Compact UWB MIMO Antenna for USB Dongles with Angle and Polarization Diversity

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Abstract

A compact dual-element antenna suitable for ultrawideband (UWB) MIMO operation is proposed in this work. The size of the antenna is 25 mm by 40 mm and it covers the lower UWB band of 3.15-5.15 GHz. Apart from the inherent wideband isolation obtained through the different angle and polarization characteristics in the radiation patterns of the individual elements, the gap between the two antenna elements is also utilized to enhance both the isolation and impedance bandwidths. Simulation and experimental results reveal that, within the band of interest, the achieved isolation is over 20 dB and the envelope correlation of the radiation patterns is below 0.1.

1. Introduction

Ultrawideband (UWB) systems, which transmit data in low power over very large frequency bands, have attracted significant interest in recent years as a candidate for short range, very high data rate applications, including home entertainment [1]. On the other hand, multiple-input multiple-output (MIMO) technology that utilizes multiple antennas at both the transmitter and receiver has been adopted in major cellular standards to achieve high data rates. Therefore, the two technologies can be combined to enable even higher data rates to be achieved [2]. In this paper, a compact dual-element UWB MIMO antenna is proposed for USB dongles. Despite its compactness, the antenna achieves very high isolation between the two elements through two primary mechanisms: 1) The use of antenna elements (i.e., monopole and half-slot antennas) that have different angle and polarization characteristics in the antenna patterns, thus allowing the two antennas to be placed next to each other without causing significant performance degradation; 2) The gap (or slot) between the two closely positioned antenna elements is used to enhance the isolation and impedance matching at the lower frequency edge of one antenna element.

2. Antenna Configuration

The proposed UWB MIMO antenna is illustrated in Fig. 1. The antenna is printed on an FR4 PCB substrate, with a thickness of 1.55 mm, dielectric permittivity of 4.7 and loss tangent of 0.015. The top end of the UWB monopole antenna (Antenna 1) is a crescent, in order to enlarge the length of the slot formed between Antenna 1 and the second antenna (Antenna 2). The ground plane of Antenna 1 is in a semi elliptical shape, with a minor axis of 5 mm and a prolate axis of 40 mm, which serves to improve impedance matching. Antenna 2 is a half UWB slot antenna and it is based on the full UWB slot antenna [3]. The two antenna elements and their orientations are chosen such that their radiation patterns are orthogonal to each other in terms of angle and polarization characteristics. The semi-circular slot formed between the two antennas serves to enlarge the bandwidth of Antenna 2 and reduce the coupling between the antennas at the lower frequencies.

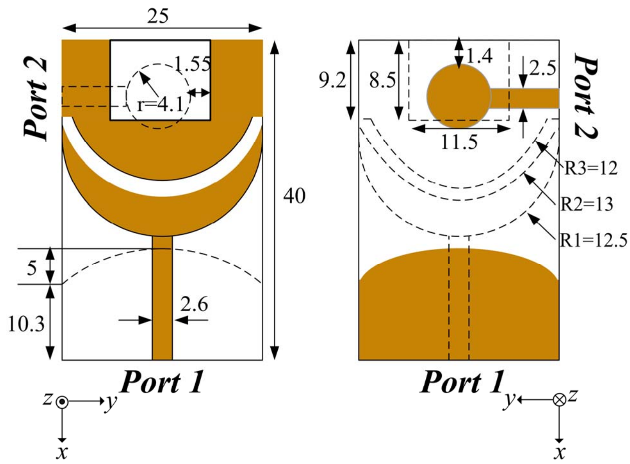

Figure 1: The proposed UWB MIMO antenna with detailed dimensions (in mm): (a) top view, (b) back view. The grey area represents the copper layer and the dashed lines trace the edges of the copper layer on the opposite side of the PCB. The centers of the incomplete circles indicated by R1, R2 and R3 are 28.5 mm, 33.8 mm and 34.8 mm away (along the –ve direction of x-axis) from the midpoint along the bottom edge of the PCB, respectively

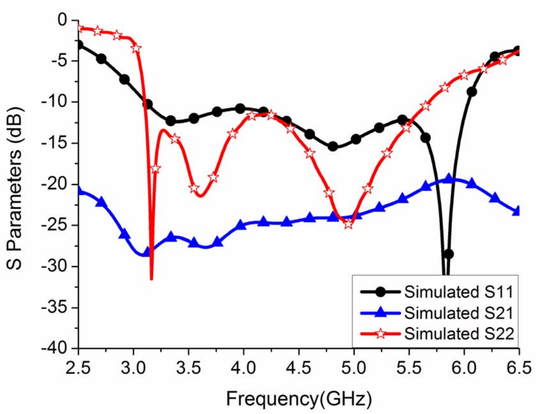

Figure 2: Simulated scattering parameters of the proposed UWB MIMO antenna

3. Simulation Results

The scattering (S) parameters and radiation patterns of the proposed MIMO antenna are obtained using CST Microwave Studio and illustrated in Figs. 2 and 3, respectively. It is assumed that when one port is excited, the other port is terminated in a 50 ohm load. It can be seen in Fig. 2 that reflection coefficients (S_{11}, S_{22}) of less than -10 dB and coupling coefficient (S_{21}) of less than -20 dB is achieved for the entire band of 3.15-5.15 GHz. Moreover, as mentioned above, the antenna elements and their orientations are chosen such that the angle and polarization characteristics of their patterns are orthogonal. This can be seen in Fig. 3 by comparing the left and right subplots. In fact, the radiation pattern for each antenna in the absence of the other antenna closely resembles the corresponding radiation pattern for the dual-antenna case, which further confirms that the two antennas do not interact with each other appreciably. Nevertheless, when the two single elements are placed next to each other as in Fig. 1, the bandwidth of Antenna 1 tends to improve at the lower band edge, due to the capacitive loading introduced by the presence of Antenna 2's ground plane. On the other hand, Antenna 2 does not benefit from the same phenomenon, which results in dissimilar lower band edges. To solve this problem, the naturally formed slot between the two antennas is optimized to provide an additional resonance at 3.2 GHz to Antenna 2, allowing it to have the same lower band edge as Antenna 1. Conveniently, the optimized slot also serves as a decoupling structure, in order to reduce the coupling around the lower band edge.

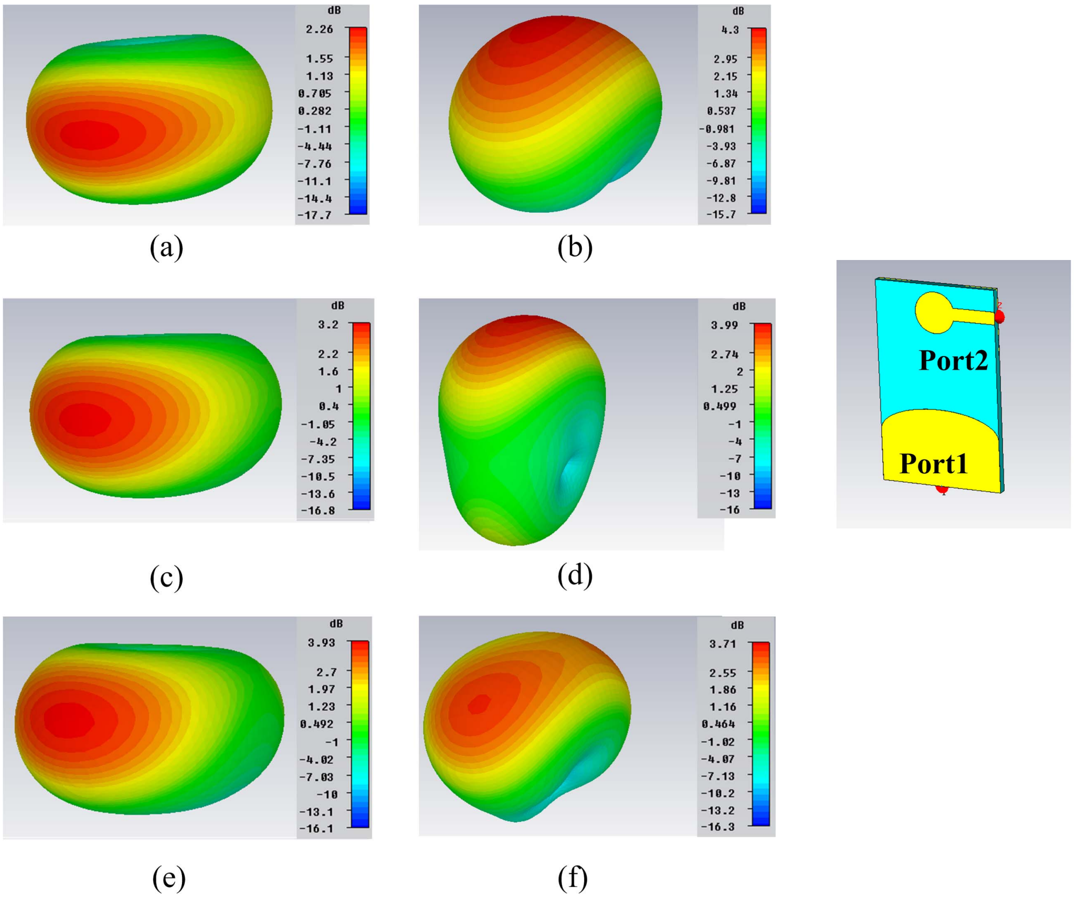

Figure 3: Simulated radiation patterns of Antenna 1 at (a) 3.2 GHz, (c) 4.2 GHz, (e) 5.2 GHz, and Antenna 2 at (b) 3.2 GHz, (d) 4.2 GHz, (f) 5.2 GHz. The antenna orientation is shown on the right

4. Experimental Results

The proposed MIMO antenna has been fabricated and measured to verify the simulation results. The S parameters are measured in a vector network analyzer and the radiation patterns are measured in an anechoic chamber using a SATIMO measurement system. To mitigate the influence of the cable on the measured results, each of the feed cables is equipped with a ferrite ring. For the sake of conciseness, the measured results are not presented here. However, good agreement has been found between the simulated and measured results. The only significant discrepancy is in the total antenna efficiency, since in the process of attenuating the currents in the cable, the ferrites introduce an efficiency loss of about 25% across the band of interest. Nevertheless, since external feed cables are not used in practice, such an efficiency loss is not expected in real applications.

5. MIMO Performance

The envelope correlation coefficient ρ_e of the MIMO antenna is calculated using the measured 3D radiation patterns and the assumed angular power spectrum (APS) of the incident waves [4]. For uniform 3D APS, it is found that $\rho_e \leq 0.1$ for the entire band.

In addition, the multiplexing efficiency [5] of the proposed MIMO antenna is presented in Fig. 4. The multiplex efficiency defines the difference in power required for an ideal MIMO antenna (of zero correlation and 100% total efficiency) and a MIMO antenna-under-test (AUT) to achieve a given capacity. It generalizes the concept of total antenna efficiency to the multi-antenna case, since the metric not only accounts for the total antenna efficiency, but also correlation and efficiency imbalance. For uniform 3D APS, the multiplexing efficiency of a two-element MIMO antenna is [5]

$$\eta_{MUX} = \sqrt{(1-|\rho_c|^2)\eta_1\eta_2}\ , \tag{1}$$

where η_1 and η_2 are the total antenna efficiencies of Antennas 1 and 2, ρ_c is the complex correlation coefficient, and $\rho_e = |\rho_c|^2$. As can be seen in Fig. 4, the multiplexing efficiency of the two antennas is similar to the total antenna efficiency of either antenna, which is due to the low correlation (i.e., $\rho_e \le 0.1$) over the operating band.

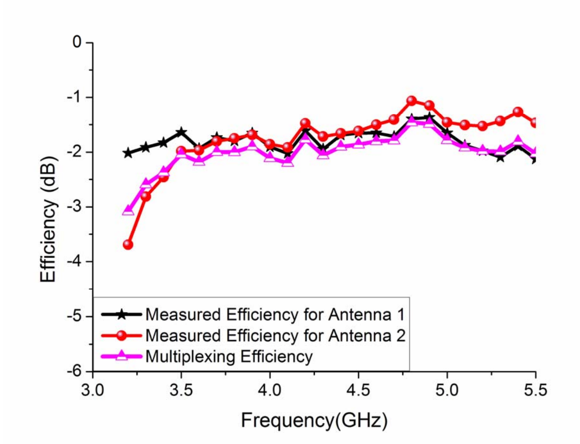

Figure 4: Measured total efficiencies for Antennas 1 and 2 and multiplexing efficiency

6. Conclusions

The design of compact MIMO antennas is challenging since the interaction between closely spaced multi-antennas tend to increase signal correlation and decrease antenna efficiency, which degrade MIMO performance. In this work, we showed that diversity mechanisms and antenna arrangement can be utilized to achieve an efficient compact MIMO antenna for UWB applications. Moreover, the philosophy underlying the design concept is general and can be used to design other MIMO antennas as well. More detailed analyses of the proposed MIMO antenna will be published in a journal form [5].

Acknowledgments

The work was supported by VINNOVA under Grant no. 2008-00970, VR under Grant no. 2010-468 and a scholarship within EU Erasmus Mundus External Cooperation Window TANDEM.

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