Planar Arc-shaped Monopole Antenna with Broadband Operation for UWB System

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1. Introduction

Since the Federal Communication Commission (FCC) officially allocated the spectrum from 3.1 to 10.6 GHz for unlicensed ultra-wideband (UWB) communication applications in 2002 [1], UWB radio has become the most promising candidate for wireless personal area networks [2]. With low-profile, light-weight and easy fabrication, planar ultra-wideband (UWB) antennas have attracted much attention to provide quick and easy wireless access for multimode communication systems. Schantz proposes a variety of new designs including planar elliptical dipole antenna [3] and COTAB magnetic slot antenna [4]. Chen et al. also propose new design like the bi-arm rolled monopole [5] and discuss the effect of a human head on the performance of small planar UWB antennas [6]. There is increasing demand for antennas having more compact size to be suitably embedded in the practical portable devices for UWB applications. Therefore, in this article, we propose a novel planar arc-shaped monopole antenna with a rectangular parasitic patch for broadband communication. By introducing the rectangular parasitic patch gap-coupled by the arc-shaped monopole strip, more resonant modes can be excited with better impedance matching to achieve broadband operation. From the related measured results, this proposed simple monopole antenna can provide relatively wider impedance bandwidth of 10.25 GHz, which is operating from 3.02 GHz to 13.27 GHz. The proposed planar monopole antenna also provides the nearly omni-directional radiation patterns with maximum measured peak antenna gains and radiation efficiencies of 1.2 ~ 5.3 dBi and 85 ~ 91 % across the operating band, respectively. Details of the proposed simple monopole antenna design are described, and experimental results for the obtained performance operated across the operating bands are presented and discussed as well.

2. Antenna Design

Fig. 1 illustrates the geometry and photo of the proposed arc-shaped monopole antenna with a rectangular parasitic patch. A 50Ω microstrip line is etched as the feeding structure on the inexpensive FR4 substrate with the overall volume of L × W × H, dielectric constant εr, and loss tangent tan δ = 0.0245. In this study, the arc-shaped monopole strip (point A → point B → point C) is used to excite the first and third modes near 3.5 / 7.8 GHz bands, respectively. Then, with the gap of 0.3 mm to the arc-shaped strip, the rectangular parasitic patch with the dimension of L4 × W4 is used to excite the second and fourth modes close to 4.43 / 11.25 GHz band. First, for achieving the resonant mode at 3.5 GHz band, the surface current length of the arc-shaped strip is chosen to be about 18.1 mm corresponding approximately to 0.22 and 0.47 wavelengths of 3.5 / 7.8 GHz bands. Furthermore, the rectangular parasitic patch’s length (L4) is chosen to be about 13 mm to have the exciting surface current path (point A → point B → point D) corresponding approximately to 0.28 operating wavelength of 4.43 GHz band, which is little more than quarter-wavelength of the conventional monopole antenna probably due to the capacitive effect caused by the gap-coupled connection. Also, by properly insetting a small rectangular slit of L5 × W5 into the ground plane, good impedance matching across the operating band can easily be obtained.
3. Results and Discussion

To demonstrate the above deduction and guarantee the correctness of simulated results, the electromagnetic simulator HFSS based on the finite element method [7] has been applied for the proposed broadband monopole antenna design. Fig. 2 shows the related simulated and experimental results of return loss for the proposed arc-shaped monopole antenna design of Fig. 1 with the rectangular parasitic patch or not. Results show the satisfactory agreement for the proposed arc-shaped monopole antenna design covering 3.1 ~ 10.6 GHz band to meet the bandwidth specification of UWB system. From the experimental results, the measured impedance bandwidth (RL $\geq 10$ dB) can reach 10.25 GHz, which is operating from 3.02 GHz to 13.27 GHz to provide much greater bandwidths for the operating band. Also, it is easily found that the second and fourth modes close to 4.43 /11.35 GHz bands are excited by introducing the rectangular parasitic patch close to the arc-shaped strip. To fully comprehend the excitation of each operating band, the surface current distributions at 3.5, 4.5 and 7.8 GHz are shown in Fig. 3, along with an additional pinky arrow sign showing the path length of each resonant mode. For both 3.5 and 7.8 GHz modes, they are clearly the conventional MA modes showing a near 0.25 and 0.5 wavelength distribution along the surface current path (A $\rightarrow$ B $\rightarrow$ C), respectively. As for 4.5 GHz resonant mode, a 0.25 wavelength distribution along an effective path (A $\rightarrow$ B $\rightarrow$ D) is observed. The simulated and measured 2D radiation patterns in three principal planes of the planar arc-shaped monopole antenna centered at 3.5 / 4.5 / 7.8 GHz are plotted in Fig. 4. It is easily found that the radiation patterns are with good omni-directional radiation pattern in the XY plane and broadside radiation in the XZ and YZ planes for the first two operating bands. However, multi-null points are observed in the XY plane for the 7.8 GHz band probably due to the null surface current distributed on the arc-shaped strip as shown in Figure 3(c). The difference between the measured and simulated radiation patterns for $E_\theta$ may be due to the scattering radiation caused by the SMA connector and the feed coaxial cable placed in the near field of the proposed monopole antenna. The measured and simulated peak gain and radiation efficiency across the operating bands are shown in Fig. 5. Good agreement is seen between the measured and simulated results. It is easily found that, due to the antenna having relatively larger dimension compared with the shorter electrically operating wavelength and more directional radiation properties at higher frequencies, the peak gain of this proposed antenna increases with the operating frequency increasing. The measured peak antenna gains and radiation efficiencies are 1.2 $\sim$ 5.3 dBi and 85 $\sim$ 91 % across the UWB operating band. Owing to the stronger cross-polar radiation and impedance mismatching at certain operating frequencies, the variations of antenna peak gain and radiation efficiency across the operating band are less than 1.0 dBi and 6%, respectively. And, under the condition of the same antenna peak gain, this proposed monopole antenna has more than 30 % antenna size reduction than that of the smallest monopole antenna using the same FR4 substrate with the dimension of $35 \times 40 \times 1.6$ mm$^3$ [8] to obtain compact operation.

4. Conclusions

A novel broadband design of planar arc-shaped monopole antenna for UWB system has been proposed. The obtained impedance bandwidth across the operating band can reach about 10.25 GHz, which is operating from 3.02 GHz to 13.27 GHz. The proposed planar monopole antenna also provides the nearly omni-directional radiation patterns with maximum peak antenna gains and radiation efficiencies of 1.2 $\sim$5.3 dBi and 85 $\sim$ 91 % across the operating band.

Acknowledgments

This article was supported by the National Science Council (NSC), Taiwan, R.O.C., under Grant NSC97-2221-E-022-005-MY3.
Fig. 1 Geometry of the proposed arc-shaped monopole antenna with a rectangular parasitic patch for broadband operation.

Fig. 2 Simulated and measured return loss against frequency for the proposed arc-shaped monopole antenna.

(a) $f = 3.5 \text{ GHz}$  
(b) $f = 4.5 \text{ GHz}$  
(c) $f = 7.8 \text{ GHz}$

Fig. 3 Simulated surface current distributions for the proposed arc-shaped monopole antenna with a rectangular parasitic patch shown in Fig. 1.
Fig. 4 Simulated and measured 2D radiation patterns for the proposed arc-shaped monopole antenna with a rectangular parasitic strip in the XY plane.

Fig. 5 Measured and simulated peak gain and radiation efficiency across the operating frequencies for the proposed arc-shaped monopole antenna with a rectangular parasitic patch.

References