

Design and Optimization of a Printed Rectangular Antenna for Ultra-Wideband Applications

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Abstract: A compact rectangular shaped planar antenna has proposed and optimized for UWB applications. The antenna structure is composed of a square patch and a partial ground plane with multiple slots. The result shows that the antenna achieves an impedance bandwidth ($VSWR \leq 2$) of 145.66% (2.77 to 17.62 GHz). A stable bidirectional radiation pattern with low cross polarization level makes the proposed antenna suitable for being used in wireless communication and microwave imaging system. Details of the proposed compact planar antenna design are presented and discussed.

Key words: Printed antenna • Ultrawideband technology • Slotted ground plane • Wireless communication

INTRODUCTION

After the Federal Communication Commission (FCC)'s authorization of frequency band of 3.1 to 10.6 GHz with power spectral density limit of -41.3 dBm/MHz for unlicensed ultra-wideband (UWB) radio applications, UWB technology become the most promising candidate for a wide range of new applications that will provide significant benefits for public safety, business and consumers [1]. These applications include wireless local area network (WLAN), wireless personal area network (WPAN), wireless body area network (WBAN), wireless sensor network and bio-medical instrument, radar and detector. UWB technology has the advantages of high data transmission rates, high precision ranging, low complexity, very low interferences and easy connections among a large number of devices such as laptops, high definition TVs, digital cameras and wearable bio-medical sensors. In all these applications, antenna- the key component of UWB system needs to be of low cost and small enough to be embedded into the wireless devices or integrated with other RF circuits and have broad impedance bandwidth with stable radiation characteristics. To design an efficient and compact antenna for UWB applications is still a major challenge. One of the popular UWB antenna types requires a perpendicular ground plane, which resulted in increased

antenna size and difficult to integration with microwave-integrated circuits. Compared with the three dimensional type of antenna, planar structure in which the antenna can be printed onto a piece of printed circuit board (PCB) is one of the possible options to satisfy the requirements for small UWB antennas. Due to this advantage, industry and academia have put enormous efforts on researches to study, design and develop planar antennas for UWB communication systems.

Many antennas fed by microstrip-line and coplanar waveguide have been investigated for UWB applications. These antennas use the monopole configuration such as square, elliptical, circular ring, annular ring, triangle, pentagon and hexagonal antennas [2-7]; the dipole configuration [8-10] like bow-tie and double printed rectangular antennas. Some of reported UWB antennas do not have a planar structure due to their ground planes perpendicular to the radiators. This drawback makes them difficult to be integrated with the printed circuit boards.

Several UWB antennas have also been reported with various bandwidth enhancement techniques. Some of the techniques are association of several elements to form an array antenna [10], use of log periodic arrays in which the different elements are deduced from an homothetic ratio in order to reach the desired bandwidth [11], introduction of a capacitive coupling between the radiating element and the ground plane [12], addition of slots on the side of

the radiating element [13], using a tapered feed line [14], notching the ground plane and/or the patch [15], modifying the shape of the radiating element and adding a shorting pin [16].

Recently other techniques have also been examined to enhance the bandwidth of UWB planar antenna, including the insertion of a modified trapezoid-shaped slot in the patch [17], the use of trident-shaped feeding strip and a tapered impedance transformer [18] and embedding a pair of notches in the two lower corners of the patch and the notch structure in the upper edge of the ground plane [19]. The use of two bevel slots on the upper edge and two semicircle slots on the bottom edge of the ground plane [20], insertion of rectangular slot on the top side of the ground plane [2] and a half-bowtie radiating patch with staircase shape [21] have been also reported for the bandwidth enhancement. Techniques such as adding steps to the lower edge of the patch [22], increasing the ellipticity ratio of ellipse-shaped patch [23] and the insertion of additional stub to the one side of circular patch [24] have also been reported for bandwidth enhancement in planar monopole antennas. All these techniques are based on the modification of the surface current distribution to ameliorate the antenna's impedance bandwidth. Many of the antennas reported earlier do not possess physically compact profile and not suitable to be integrated with the printed circuit boards.

In this paper, a microstrip-fed printed rectangular antenna that achieves a physically compact planar profile, sufficient impedance bandwidth and stable radiation pattern is proposed. In the proposed structure, we optimized the antenna parameters to achieve the widest frequency bandwidth and impedance matching. The proposed antenna consists of a square shape radiating patch and partial ground plane with multiple rectangular slots on the top side to cause a wider bandwidth for UWB applications. The antenna structure is simple and its design is straightforward and easy to fabricate.

Antenna Geometry and Optimization: Figure 1 illustrated the configuration of the proposed antenna, which consists of a square patch and a partial ground plane with multiple rectangular slots on the top side. The patch having a compact dimension of $W_l \times L_l$, is printed in the front side of a FR4 PCB substrate of thickness 1.6 mm and relative permittivity 4.6. The dimension of partial ground plane which is printed in the back side of the substrate is chosen to be $W \times L_g$ in this study. The dimension of each slot is $2 \times 1 \text{ mm}^2$. The bottom of the square patch is connected by a microstrip line of length 7 mm and width

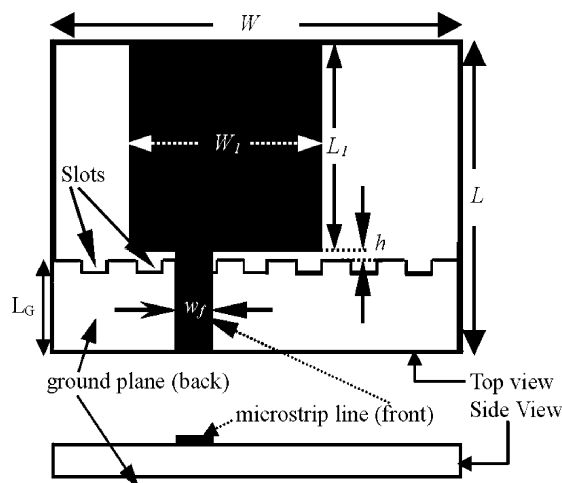


Fig. 1: Geometry of the proposed antenna

w_f , which is fed by a 50Ω ohms coaxial probe from the side of the antenna. The microstrip line was etched on the same side of the patch on the substrate as the radiator. The gap between radiating patch and ground plane is h .

A parametric study was conducted to optimize the antenna parameters. It helps to investigate the effects of the different parameters on the impedance bandwidth. It is also important because it provides some understanding of antenna characteristics to the antenna designer. The effects of varying the ground plane width (W) and length (L_g), patch width (W_l) and length (L_l), width of the microstrip line (w_f) and the gap between patch and the ground plane (h) are studied. In the simulations, except for the parameter of interest, the other parameters are kept constant.

The length of the ground plane is the first parameter to be optimized. Fig. 2 shows the simulated return losses of the proposed antenna with different length of ground plane. It is observed that, a ground plane with length 5.5 mm can maintain the good impedance bandwidth with highest return loss values. However, the impedance matching deteriorates as the ground plane length become smaller.

Fig. 3 shows the variation of the return loss with the width of the ground plane, W . It can be observed that with decreasing W , the bandwidth is decreased especially at the upper edge frequencies of the operating band and the third resonance frequency shifted. Again, with the increasing W , the impedance matching becomes poor at higher frequencies though it gives better return loss values. A ground plane width of 29 mm can be taken as the optimized value to give wider bandwidth.

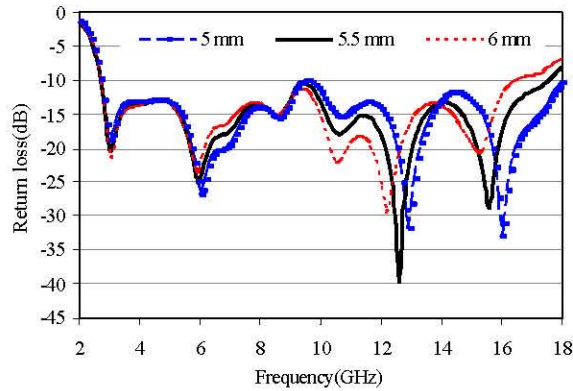


Fig. 2: Return loss for different values of L_G

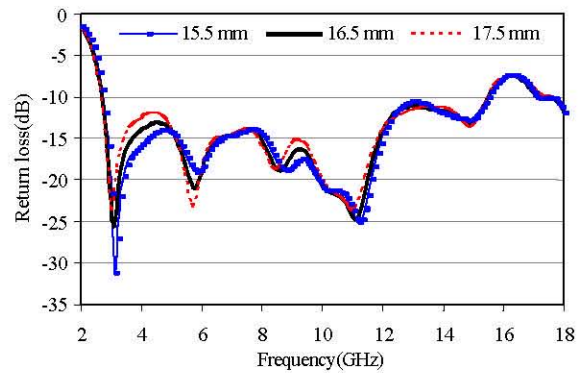


Fig. 5: Return loss for different values of L_l

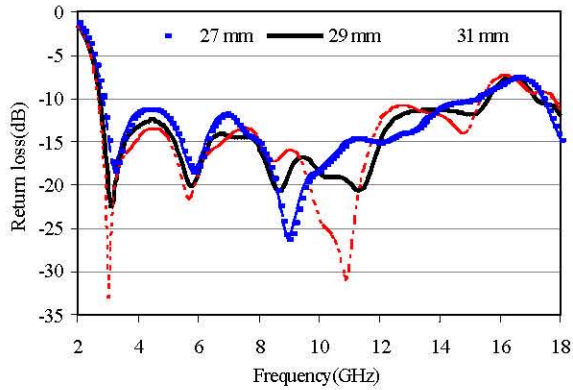


Fig. 3: Return loss for different values of W

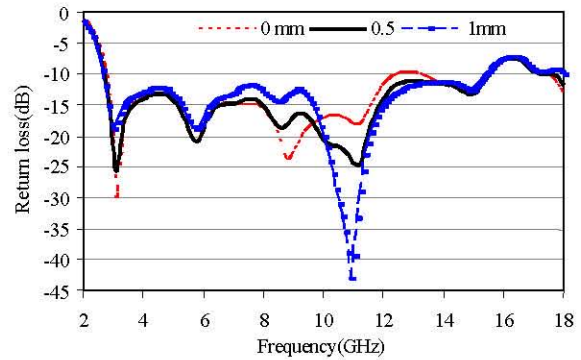


Fig. 6: Return loss for different values of h

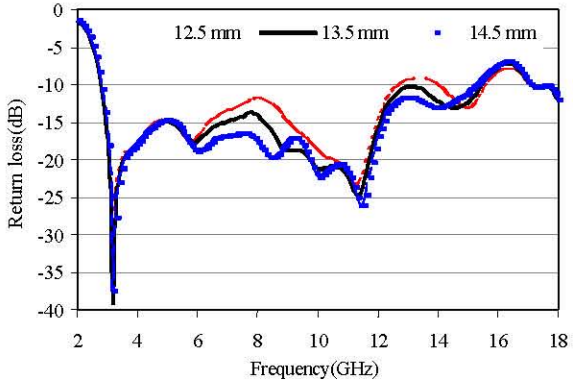


Fig. 4: Return loss for different values of W_l

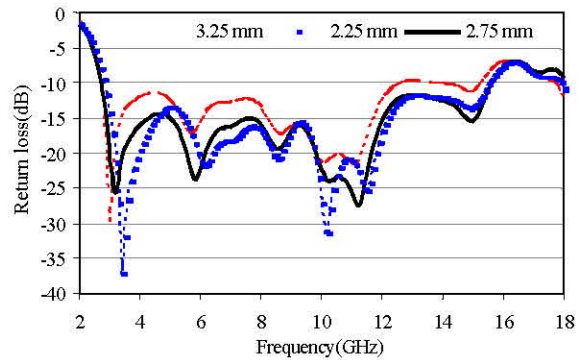


Fig. 7: Return loss for different values of wf

To compact the antenna, the width and length of the patch should be small. It can be seen from figures 4 and 5 that a larger patch can covers less bandwidth with good return loss at the cost of antenna size. The smaller one cannot meet the requirement at the upper edge frequencies of the operating band and also bring poor return loss in the lower frequencies. As shown in figures, a patch with dimensions 13.5 mm \times 16.5 mm can maintain good impedance matching.

Fig. 6 demonstrates the simulated return losses with different gaps ($h = 0, 0.5, 1$ mm) while the other parameters are fixed. Since the ground plane serve as an impedance matching circuit, the gap between the ground plane and feed point can tune the input impedance of the antenna resulting in changing the operating bandwidth. It is observed that a feed gap of 0.5 mm can give the better return loss value within the operating bandwidth.

The impedance matching is also very sensitive to the changes in the width of microstrip line (w_f) as shown in Fig. 7. Increasing and decreasing the values of w_f from a certain value improves the return loss value but the increase in resistance resulting in an overall decrement in the impedance matching. The feeding width of 2.75 mm is used as the optimized value.

To compact the proposed antenna further and to enhance the impedance bandwidth, seven rectangular slots is introduced in the top side of partial ground plane. The slots on the partial ground plane have an effect on matching as the gap between the radiating element and ground plane is increased. As a result the bandwidth is increased due to extra electromagnetic coupling between patch and the ground plane.

RESULTS AND DISCUSSION

The performance of the proposed antenna has been analyzed and optimized by method of moments based full-wave electromagnetic simulator Zeland IE3D.

The return loss of the proposed antenna is depicted in Fig. 8. The plot of the return loss shows that the impedance bandwidth (VSWR ≤ 2) of the proposed antenna is 14.85 GHz (from 2.77 GHz to 17.62 GHz) which is equivalent to 145.66%. Its covers the entire UWB frequencies mentioned earlier.

Fig. 9 shows the antenna gain in the frequency range of 3-11 GHz and the maximum gain is 1.3 dBi. The gain is affected by the high losses of dielectric substrate and the size of the finite ground plane

Figs. 10 and 11 respectively show the E- and H-plane radiation patterns of the proposed antenna at four resonance frequencies of 3.2, 6.1, 12.7 and 15.8 GHz. Fig. 12 shows the 3D radiation patterns at 3.2 and 6.1 GHz. It is seen from the figures that, the proposed antenna has a main beam in broadside direction (0° , 180°) throughout the operating frequencies. Although at higher frequencies, more harmonic is observed mainly in cross-polarization radiation field, the antenna has a good stable radiation in the broadside direction without gain degradation unlike the existing UWB monopole antennas.

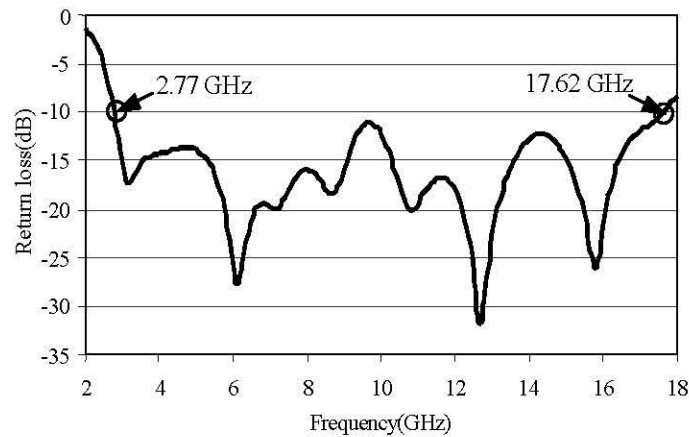


Fig. 8: Return loss of the proposed antenna

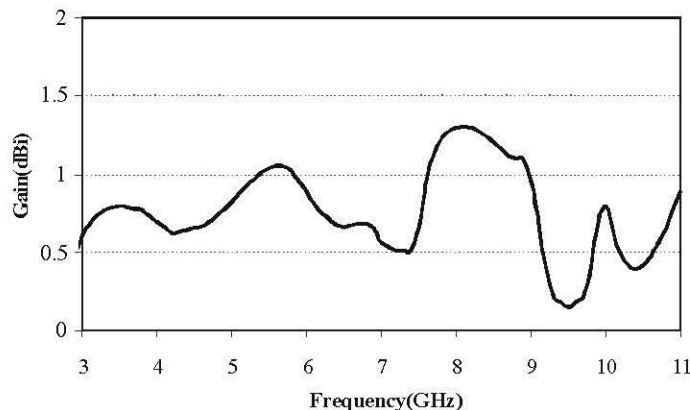


Fig. 9: Peak gain of the proposed antenna

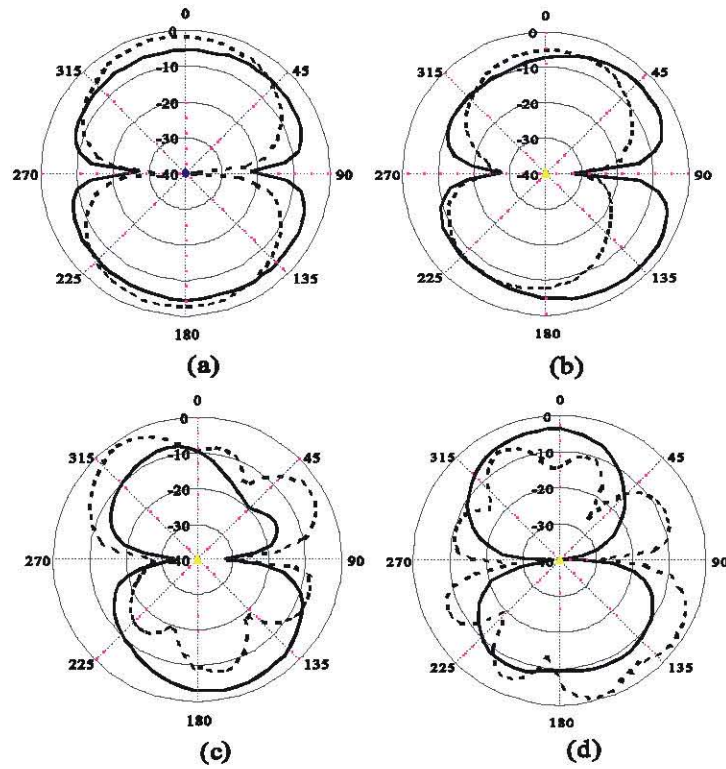


Fig. 10: E-plane at (a) 3.2 (b) 6.1 (c) 12.7 and (d) 15.8 Ghz [— Copolarization, ---- Crosspolarization]

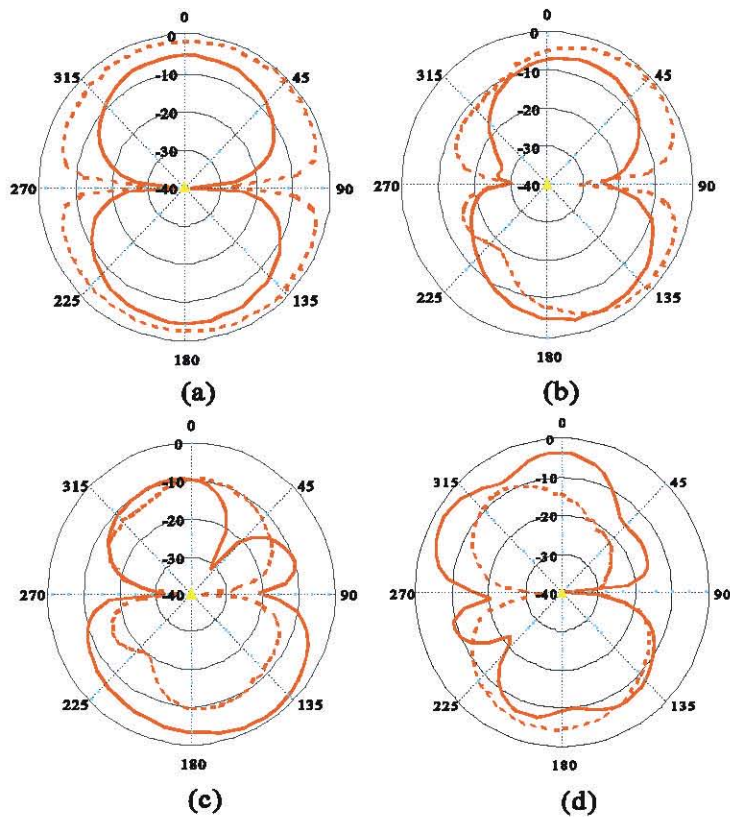


Fig. 11: H-plane at (a) 3.2 (b) 6.1 (c) 12.7 and (d) 15.8 Ghz [— Copolarization, ---- Crosspolarization]

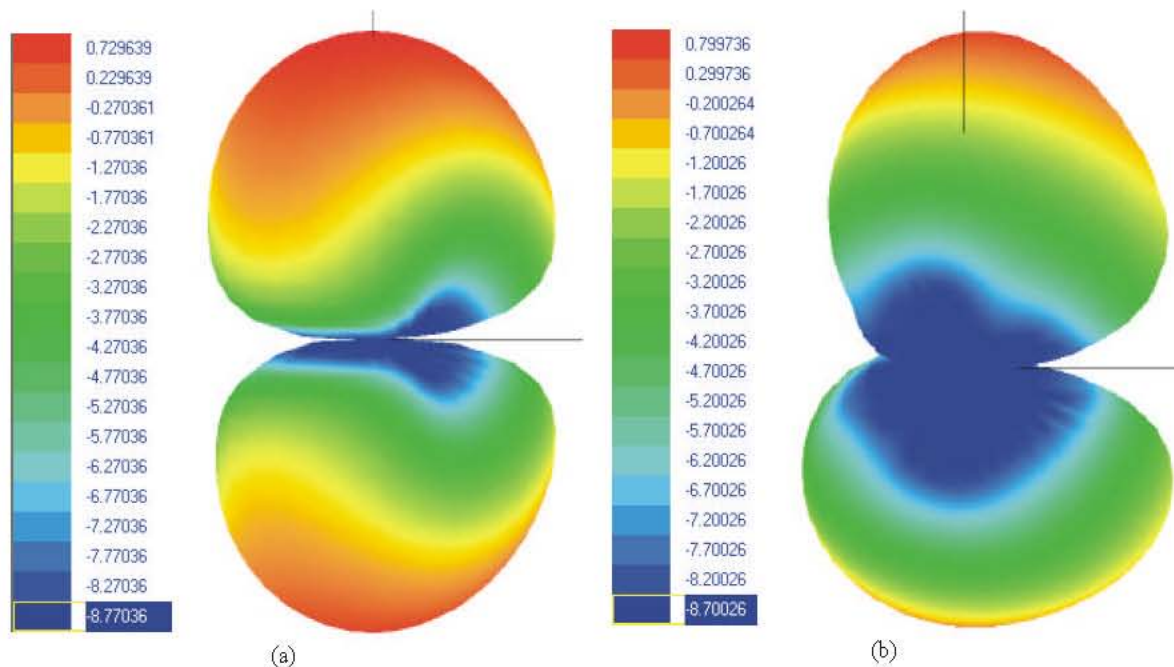


Fig. 12: 3D radiation pattern at (a) 3.2, (b) 6.1 GHz

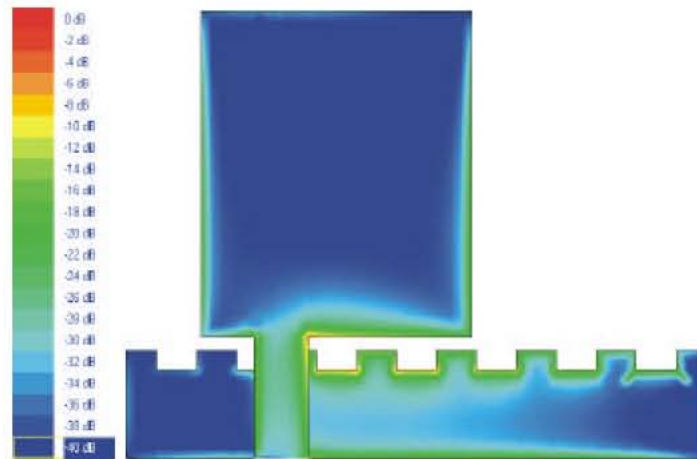


Fig. 13: Surface current distribution at 6.1 GHz

In H-plane, the cross-polarization field has a smaller value which is desired for many UWB applications. In the E-plane, the half-power beam width (HPBW) at 3.2, 6.1, 12.7 and 15.8 GHz are respectively 85.47° , 74.39° , 40.53° and 67.45° and the radiation patterns are almost similar and stable. The HPBW in H-plane are 86.07° , 68.81° , 79.44° and 41.52° at 3.2, 6.2, 12.7 and 15.8 GHz respectively.

The surface current distribution at 6.1 GHz is presented in Fig. 13. The current distribution of the proposed antenna is obtained by accounting the optimal design parameter values. It is seen that for the antenna mode, the square patch is more like a resonance curved

half-wave length dipole, rather than a low Q factor disc resonator. It is also seen that, the currents are mainly around the upper edge of the radiating patch. However, the current is uniformly distributed elsewhere.

CONCLUSION

A low cost rectangular shape compact planar antenna has been proposed and optimized. The antenna structure is flat and its design is simple and straightforward, so it is easy to fabricate. The proposed antenna has achieved a bandwidth ($\text{VSWR} \leq 2$) of 145.66% (2.77 - 17.62 GHz).

A parametric study on the impedance matching has also been conducted to enable antenna researchers to design according to the required specifications. The nearly stable bidirectional radiation pattern with low cross polarization and flat gain makes the proposed antenna suitable for being used in various UWB applications.

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