Dual-polarized Ultra-wideband Antenna with Improved Polarization Purity

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Abstract In this paper, a compact UWB dual-polarized antenna with improved co-to-cross-polarization ratio is proposed. This antenna is fed by two orthogonal tapered CPW lines to achieve dual-polarization operation. To enhance the polarization purity and the isolation level between the antenna's ports, a new technique is proposed. The detailed design, as well as the analysis of the obtained results are presented and discussed, which revealed that the proposed antenna is matched over the entire UWB band with good isolation level between its ports of 20dB and high co-to-cross polarization ratio of more than 20dB. With these features, the proposed antenna is an optimized candidate for media applications.

Keywords: UWB antennas, diversity applications, polarization purity.

1. Introduction

To satisfy the growing requirements of today media applications, the quantity and quality of the provided services must be optimized, which can be achieved through improving the data rate and enhancing the communication channels capacity. Therefore, it is convenient to propose using technologies that can provide high data rate and wise utilization of the communication channels. UWB technology along with the diversity techniques can satisfy those requirements at the same time. UWB technology has gained wide interest since the release of the FCC, in 2002, which allows the use of the band from 3.1 to 10.6 GHz without license for the UWB applications¹⁾. This wide band allows the transfer of pulses with a high speed, which can provide a high data rate and thus interference mitigation. As a result, UWB technology has become one of the most developed and promising technologies and the first choice for some applications such as wireless personal area networks (WPAN)²⁾. On the other hand, the diversity techniques have been proposed to optimize the capacity of the communication systems and improve the quality of the transmission by reducing the fading effect caused by interference and multipath phenomena as demonstrated by several studies³⁾⁴⁾. One of the best

diversity techniques is the polarization diversity, which enables the increase of the system capacity by caring separate information on orthogonal polarizations over the same physical link at the same frequency. Therefore, ultra-wideband dual-polarized technology is of great interest for short range communications, such as media applications. Much research has been done to develop ultra-wideband antennas with dual-polarization operation⁵⁾⁻⁸⁾. The proposed antennas suffer from several problems such as a narrow bandwidth⁵⁾, which is not large enough to cover the entire UWB band; bulky forms⁶⁾, with complicated feeding structures require more than one substrate, which increases the overall cost of the antenna⁷⁾⁸⁾. The problem of low isolation level between the used ports to achieve dual-polarization operation has been studied in²⁾. In⁹⁾, an UWB dual-polarized antenna based on microstrip technology has been proposed. However, compared to microstrip technology, CPW (coplanar waveguide) technology has superior advantages regarding dispersion, radiation loss and easy integration with monolithic microwave integrated circuits. Furthermore, CPW-fed slot structures printed on one side of the substrate allow to avoid the misalignment errors, which is critical in microstrip-fed structures¹⁰⁾.

The high cross-polarization level may deteriorate the radiation characteristics of the antenna, especially those with dual-orthogonal-polarization operation, which need to have quite good polarization purity. Some applications require precise co-to-cross polarization level to enable

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certain operations such as the avoidance of the cross-talk in the communication channels. Therefore, several techniques have been proposed to overcome the problem of high cross-polarization level¹¹⁾¹²⁾. In¹¹⁾, two substrates have been used to enhance the polarization purity of conventional tapered slot antenna, and this technique has also been used by some dual-polarized antennas, but it increases the overall cost of the antenna by using multiple substrates instead of one. In¹²⁾, differential feeding technique has been used, where a single polarization is radiated through two oppositely lying ports and dual-polarization by four ports, which require the employment of out-of-phase power divider, operating at each frequency of the interested band to feed the antenna's ports by signals equal in amplitude and out-of-phase. Therefore, to overcome this problem, we first propose the design of a compact ultra-wideband dual-polarized antenna based on CPW technology. After that, we propose a technique to enhance the isolation level across the entire UWB band while keeping the ability of the antenna to radiate over the same band with two orthogonal polarizations. The effect of this technique on the cross-polarization level is subsequently studied, and its negative influence is corrected to obtain good isolation and low cross-polarization level at the same time. The details of the proposed antenna design and the proposed techniques are presented and discussed in the next sections. It worth to mention that the analysis and optimization were performed using CST MICROWAVE STUDIO 2015.

2. Antenna design

The proposed antenna is a circular slot cut of a ground plane printed on substrate RO4003C of dielectric constant of 3.38, loss tangent of 0.0027 and dimensions of (72mm × 72mm), this way, a dipole-like radiation can be obtained. The circular slot is fed by two orthogonal 50Ω CPW tapered lines through two semi-discs, placed in an orthogonal manner to achieve dual-polarization operation, as shown in Fig.1.a. The impedance matching band of this structure is governed by several parameters such as the dimensions of the circular slot and the semi-circular discs as well as those of the CPW lines that are tapered to increase the matching band, especially at high frequencies. All these parameters were optimized to enable an operating band from 3.1 to 10.6GHz with reflection coefficient inferior to -10dB, as shown in Fig.2. However, the isolation between the antenna ports is inferior to 15dB, which is not sufficient for the diversity

Fig. 1 Steps of designing the proposed antenna.

Fig. 2 S-parameters of the structure 1.a with and without the isolation.

requirements. Therefore, it needs to be improved. To accomplish so, two strips are inserted diagonally around the center of the circular slot as shown in Fig.1.b. As a result, the isolation level is enhanced while keeping an UWB operating band as also indicated in Fig.2. The insertion of the isolation strips modifies the current distribution on the structure and minimizes the mutual coupling between the two ports by intercepting the radiation coming from the excited port. Hence, a high isolation level is reached. In meanwhile, the radiation of the inserted strips affects the polarization purity of the antenna and leads to high cross-polarization, as indicated in Fig.3, where the radiation patterns of the antenna with and without the isolation structure, at 7GHz, are shown. Therefore, we propose a new technique to minimize the effect of the isolation structure on the cross-polarization while keeping the

Fig. 3 Radiation patterns of the antenna with and without the isolation at 7GHz.

Fig. 4 Co and Cross-polarized gain over Theta at 7GHz for different values of w .

Fig. 5 Co and Cross-polarized gain over Theta at 7GHz for different values of L .

high isolation level achieved and the operating bandwidth. This technique consists of inserting two diagonally strips (pol-strips) in the circular slot as illustrated in Fig.1.c; these strips minimize the effect of the isolation structure on the cross-polarization level and enhance the isolation.

To study the influence of the inserted strips on the radiation performance of the antenna, the co-polarized gain and cross-polarized gain, obtained at the center of the UWB band, over azimuth angle Theta, for different dimensions of the pol-strips, were numerically

Table. 1 Optimized values of the proposed antenna dimensions.

R_s	R_p	w_m	g	L	w
29mm	9mm	3mm	0.3mm	19mm	2.2mm

computed, and they are shown in Fig.4 and Fig.5; where w and L denote, respectively, the width and the length of the pol-strips. Fig.4 was obtained for $L=19$ mm and Fig.5 was obtained for $w=2$ mm. It can be observed that varying the width and the length of the strips affects the cross-polarization level in different ways. In the interval of $\Theta > 0$, the cross-polarized gain is inversely proportional to the strips width. In the case of swiping the length of the strips, the cross-polarized gain varies in a non-linear manner. Although the co-polarized gain, when the strips length is varying, shows weak variation especially around $\theta=0$, its variation is stronger than the results from varying the strips width. Hence, the co-polarized gain and the cross-polarized gain over Theta in the E-plane depend highly on the strips dimensions. Therefore, the cross-polarization level can be controlled by the dimensions of the strips. Both of the gains give best cross-polarization level for strips dimensions similar to those used for the isolation. Hence, the pol-strips act as a canceler of the isolation strips effect on the cross-polarization level. In order to find the dimensions that provide the best performance, in terms of the operating bandwidth, the isolation between the two ports and the cross-polarization level, the overall structure was optimized. Table.1 illustrates those dimensions that give the best performance; where R_s is the radius of the circular slot, R_p is the radius of the semi-circular patch, w_m is the width of CPW lines metal strip, and g is the gap between the strip and the coplanar ground plane. The results of the proposed antenna, with the optimized dimensions, that prove its performance are described and discussed in the next section.

3. Results and discussion

The proposed antenna was fabricated and its photograph is shown in Fig.6. The S-parameters simulated and measured, at Port1, are plotted in Fig.7. As indicated, the input reflection coefficient S_{11} is inferior to -10 dB over the entire UWB band and the transmission coefficient S_{21} , signifying the isolation level between the two ports, has a worst value of -17 dB and an average value of -20 dB across the UWB band, which satisfies the isolation level required for diversity

Fig. 6 Photograph of the fabricated prototype.

Fig. 7 S-parameters of the proposed antenna.

communication systems. In addition, a good agreement between the simulation and measurement results can be observed. It should be mentioned that, as a result of the symmetry and similarity of the antenna structure, the S-parameters obtained at the Port1 and those obtained at the Port2 are similar, and the radiation patterns are also similar with a rotation of 90 degrees. Therefore, only those simulated and measured at the Port1 are presented in this paper.

To visualize the radiation performance of the proposed antenna, the co-polarized gain and cross-polarized gain simulated at Port1 over different values of azimuth angle Theta in the E-plane at the frequencies 3GHz, 7GHz, and 10GHz, which correspond to the lower, central and upper frequencies of the UWB band, are shown in Fig.8. From these curves, it can be noticed that the gain changes according to the value of angle Theta and also varies as a function of the frequency. While the maximum radiation is in Z-direction (Theta=0) at 7GHz, it is aligned at 3GHz and 10GHz. In order, to validate the concept of the proposed technique to minimize the cross-polarization level and to prove its effectiveness, the co-polarized gain and cross-polarized gain of the

Fig. 8 Co and Cross-polarized gain over theta in E-plane with and without pol-strips.

proposed structure without pol-strips are also shown in Fig.8. The comparison between the co- and cross-polarized gains of the antenna with and without pol-strips reveals that in addition to the ability of the pol-strips to reduce the cross-polarized gain, they are also capable of enhancing the co-polarized gain and significantly reducing the cross-polarization level. Comparing with the antenna without pol-strips, the cross-polarization level of the proposed antenna (antenna with pol-strips) is reduced by more than 15dB across the UWB band. Based on these results, we can say that the insertion of the pol-strips enhances the polarization purity of the antenna by overcoming the effect of the isolation strips radiation and improves the

Fig. 9 Co-to-cross polarization ratio at different frequencies.

isolation between the two ports. Finally, the Co-to-cross polarization ratio of the proposed antenna, at different frequencies of the UWB band, is shown in Fig.9. As indicated, the co-to-cross polarization ratio is more than 20dB around the angles at which the maximum radiation occurs and its worst values are at the angles -90° and 90° , where the radiation nulls occur.

4. Conclusion

Easy fabrication, compact size and low profile are some of the attractive merits that increase the demand of planar antennas for different applications. Therefore, recently, many planar antennas have been proposed for ultra-wideband systems with diversity techniques. The diversity techniques can maximize the capacity of UWB systems and improve their services. However, the proposed antennas for these applications suffer from several problems, such as narrow bandwidth, large size, low isolation level and high cross-polarization. The proposed antenna aims to overcome these problems with simple and effective techniques can also be used by other structures to increase their diversity performance as well as their radiation performance by enhancing the isolation and cross-polarization levels. The proposed antenna is compact size ultra-wideband antenna with an overall size of $(72\text{mm} \times 72\text{mm})$ printed on one side of the substrate using CPW technology. The details of its design have been described, analyzed and discussed. The results prove the ability of this antenna to operate over the band 3.1-10.6GHz with a high isolation level between its two ports. It can radiate through two

orthogonal linear polarizations providing high polarization purity across the entire UWB band which has been achieved by using new techniques to minimize the cross-polarization level and the coupling effect between the used orthogonal ports. The performance of the proposed antenna and its features make it a good candidate for UWB communication systems with diversity operation as media applications.

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