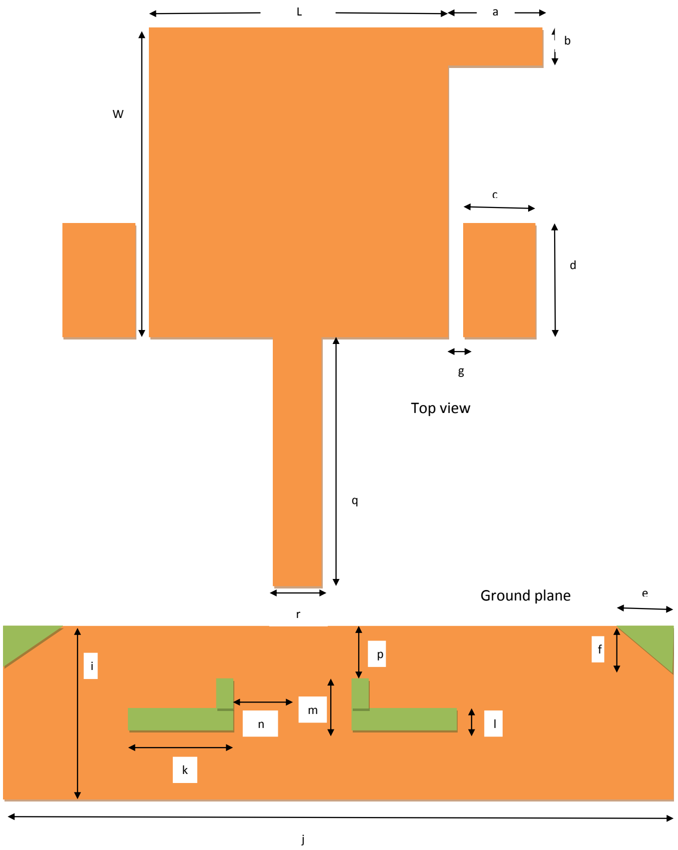

(c)

Figure 1: Geometries of the rectangular microstrip antennas (a)rectangular main patch (b)ground plane with diagonal edges and L-shaped slots.(c) Dimension of Proposed Antenna

The antenna configuration in Figure 1 is first used for the parametric study. The planar rectangular patch monopole is fabricated on a 4.7 cm 3.6 cm 0.16 cm FR-4 board with a feed line and a finite ground plane. The gap of the rectangular patch antenna is the first parameter to optimize for the lowest return loss and widest bandwidth while the other parameters are kept constant. The width of the microstrip feed line is designed to be 3 mm for the impedance of 50Ω .

3. SIMULATION RESULTS

The results in Figure 2 show that the increase of the gap will result in reductions of the return loss and the bandwidth. Even though the vertical gap of 11 mm provides the lowest return loss, we chose the radius of 10 mm for the better bandwidth.

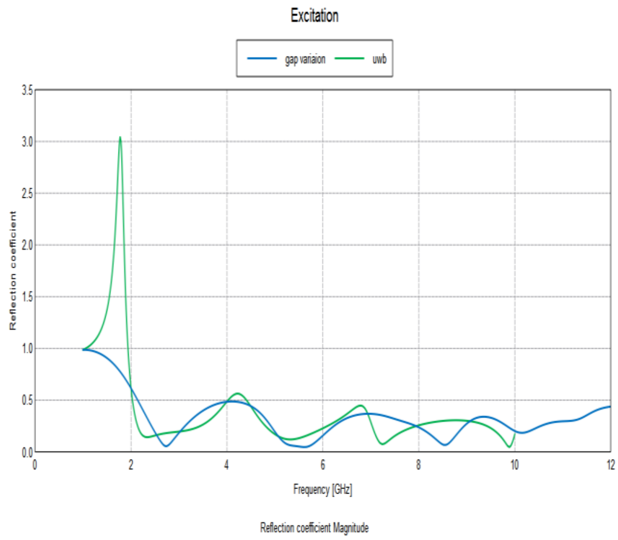

Figure 2: Return losses as functions of vertical gap.

The next parameter which is analyzed in the paper is width of the ground plane .The parameter is positive when the bottom of the patch is at the higher level than the top of the ground plane. The same can be said for the negative value of in the opposite direction. The results of the return loss and bandwidth as a function of the parameter are shown in Figure 3. Compared with the negative value of i, the positive value gives the higher return loss at high frequency while providing the lower return loss at low frequency. We chose the parameter *i* to be zero (the bottom of the patch is at the same level as the top of the ground plane) for a compromise between the observed return loss at high and low frequencies. where the antenna is applicable from 2.957 GHz to 11.892 GHz, providing a bandwidth of 8.935 GHz.

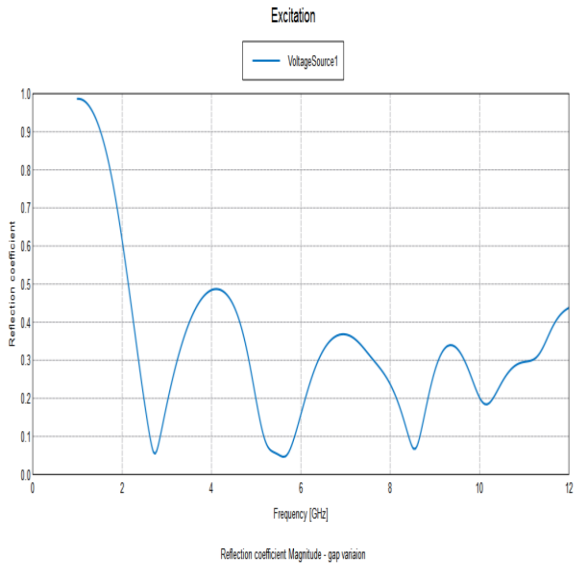

Figure 3: Return losses as functions of width of ground

To further improve the bandwidth of the antenna, we removed the top corners of the ground plane, resulting in symmetrical diagonal edges. The resultant antenna is shown in Figure 1(b) with the parameter associated with the cut area. The return losses in Figure 4 show that the parameter only has a slight effect at low frequency while it has a significant effect at high frequency. The parameter of 3 mm seems to offer a relatively low return loss and an appropriately wide bandwidth. This antenna can be used from 2.957 GHz to 12.1 GHz, providing a bandwidth of 9.15 GHz. Compared with the result in Figure 3, associated with the original shape, the antenna with diagonal edges on the ground plane can increase the bandwidth for approximately 0.21 GHz as shown in Figure 5.

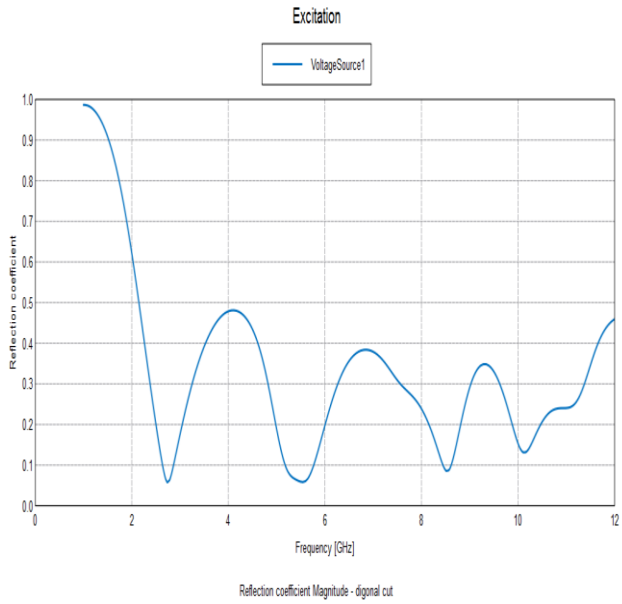

Figure 4: Return losses as a function of the parameter associated with the removed area on the ground plane.

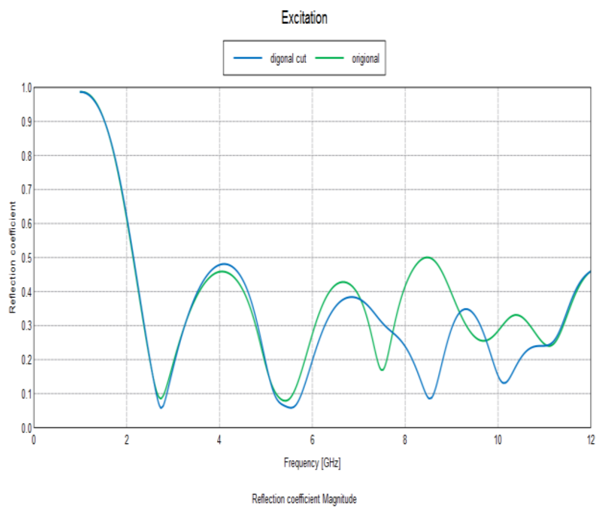

Figure 5: Comparison of return loss between the original antenna and the antenna with diagonal edges on the ground plane.

The L-shaped slot technique [8–12] is employed to improve the impedance matching in the UWB frequencies. This method introduces two identical slots at the center of the ground plane, shown in Figure 1(b), in order to moderate the reflection of the surface current, thus adjusting the antenna impedance and reducing the return loss[13-16]. The optimum values of the slot width and slot height are 7.5mm and 2.5 mm, respectively. The return losses of antenna with slot dimensions are shown in the Figure 6.

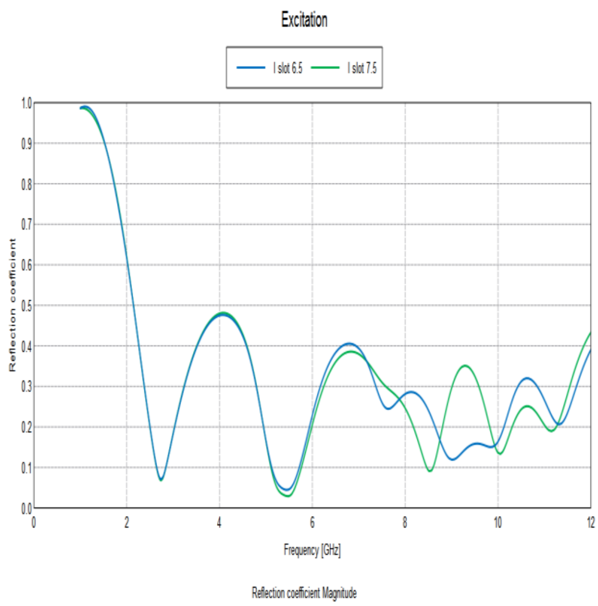

Figure 6: Return loss of antenna with slot dimension.

In addition to diagonal edges and L-shaped slots, the main patch was associated with parasitic patches (see Figure.1(b)) The results show that an accumulation of ground plane modifications and parasitic patch introduces an extra return loss dip, resulting in the optimal bandwidth.

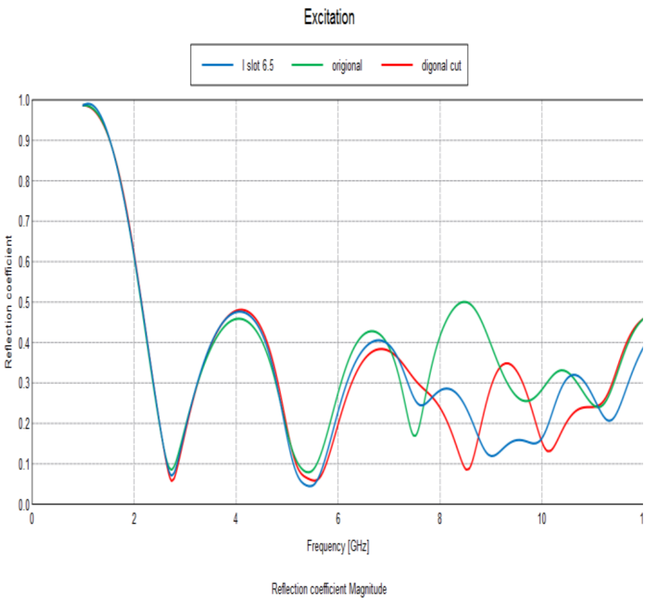

Figure 7: Comparison of return losses of all three configuration viz.original,diagonal cut,slots

Table I Dimensions of Proposed Antenna

Symbol	Size (mm)
a	4.5
b	2.0
c	3.5
d	10
e	3.0
f	3.0
g	1.0
G	1.0
h	1.6
i	10
j	47
k	7.5
L	15
l	1.0
m	2.5
n	2.0
q	11
r	3
p	3.5
W	25

4.EXPERIMENTAL RESULT AND DISCUSSION

The fabricated proposed rectangular patch antenna with diagonal edges and slots on the ground plane is shown in Figure 8. The comparison between the simulated results using commercial high-frequency structure simulator (cadfeko 6.1) and the results from the measurement of the fabricated antenna using an Agilent VNA-L series N9923A vector network analyzer is shown in Figure 9. The measured result is relatively close to that obtained from simulation. The discrepancy of the return loss at the first resonant frequency would be caused by the measurement conditions between the simulation model and the fabrication .

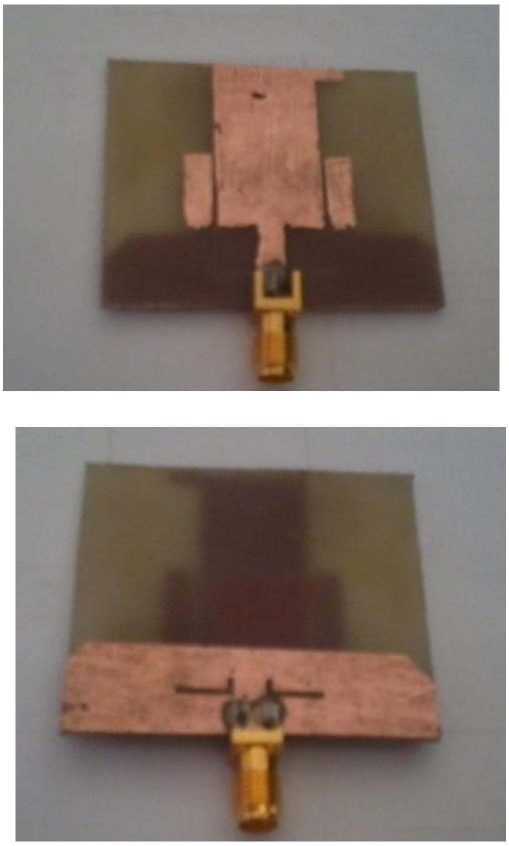

Figure 8: Photograph of the fabricated proposed antenna.

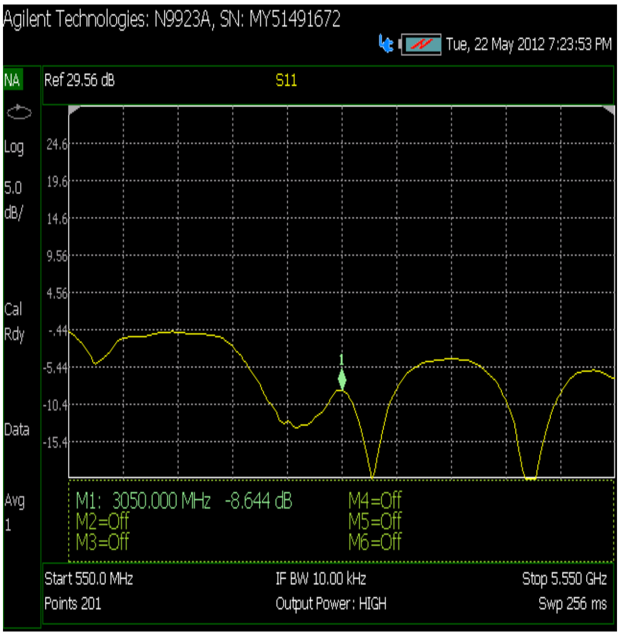

Figure 9:Measured Results

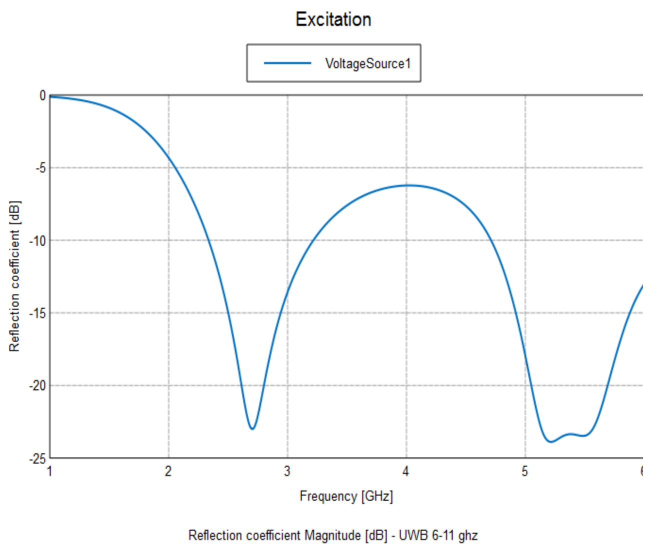

Figure 10: Comparison between simulated and measured results of the proposed rectangular microstrip antenna.

The measured radiation patterns of the antenna on the E-plane and H-plane at resonant frequencies of 1GHz, 3 GHz, 6 GHz, and 8 GHz are shown in Figures11,12 13 and 14 respectively. The results show that reasonable Omni-directional radiation pattern can be observed along the H-plane. The radiation pattern similar to that of the short dipole can be observed on the E-plane. Consistency of the patterns can also be observed across the operating frequencies. The E-plane co polarization patterns are bidirectional and H-plane co polarization patterns are Omni directional or nearly Omni-directional at higher frequency, like a regular dipole [17]. When the frequency increases to 8 GHz, the direction of the electric field becomes complex. As a result, the cross-polarization level rises and ripples appear in the E-plane but the H-plane is still omni-directional. As a conclusion, the radiation pattern of the proposed antenna is almost stable in the operation band (3–12 GHz). Figure 17 shows the relatively almost constant gain of optimized antenna from 1 to 6 GHz with some changes about 5.5 GHz .and this gain is not nearly change but it seem to be reduced at the higher frequency.

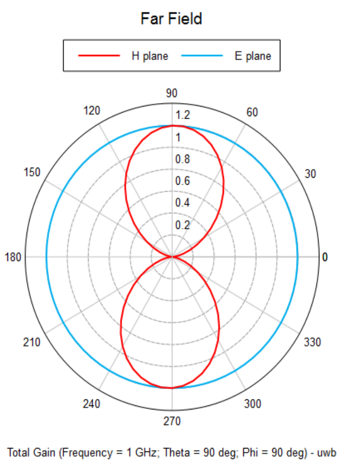

Figure 11: simulated radiation patterns at 1 GHz. (a) E-plane patterns, and (b) H-plane patterns.

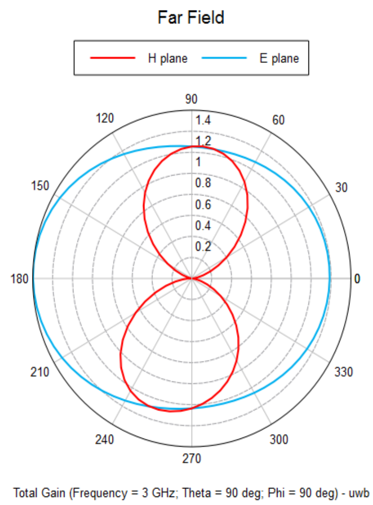

Figure 12:simulated radiation patterns at 3 GHz. (a) E-plane patterns, and (b) H-plane patterns.

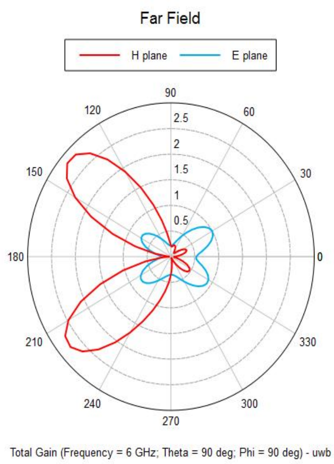

Figure 13: simulated radiation patterns at 8GHz. (a) E-plane patterns, and (b) H-plane patterns

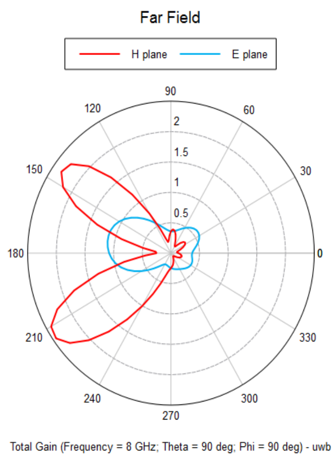

Figure 14: simulated radiation patterns at 8GHz. (a) E-plane patterns, and (b) H-plane patterns.

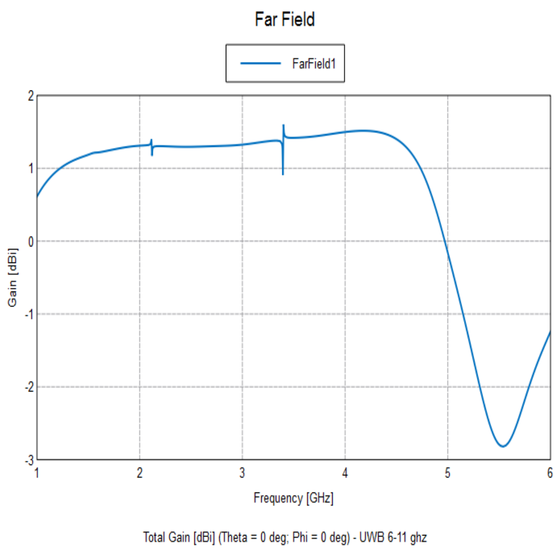

Figure 15: Gain of the optimized antenna

Several important observations from the results of the return loss are detailed as follows. First, the dimension of the rectangular patch basically corresponds to the quarter wavelength of the associated resonant frequency [18, 19]. In addition, the parameter results in not only the resonant frequency shifting but also the return loss level between the first and second resonant frequencies. For the second observation, the first resonance is barely changed for all different ground plane sizes as shown in Figures 3 When the ground plane is reduced in either length or width, the first resonant frequency is shifted slightly at around 3 GHz. These two observations imply that the resonant frequency is typically determined by the rectangular microstrip antenna size and slightly detuned by the size of the ground plane. The observation is that, as shown in Figure 2, the first resonant frequency is dependent on the size of the rectangular microstrip antenna as mentioned above while the second resonant frequency and the bandwidth obey the dimension of the cut area at the ground plane corners [20, 21]. The rectangular L- slot and diagonal cut are used to improve the impedance matching of the propose antenna to reduce the reflection of surface current, thus adjusting the parameters of slot cut to reduce return loss or enhance the bandwidth of UWB antenna.

5.CONCLUSION

A compact antenna and a technique to increase its bandwidth have been proposed and implemented. The proposed low-cost and compact-size rectangular patch antenna on4.7 cm × 3.6 cm printed circuit board (FR-4) is designed and validated through simulations and experimental observations. Results show that the bandwidth can be tuneable depending mainly on the L-slot size and the vertical gap between the patch and the ground plane. With the presence of the diagonal cut areas at the corners of the ground plane, the bandwidth can be further improved. Return losses of −17dB and −30 dB for the first and second resonant frequencies, respectively, can be achieved when the depth of the diagonal cut is at optimum value . providing a maximum 41.27% wider bandwidth (3.1–10.6 GHz) than the FCC recommended standard of 3.1–10.6 GHz. Finally, the size of the ground plane, which has an insignificant impact on the performance, can be further reduced to meet a compact size design.

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