A COMPACT DESIGN OF ORTHOGONALLY DUAL-POLARIZED ANTENNA FOR ULTRA-WIDEBAND, IMAGING, AND RADAR APPLICATIONS

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Abstract

In this study, a new design of dual-polarized ultra-wideband (UWB) antenna is proposed. The antenna design contains a circular-ring slot radiator fed by two independently semi-arc-shaped microstrip feeding lines which can exhibit polarization diversity characteristic. A low-cost FR-4 dielectric ($\epsilon = 4.4$, $\delta = 0.02$) is used as the substrate. The characteristics of the dual-polarized UWB antenna are examined using both simulations and measurements and good results are achieved. An impedance bandwidth ($S_{11} \leq -10$ dB) of 2.5-10.2 GHz with 121% fractional bandwidth (FBW) is achieved for the design. However, for $S_{11} \leq -6$ dB, this value is more than 130% (2.2-11 GHz). The proposed UWB antenna offers good isolation, dual-polarized function, and sufficient efficiency which make it suitable for different applications such as radar and microwave imaging.

1 Introduction

Ultra-wideband (UWB) technology provides some superiority such as high-speed data transmission, low cost and easily manufacture [1-3]. However, such a popular topic of technology suffers from multipath fading in the practical applications [4,5]. Precisely, the multiple-input multiple-output (MIMO) technique was raised to resolve this issue, MIMO antennas are employed to enhance the channel capacity [6-8]. The combination of UWB with MIMO technology, the use of space multipath, parallel transmission of multiple signals can obtain obvious multiplexing gain and diversity gain, and achieve a stable signal transmission in distance.

According to the requirement of wireless communication, compact and wideband antenna is an urgent demand for portable devices [9-11]. In addition, isolation is one of the most important performance indicators of MIMO antennas, achieving high isolation and small size is also a challenge. When the different antenna elements function in a cramped space, the inter-coupling between the antennas comes out to be intense and the MIMO antenna cannot achieve good impedance match and high isolation in a wide operating band under normal conditions [12].

Apart from the channel performance improvement, dual-polarized MIMO antennas can also be used for additional information gathering in case of radar and imaging applications. Several UWB MIMO antennas are reported in recent years. Plenty of methods are employed to eliminate coupling and enhance the isolation between the different elements [13,14]. Some high isolation antennas were achieved by increasing the distance of the different antenna elements, and some others papers were to introduce the decoupling

components such as parasitical slots or strips among the radiation elements or ground plane to achieve high isolation [15,16]. However, for most of the compact devices where the space is very limited and they need the simplified structure for easier manufacture. Thus, establishing a compact and capable MIMO antenna in UWB with high isolation is still desired.

We propose here a new design of dual-polarized MIMO antenna providing ultra-wide impedance bandwidth with polarization diversity using ring-slot resonator. The antenna is designed to operate at 2.5-10.2 GHz, covering different wireless systems including 4G, sub 6 GHz 5G, WLAN, WIMAX, X-band and etc. The proposed antenna is designed on an FR-4 substrate with properties of $\epsilon = 4.4$, $\delta = 0.02$, and $h = 1.6$ mm. In order to enhance the port isolation and improve the impedance-matching of the closely-spaced ports, the circular-ring slot radiator is converted to an open-ended slot by adding a rectangular strip. By exciting the radiator from the two feeding ports, two orthogonally polarized waves are generated which leads the radiation pattern and polarization diversity function. A prototype of the antenna was fabricated and tested. Good impedance bandwidth, isolation, and radiation patterns are achieved over the entire operating band. The configuration and fundamental properties of the antenna are elaborated below.

2. Antenna Schematic

Figure 1 depicts the schematic of the designed dual-polarized UWB antenna. As shown, the design is composed of an open-ended circular-ring slot radiator differently fed by a pair of semi-arc-shaped microstrip-line. The parameter values of the design are specified in Table 1.

Fig. 1. Overall view of the dual-polarized UWB MIMO antenna, (a) side view, (b) top and (c) bottom layers.

Table 1 Parameter values of the proposed antenna design

Parameter	W_s	L_s	h_s	W_f	L_f	d	W
Value (mm)	34	34	1.6	5.5	3	7.5	1
Parameter	L	W_1	L_1	r	r_1	r_2	r_3
Value (mm)	11	1.5	1.5	11.5	8.5	8	14

3 Results and Discussions

Simulated S parameters of the dual-polarized microstrip-fed slot antenna with a conventional circular-ring slot radiator (Fig. 2 (a)), with an open-ended circular-ring slot radiator (Fig. 2 (b)), and the proposed design (Fig. 2 (c)) are illustrated and compared in Figs. 3 (a), (b), and (c), respectively. As illustrated, by converting the circular-ring slot radiator to the open-ended circular-ring slot, not only the impedance bandwidth is improved but also the isolation characteristic of the design has been improved significantly. Finally, by adding pairs of small strips under the antenna feed-lines, the antenna provides good matching with wide-bandwidth and high isolation characteristic at the desired band (2.5-10 GHz).

Fig. 2. Various structures of the UWB antenna, (a) antenna with a circular-ring slot radiator, (b) the antenna with open-ended circular-ring slot (c) the proposed antenna design.

Fig. 3. S parameter results of the various antenna designs illustrated in Figs. 2 (a), (b), and (c), respectively.

The simulated radiation and total efficiencies of the design are shown in Fig. 4. It can be clearly seen from the figure that the proposed antenna achieves more than 75% radiation efficiency over the band of interest with the maximum value of 90% at the lower band. This is caused by the enhanced isolation characteristic of the antenna. Furthermore, as seen, the designed dual-polarized slot antenna provides good total efficiencies over the operation band. The total efficiency results of the design are above 50%~75% through the entire band.

Figure 5 depicts the simulated maximum gain and directivity characteristic of the designed UWB antenna within the investigated frequency range. It is apparent that although the antenna maximum gain varies with frequency, it is still higher than 3.1 dBi within the frequency band of interest. It is evident that the difference between directivity and maximum gain

values is small which is mainly because of the high-efficiency characteristic of the antenna. The overall variation of the antenna gain and efficiency is within 3 dBi in the entire frequency band, which is very good for wideband and multiband systems.

Fig. 4. Radiation and total efficiencies of the antenna from different ports.

Fig. 5. Simulated maximum gain and diversity characteristics of the design (from port 1).

Figure 6 shows simulated 2D-polar radiation patterns of the antenna at 3, 6, and 9 GHz. These three frequencies are chosen from the lower, middle, and upper frequencies, respectively. In this design, xz plane is H-plane ($\phi=0^\circ$) and yz -plane is E-plane ($\phi=90^\circ$) for the antenna. From Fig. 6, we can see that the antenna can give dumbbell-like radiation characteristics in E-plane and nearly Omni-directional characteristic in H-plane [17-19]. It was found that the radiation patterns of the UWB antenna deteriorate more or less with the increasing frequency. However, the radiation characteristics are still stable.

A prototype sample of the proposed UWB dual-polarized slot antenna was fabricated and tested. Figure 7 shows the fabricated prototype. The measured and simulated S-parameters (S_{11} & S_{21}) of the fabricated sample, using vector network analyzer and CST software, is compared and illustrated in Fig. 8. It should be noted that it is sufficient to show the fundamental characteristic of the antenna from one port since the dual-polarized antenna structure is symmetric with similar characteristics from two feeding ports. It is observed that the fabricated antenna works properly and provides an acceptable agreement with the simulated results, which help to verify the accuracy of the simulation. The small differences between the simulated and measured values may be due to the errors of the manufactured antenna.

Fig. 6. 2D-Polar radiation patterns of the antenna at (a) 3 GHz, (b) 6 GHz, and (c) 9 GHz.

Fig. 7. The fabricated prototype of the UWB antenna.

Fig. 8. Measured and simulated S-parameters of the proposed UWB-MIMO antenna.

As shown, a good impedance bandwidth ($S_{11} \leq -10$ dB) of 2.5–10.2 GHz is achieved for the fabricated dual-polarized UWB antenna. However, for $S_{11} \leq -6$ dB, this value could be from 2.2–11 GHz. In addition, it is evident that the mutual-coupling of the design is less than -10 dB over the entire UWB operation.

In a UWB system, the antenna needs to possess a high level of pulse-handling capability to handle high-frequency impulses [20]. Hence, the time-domain properties are equally as important as the frequency domain. Two identical designs of the dual-polarized antenna are mounted on the surface of the dielectric surface with 100 mm shift of their center points. The antenna in the transmitting mode is excited by using a modulated Gaussian pulse. In order to evaluate the pulse transmission characteristic, two configurations, including side-by-side and face-to-face orientations, have been selected. The correlation between the transmitted and received signals is calculated using the fidelity factor, as defined below:

$$F = \text{Max}_\tau \left| \frac{\int_{-\infty}^{+\infty} s(t)r(t-\tau) dt}{\sqrt{\int_{-\infty}^{+\infty} s(t)^2 dt \cdot \int_{-\infty}^{+\infty} r(t)^2 dt}} \right|, \quad (1)$$

As shown in Fig. 9, although the received pulses in each of the two orientations are broadened, a relatively good similarity exists between the R_X and T_X pulses. Using (1), the fidelity factors were obtained equal to 0.85 and 0.75, for the face-to-face and side-by-side configurations, respectively.

Fig. 9. Transmitted and received pulses for (b) side-by-side and (c) face-to-face orientations.

4 Conclusion

A compact design of dual-port ultra-wideband (UWB) antenna is proposed in this study. Its schematic contains a circular-ring slot radiator differently fed by a pair of semi-arc-shaped microstrip lines. By adding a bridge strip inside the circular-ring slot radiator, the mutual coupling of the design has been improved significantly. The antenna is designed on a cheap FR4 material. Dual orthogonal polarization and good differential isolation is obtained for the proposed design. A prototype of the antenna was fabricated and tested. Results show that the proposed antenna achieves an impedance bandwidth of larger than 110% (2.5 to 10.2 GHz). Besides, the high-efficiency characteristic has been obtained.

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6 References

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