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DESIGN AND INVESTIGATION OF CLOSELY-PACKED DIVERSITY UWB SLOT-ANTENNA WITH HIGH ISOLATION

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Abstract—A closely-packed (4 mm) diversity slot antennas operating in the UWB frequency is proposed. High isolation ($S_{21} < -20\,\text{dB}$) of two closely-packed slot antennas can be easily achieved in a broad band by taking advantage of the directional radiation characteristics of slot antenna. Quarter-wavelength slot resonator is adopted to improve the isolation in the low-band of the UWB. The simulated current distribution and the radiation patterns of the single antenna element with and without slots are also presented to explain the mechanism of decoupling in the diversity system. Furthermore, the diversity performance of correlation coefficient, mean effective gains (MEGs), diversity gain (DG) are also studied.

1. INTRODUCTION

It is well known that diversity antenna has advantages of reducing multipath fading and increasing transmission capacity [1, 2]. In wireless communication system, the signals received at the receiver come from all directions with different phases, and these signals are combined in the receiver, which causes multipath fading. Multipath fading deteriorates the quality of signal, which can be solved by diversity technology. Diversity antenna/MIMO system can be used to improve the reliability and increase transmission capacity of the system [3–5].

Ultra-wideband (UWB) technique (3.1–10.6 GHz) is another promising technology for inherent advantages, such as low-power, high data rate in a limited range. UWB technology enables portable

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consumer devices, such as printers, digital cameras and computers, which wirelessly connect with each other and offer very high data transfer rate within a short range. It is believed that UWB technology will be a candidate for short range wireless communication. Therefore, the combination of UWB technique and antenna diversity technology is a promising research direction. The main challenge of UWB diversity antenna system designing is decoupling when antenna elements are closely packed in a small space. Various diversity antennas operating in UWB are proposed [6–11]. High isolation between antenna elements can be achieved by etching slots in the ground or extending branch from the ground [12–15], inserting parasitic elements between antenna elements [16] or incorporating a neutralization line into antenna elements of the system [17].

In this paper, a diversity slot antenna operating in UWB is presented. The antenna element is a UWB slot antenna with tapering slot in the ground, which can realize broad impedance matching characteristics. High isolation in a broad band can be achieved easily by taking advantage of directional radiation characteristics of slot antenna. Besides, mutual coupling in the low frequency can be reduced by etching a quarter-wavelength slot in the antenna. Furthermore, the diversity characteristics of correlation coefficient, mean effective gains (MEGs) and diversity gain (DG) are also studied. Simulated and measured results show that the proposed UWB diversity antenna has broad impedance matching, high isolation and stable radiation patterns in the UWB, which demonstrate that the slot antenna is a candidate for diversity antenna designing.

2. UWB ANTENNA DESIGN

Figure 1 shows the geometry and configuration of the proposed UWB diversity antenna. The antenna system is printed on FR4_exopy substrate with dielectric constant of 4.4 with overall size of 60 mm $\times$ 40 mm $\times$ 0.8 mm. The system is composed of two slot antenna elements, which is fed by 50 Ohm microstrip lines. The tapering slots can be used to realize broad impedance matching bandwidth to cover the whole UWB frequency. The MIMO antenna is symmetrical with the x axis. It is known that slot antenna has directional radiation feature, which can be used to achieve high isolation in a broad band without adding other decoupling structures as traditional designing [12–17]. Furthermore, a quarter-wavelength slot is etched in the antenna to reduce the mutual coupling at the low band of UWB. The slots can prevent the current flowing from one port to another. The process of designing and optimization is conducted by High Frequency Simulation

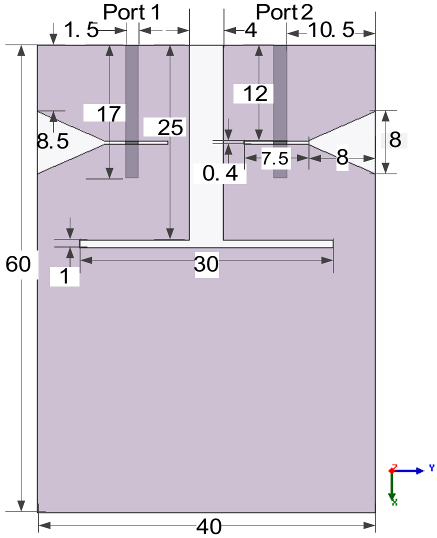

Figure 1. The geometry and configuration of UWB diversity antenna.

Software (HFSS), and optimized parameters are also given in the figure.

Figure 2 shows a photograph of the UWB diversity antenna. The antenna is fabricated and measured with R3770 Vector Network Analyzer. The simulated and measured S parameters are plotted in Fig. 3. It is observed that the antenna has a broad impedance matching characteristics ($S_{11} < -10\,\text{dB}$), and high isolation ($S_{21} < -20\,\text{dB}$) is realized between two antenna elements within the whole UWB frequency. The discrepancy between the measured and simulated results can attribute to the measurement error and influence of SMA connector.

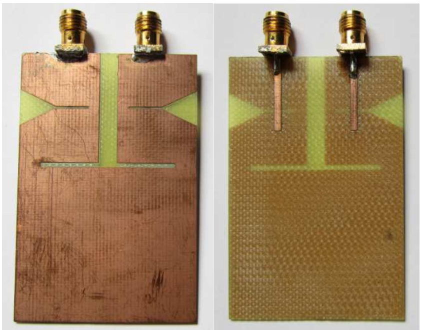

Figure 2. The photograph of the UWB diversity antenna.

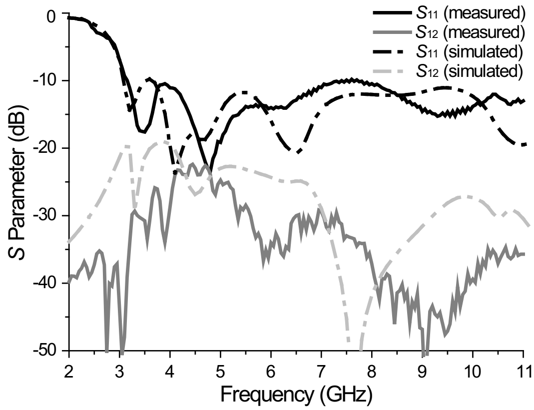

Figure 3. The simulated and measured S parameters of UWB diversity antenna.

3. DECOUPLING ACHIEVEMENT

In order to understand the method of decoupling of the UWB diversity antenna, the characteristics of single-element antenna, especially radiation characteristics are studied. Fig. 4 shows the geometry of the single UWB antenna element with and without slot, refer to Antenna-I and Antenna-II. The simulated 3-dimension radiation patterns at 4 and 8 GHz is shown in Fig. 5. It is observed that Antenna-I (with slot)

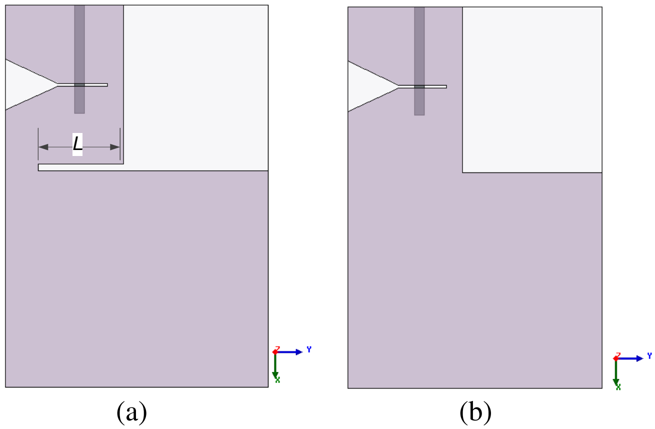

Figure 4. The geometry of UWB antenna element with and without slot: (a) Antenna-I, (b) Antenna-II.

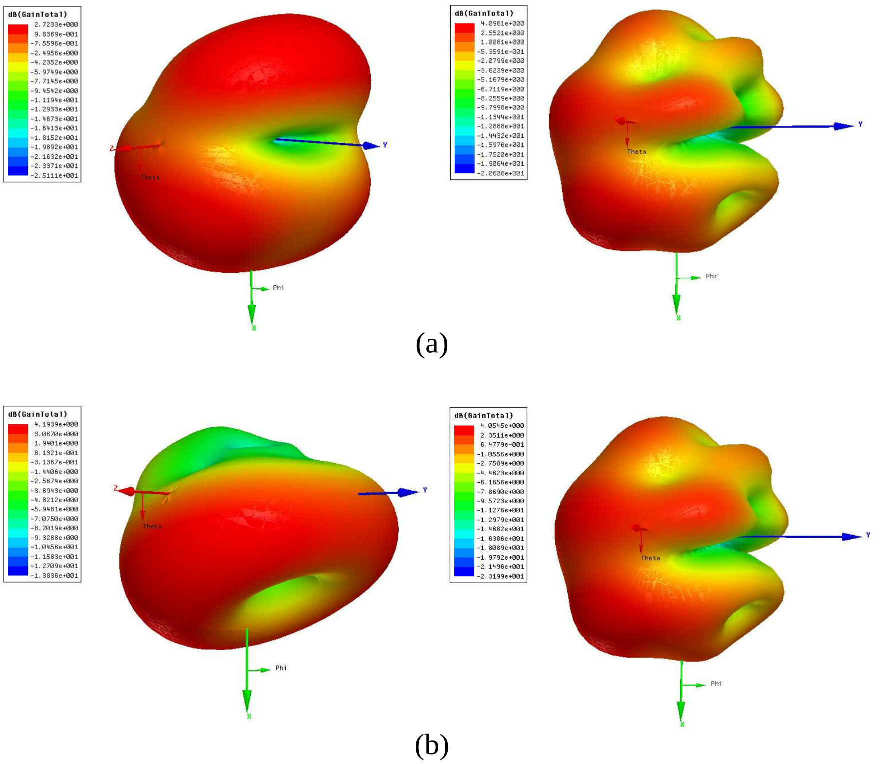

Figure 5. The simulated 3-dimension radiation pattern at 4 and 8 GHz: (a) Antenna-I, (b) Antenna-II.

mostly radiates in one direction ($-y$ axis direction), while the radiation in y axis direction is very weak without adding any reflector no matter in low or high frequency. For Antenna-II (without slot), the radiation in y-axis direction is strong, which will cause intense coupling between the antenna elements in low frequency (about 4 GHz). However, when frequency increases, the radiation in y-axis direction is reduced, which attributes to the directional radiation characteristics of this kind of slot antenna.

In order to further verify the directional radiation characteristics and function of the slot in improving the isolation in low frequency, the current distribution of diversity antenna with and without quarter wavelength slot at 4 and 8 GHz is depicted in Fig. 6. The two antenna elements are packed very closely, only 4 millimeter away. It is observed from Fig. 6(a) that when port 1 is excited and port 2 terminated with 50 Ohm load, strong current flows from port 1 to port 2 through the corner between the two antenna elements, which causes poor isolation between the two antenna elements at low frequency band. When the quarter-wavelength slots are etched in the antenna, the current flows in the short end of the slot, and the current in the center part of two antenna elements is very weak for the slots transform from short end to open end after quarter wavelength. As a result, high isolation at that frequency can be achieved. Referring to Fig. 6(b), in high frequency, little current flows from one port to another port no matter the slots are etched or not, and the current on the antenna mostly flows on the

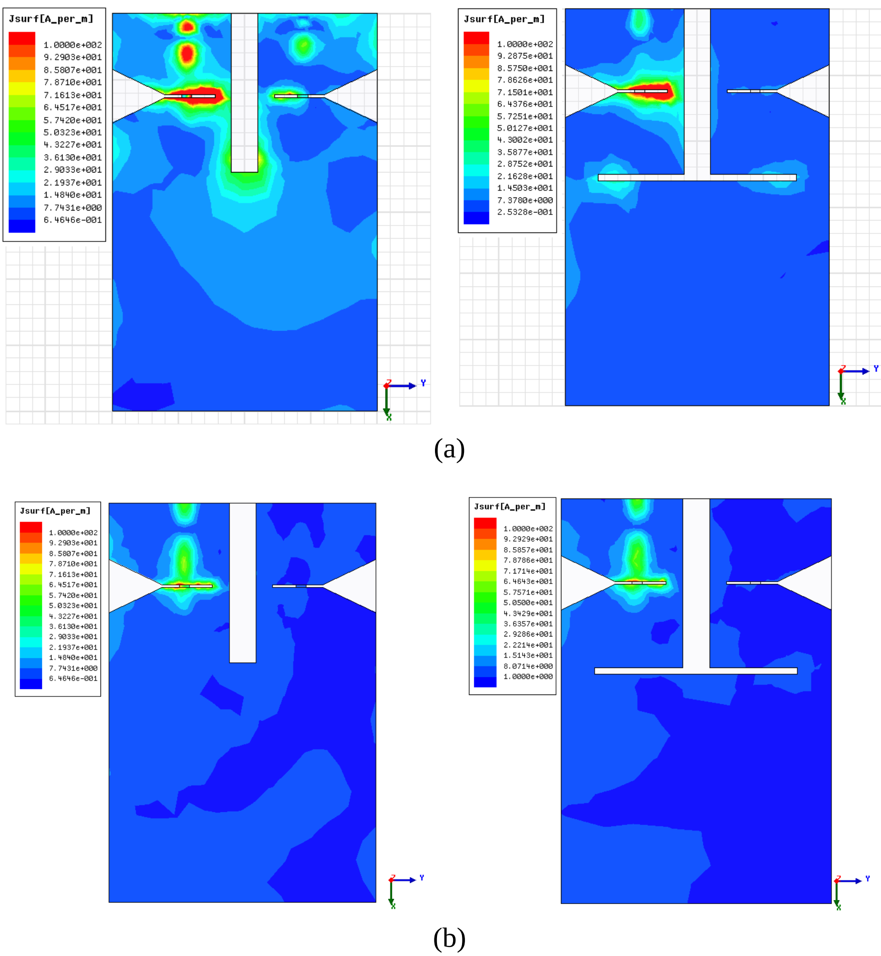

Figure 6. The current distribution of the antenna with and without slots: (a) 4 GHz, (b) 8 GHz.

open-end of the slot as frequency increases, which will cause directional radiation characteristics of the slot antenna and improve the isolation of the diversity antenna.

The length of the slot aforementioned is quarter wavelength of the frequency for decoupling, which can be derived by the following equation,

$$L \approx \frac{1}{4}\lambda = \frac{c}{4f_c\sqrt{\varepsilon_{eff}}} \tag{1}$$

where, L is the length of the slot, c the velocity of light, f_c the frequency for decoupling, and ε_{eff} the effective dielectric constant. Fig. 7 shows that the simulated S_{21} varies with different lengths of short ended slot. It is observed that the isolation is poor in 3–5 GHz without slitting a slot. When the quarter wavelength slot is etched, the isolation from 3 to 5 GHz is greatly improved. We can also observe that the frequency indicated in the figure moves to lower frequency as the length of slot increases. So, we can improve the isolation at given frequency by adjusting the length of the slot.

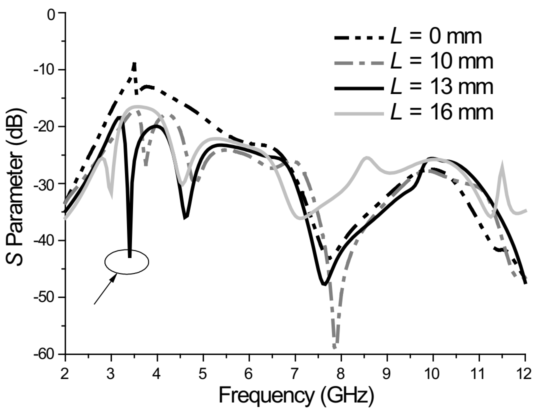

Figure 7. The simulated S_{21} of UWB diversity antenna vary with different L.

4. RESULTS AND DISCUSSION

Figure 8 shows the simulated and measured normalized radiation patterns of UWB diversity antenna at 4 and 8 GHz in xy, xz and yz planes, respectively. In measurement, port 1 is excited and port 2 terminated with 50 Ohm load. It can be observed that the antenna keeps quasi omni-directional in the xz and yz planes. In xy plane, the

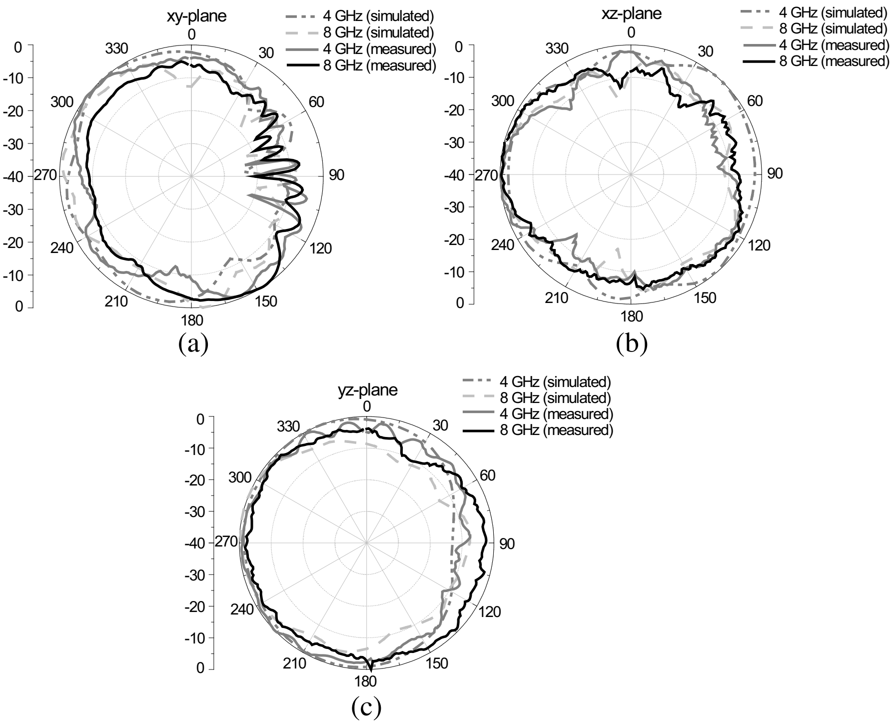

Figure 8. The simulated and measured radiation pattern: (a) xy plane, (b) xz plane and (c) yz plane.

radiation in y-axis direction is weak due to the directional radiation characteristics of the slot antenna. The discrepancy between the simulated and measured results can be attributed to the measurement error and influence of coaxial cable.

Figure 9 shows the measured antenna gain and radiation efficiency of the antenna proposed in the UWB frequency band. It is observed that the antenna keeps stable gain of about 4 dBi. It is observed that the radiation efficiency is about 0.9, which proves that the UWB MIMO antennas have high antenna efficiency.

In a diversity system, the correlation, mean effective gain, diversity gain and diversity antenna capacity are important criteria to evaluate the diversity performance. To increase the transmission capacity and improve the multipath fading, the correlation coefficient should be small. The correlation coefficient ρ and envelope correlation coefficient ρ_e can be derived from the S parameters and radiation efficiency [19–

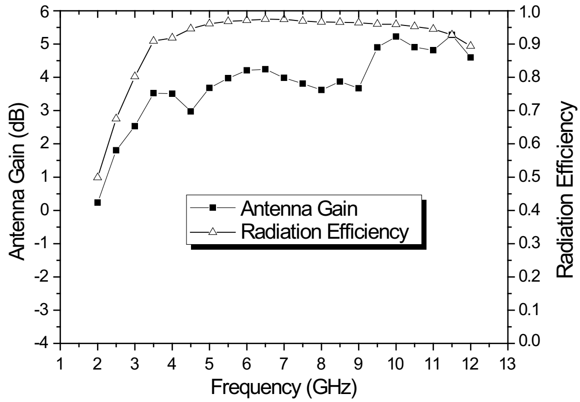

Figure 9. The antenna gain and radiation efficiency.

21],

$$\rho_e = |\rho_{ij}|^2 = \left| \frac{\left|S_{ii}^* S_{ij} + S_{ji}^* S_{jj}\right|}{\sqrt{1-|S_{ii}|^2-|S_{ji}|^2} * \sqrt{1-|S_{jj}|^2-|S_{ij}|^2} * \sqrt{\eta_{rad,i}\eta_{rad,j}}} \right|^2 \quad (2)$$

where $\eta_{rad,i}$ is the radiation efficiency of the i-th antenna element $(i = 1, 2)$. The correlation coefficient ρ is calculated from the measured S parameters and shown in Fig. 10. It is observed that the measured correlation coefficient is lower than 0.06 in the whole UWB band, which demonstrates that low correlation is achieved between the antenna elements.

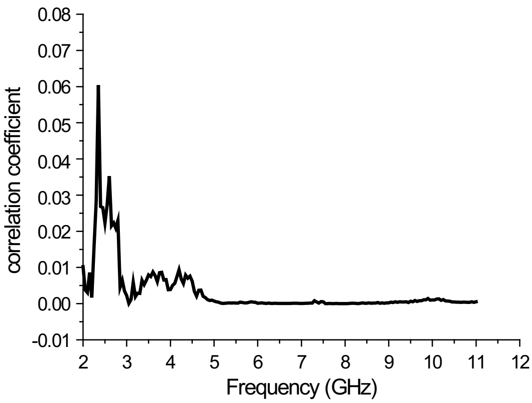

Figure 10. The measured correlation coefficient.

The mean effective gains (MEGs) are calculated to quantify the average received signal strength of each antenna elements, which is defined as the ratio of the mean received power (P_{rec}) to the mean incident power (P_{inc}) at the element [20]. The calculation of MEGs can be simplified as,

$$\text{MEG}_i = \frac{e^i_{tot}}{2} \tag{3}$$

where, e^i_{tot} is the total efficiency of the i-th antenna element, which can be calculated by

$$e^i_{tot} = e^i_{mis} \cdot e^i_{rad} \tag{4}$$

$$e^i_{mis} = 1 - \sum_{j=1}^{N} |S_{ij}|^2 \tag{5}$$

where e^i_{mis} is the antenna mismatch efficiency, and e^i_{rad} is the radiation efficiency. The MEGs of antenna elements can be calculated about -3.7 and -3.6 dB.

The ratios of mean effective gains ($\text{MEG}_i/\text{MEG}_j$) are calculated to quantify the power imbalance of the antenna elements. The signal received from the antenna elements satisfies the following criteria [20],

$$|\text{MEG}_i/\text{MEG}_j| \cong 1, \qquad \rho \ll 1 \tag{6}$$

where, $i, j = 1, 2$, which denotes the antenna elements 1 and 2, respectively. From the discussion above, the diversity antenna system can easily meet the requirement of Equation (6).

The diversity gains (DG) is defined as the improvement in signal-to-noise ratio (SNR) from the combined signal from all the antenna elements of the diversity system relative to the SNR from a single antenna element [21]. The DG of the diversity antenna can be simplified and calculated as,

$$\text{DG} = \text{DG}_0 \cdot \text{DF} \cdot K \tag{7}$$

$$\text{DF} = \sqrt{1 - \rho_e} \tag{8}$$

$$K = \min(\text{MEG}_1/\text{MEG}_2, \text{MEG}_2/\text{MEG}_1) \tag{9}$$

where DG_0 is the diversity gain of the antenna in ideal case, and DF is the effects of ρ_e and power imbalance of the two antenna elements on DG. K is the minimum value of MEG_i to MEG_j, which is used to illustrate the side effect of power imbalance of signal on the DG [14].

In an ideal case, DG using a selection combiner of 10 dB, where the radio link reliability is 99%. In a diversity system, a signal received from the antenna elements should exhibit low correlation, and the discrepancy of the power levels of the signals received by two elements should be reduced. Using Equations (7)–(9), DG of the antenna at 99% reliability can be calculated about 9.89 dB.

5. CONCLUSION

In this paper, a closely-packed diversity slot antennas operating in the UWB has been proposed. High isolation ($S_{21} < -20\,\mathrm{dB}$) has been achieved by taking advantage of the directional radiation characteristics of slot antenna and etching a quarter-wavelength slot resonator in the antenna. The simulated current distribution and radiation patterns of single antenna-element have also been studied to understand the method of decoupling. Furthermore, the diversity characteristics of correlation coefficient, mean effective gains (MEGs), diversity gain (DG) have been studied, which demonstrate that the diversity antenna proposed is a candidate for short range, high rate UWB communication.

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