Bandwidth Enhancement of UWB Microstrip Antennas with Ground Plane Modifications

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1. Introduction

Ultra-wideband (UWB) technology has been regarded as one of the most promising wireless technologies that have a capability of revolutionizing high data rate transmission. Since released by the FCC of UWB wireless communication bandwidth of 7.5 GHz (3.1 - 10.6 GHz), a number of new developed techniques to support high data rate wireless communication for the next generation technologies have been rapidly increasing. Basically, the maximum achievable data rate or capacity is related to the bandwidth and the signal-to-noise ratio through Shannon-Hartley criterion [1]. Since the transmission power can not be readily increased due to the size of portable devices, a large frequency bandwidth seems to be the proper solution to achieve a high data rate.

Due to the low UWB performances offered by wire antennas, a large number of patch antennas have been introduced to give superior performances for a variety of UWB applications. Among several shapes of patch antennas, circular or elliptic discs provide the wider impedance bandwidth compared with square plates [2]. Due to their simple geometries and the ease of fabrication, several methods to increase the impedance bandwidth including the use of beveling, semi-circular base, and cutting notches at the bottom. The aim of such techniques was to adjust the electrical distance between the bottom part of the planar monopole antenna and the ground plane so that the coupling between these structures can be tuned for wider impedance bandwidths. In this paper, we report the techniques to enhance a bandwidth using a microstrip-fed circular disc planar monopole. We modified the ground plane by superimposing the uses of diagonal cuts at the corners, rectangular slots, and T-shaped cuts where each of these techniques have been previously reported [3]-[5]. The simulation analysis of our proposed antenna was compared with measurement counterpart. Following this introduction, we have organized the rest of the paper as follows. The detail of antenna design and preliminary results from simulations are described in Section 2. Section 3 discusses the experimental results. This work concludes in Section 4.

2. Antenna Ground Plane Design

The geometries of the planar monopole antennas in our study are shown in Fig. 1. We used the microstrip structure due to many advantages, such as compact in both size and weight, and inexpensive. Our objectives were to modify the structure by incorporating several techniques to improve the bandwidth. The antenna configuration in Fig. 1(a) was first used as a baseline for parametric study. The circular disc planar monopole was fabricated on a 3 cm × 5.1 cm × 0.16 cm FR-4 board (εr = 4.4) with a feed line, and a finite ground plane. The radius R of the circular disc, the width wg of the microstrip feed line, the ground plane dimensions L and W, and the distance between the bottom part of the disc and the top part of the ground plane h were already optimized in our previous study [6]. The ground plane modifications, which are the diagonal cuts at the corners, rectangular slots, and T-shaped cuts, are our main design in this paper. The preliminary simulation results determined using the commercial high frequency structure simulator (IE3D) [7].
2.1 Diagonal Cuts at the Corners

To 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 Fig. 1(b) with the parameter $G$ associated with the cut area. The simulated return losses in Fig. 2(a) show that the parameter $G$ only has a slight effect at low frequency while it has a significant effect at high frequency. The parameter $G$ of 5 mm seems to offer the relatively low return loss and acceptable bandwidth. This antenna can use from 2.957 GHz to 12.1 GHz, related to the bandwidth of 9.15 GHz. Compared with the result in Fig. 4, associated with the original shape, the antenna with diagonal edges on the ground plane can increase the bandwidth of approximately 0.21 GHz.

2.2 Insertion of Rectangular Slots

To further improve the UWB frequency coverage, the rectangular slot technique was employed. This method introduces two identical slots at the center of ground plane as shown in Fig. 1(c), in order to mitigate the reflection of the surface current, thus adjusting the antenna impedance and reducing the return loss. The optimum values of the slot width $W_s$ and slot height $H_s$ are 5 and 3 mm, respectively. The return losses of antenna with slot dimensions are shown in the Fig. 2(b).

2.3 T-Shaped Cuts

In addition to diagonal cuts at the corners and rectangular slots, the ground plane was reshaped as a letter ‘T’ as shown in Fig 1 (d). The T-shaped ground plane achieves the highest bandwidth when the width $W_t$ and the height $H_t$ of the cut portion are 8 mm and 4 mm, respectively, where the results of return losses with different cut sizes can be seen in Fig. 3(a). A comparison among the antenna with the superimposition of ground plane modifications is shown in Fig. 3(b). The results show that an accumulation of ground plane modification effects introduces the extra return loss dip, resulting in the enhanced bandwidth.
3. Experimental Results and Discussion

The photograph of the fabricated proposed circular disc antennas with diagonal edges and slots on the T-shaped ground plane are shown in Fig. 4(a). The comparison between the simulated results and the results from the measurement of the fabricated antenna using an Agilent PNA-L series N5230A vector network analyzer is shown in Fig. 4(b). The measured result with the range of impedance bandwidth from 3 to 12.615 GHz is relatively close to that obtained from simulation. The discrepancy of the return losses at the first resonant frequency would be caused by the slight difference of the circular disc sizes between the simulation model and the fabrication.

Figure 4: (a) Photograph of the fabricated proposed antennas and (b) comparison between simulated and measured results.

The measured radiation patterns of the antenna on the E-plane (H-plane’s are not shown here) at resonant frequencies of 3.2 GHz, 6.40 GHz, and 7.65 GHz are shown in Figs. 5(a), 5(b), and 5(c) 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. When the frequency increases to 7.65 GHz, the cross-polarization level rises and ripples appear. It can be concluded that the radiation pattern of proposed antenna is almost stable in the operation band. Fig. 5(d) shows the gains from 1 to 13 GHz of the structures shown in Fig. 1. The maximum gain is 2.7 dB at 6.4 GHz with the average value of 2 dB inside the UWB region. Several important observations from the results of the return losses can be detailed as follows. First, the circular disc is capable of supporting multiple resonant modes providing a wide impedance bandwidth as shown in Fig. 2, the first two resonances are dependent on the size of the circular disc while the third resonant frequency is introduced by the presence of the cut areas at the ground plane corners. The rectangular slots and T-shaped cuts can further improve the impedance matching of the antenna by reducing the reflection of surface current, thus enhancing the bandwidth of UWB antennas.
5. Conclusion

A compact circular disc planar antenna with a ground modification technique to increase a bandwidth has been proposed and validated through simulations and experimental counterparts. Results show that the bandwidth can be tunable depending mainly on the ground plane’s geometrical adjustment. With the superimposition of the diagonal cut areas at the corners, the rectangular slots, and the T-shaped cuts on the ground plane, the impedance bandwidth can be improved due to the accumulation of ground plane modification effects. Return losses of -19 and -26 dBs for the first and second resonant frequencies, respectively, can be achieved when the depth of the diagonal cut is at optimum value of 5 mm, the rectangular slot dimension of $5 \times 3$ mm$^2$ and the T-shaped cuts size of $8 \times 4$ mm$^2$ providing a maximum 28.67% wider bandwidth (3 - 12.615 GHz) than the FCC recommended standard (3.1 - 10.6 GHz).

References