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INVESTIGATIONS OF REDUCTION OF MUTUAL COUPLING BETWEEN TWO PLANAR MONOPOLES USING TWO $\lambda/4$ SLOTS

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Abstract—This article presents a simple structure for reducing mutual coupling between two diversity planar monopole antennas for WLAN 5.2/5.8 GHz applications. The structure has two $\lambda/4$ (λ-wavelength in the substrate) slots cut into the ground plane between the two monopoles. In $0.5\lambda_o$ (λ_o-wavelength in the air) of the antenna spacing, mutual coupling was -33.3, -21.1 dB at 5.2, 5.8 GHz, respectively. The lowest mutual coupling of -33.3 dB was achieved at 5.2 GHz, which are 20.8 dB improvements over the reference.

1. INTRODUCTION

Growing interest in both antenna diversity and multiple-input multiple-output (MIMO) systems has emerged owing to their ability to combat multipath fading and to deliver higher data rates, respectively. In a MIMO system, multi-element antennas are used at each end of the radio link and, to achieve a high capacity [1–8]. However, multiple antennas spaced closely in small device results in strong mutual coupling that makes distorted radiation pattern and decreases channel capacity. Achieving high isolation between closely-packed antenna elements is difficult to achieve and has been well studied [9–18]. A quarter-wavelength slot was used in [9] to reduce mutual coupling at 5.0 GHz. Compared to a reference, the achieved reduction in mutual coupling was about 7 dB. In [10], reduction of mutual coupling was studied by using a quarter-wavelength slot between two compactly spaced monopole antennas. By using a 13.5 mm slot between the antennas, mutual coupling was reduced by approximately only 6 dB

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compared to a reference at a centre frequency of 3.5 GHz. In [11], Chi-Yuk Chiu proposed slitted pattern etched onto ground plane to reduce mutual coupling between closely-packed antenna elements. Though this method the reduction of mutual coupling of more than 20 dB can be achieved. However, the using of the several pairs of slots makes the structure complicated. Some researchers have found that mushroom-like EBG structures are able to suppress surface wave propagation [12–16], and thus reduce mutual coupling between radiating elements. However, an intricate fabrication process with cells shorted to the ground through vias is involved. Additionally the defected ground structure (DGS) is also found to be able to provide a bandstop effect due to the combination of inductance and capacitance [17, 18].

This article presents a simple structure for reducing mutual coupling between two diversity planar monopole antennas for WLAN 5.2/5.8 GHz applications by cutting two quarter-wavelength slots into the ground plane. The method offers low mutual coupling between the studied antenna elements over a wide frequency bandwidth. It was −33.3 dB, −21.1 dB at 5.2 GHz, 5.8 GHz, respectively. The lowest mutual coupling of −33.3 dB was achieved at 5.2 GHz, which are 20.8 dB improvements over the reference. Design considerations of the proposed antennas and parametric studies are described in the article. Results of the constructed prototype are presented.

2. DEFINITION OF ENVELOPE CORRELATION COEFFICIENT

For diversity and MIMO applications, the set of correlations, between the signals received by the target antennas on the same side of the wireless link, is an important figure of merit. Usually, the envelope correlation coefficients are presented to evaluate some of the diversity capabilities of a multi-antenna system. Usually, the envelope correlation coefficient could be computed from theoretical or measured full-sphere complex (amplitude and phase) radiation patterns [19, 20] or scattering parameters of the structure. Assuming that the two antennas will operate in a uniform multi-path environment, the envelope correlation coefficient can be expressed in spherical coordinates $\Omega = (\theta, \varphi)$

$$\rho_{12} = \frac{|\oint (XPR \cdot E_{\theta 1}(\Omega) E^{*}_{\theta 2}(\Omega) + E_{\phi 1}(\Omega) E^{*}_{\phi 2}(\Omega) d\Omega|^2}{\oint (XPR \cdot G_{\theta 1}(\Omega) + G_{\phi 1}(\Omega)) d\Omega \cdot \oint (XPR \cdot G_{\theta 2}(\Omega) + G_{\phi 2}(\Omega)) d\Omega} \quad (1)$$

where $G_{\theta 1} = E_{\theta 1}(\Omega) E^{*}_{\theta 1}(\Omega)$, $G_{\theta 2} = E_{\theta 2}(\Omega) E^{*}_{\theta 2}(\Omega)$ and $E_{\theta 1}(\Omega)$, $E_{\theta 2}(\Omega)$ being the θ (vertical) polarised complex radiation patterns of antennas

1 and the antenna 2 of the system, and $E_{\phi 1}(\Omega)E_{\phi 2}(\Omega)$ being the ϕ (horizontal) polarized complex radiation patterns of antenna 1 and the antenna 2 of the system; XPR being the cross-polar discrimination is defined as time-averaged vertical-to-horizontal power ratio.

If the antenna system is positioned in a uniform multi-path environment (each direction of arrival and each polarisation have equal probability) and the antenna element is matched. An interesting and quick alternative consists of computing these coefficients from the scattering parameters of the structure [19–21]. For example, in a two-antenna system, $\rho_{12}$is given by (2)

$$\rho_{12} = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)} \tag{2}$$

Using the S-parameters for calculating the envelope correlation is less laborious and relatively cheaper, as compared to the radiation-pattern approach. It is shown that the formula can be used with high accuracy, even if the radiation efficiency is rather low (less than 80%) [22].

3. ANTENNA STRUCTURE

Figure 1(a) shows the configuration of the two-antenna structure that function as MIMO system. Two identical monopoles are printed on FR4 substrate of dielectric constant $\varepsilon_r = 4.4$ and a substrate thickness of $H = 1\,\text{mm}$. The ground plane is placed on the same side of the radiating patch. By using a T-shaped coupling-fed structure on the other side of the substrate the impedance bandwidth is improved, thus it could cover WLAN5.2/5.8 bands easily for the monopole antenna. The studied slotted ground plane structure is shown in Figure 1(b). It consists a pair of slots, the length of which is denoted as sl, width sw and slot separation sd. The slots are cut through the ground plane and are air-insulated.

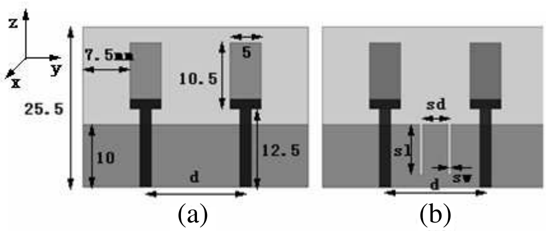


Figure 1. Configuration of the two-antenna structure that function as MIMO system, (a) a reference ground plane, (b) a ground plane with two slots.

4. STUDIES WITH ANTENNA SPACING AND SLOTS

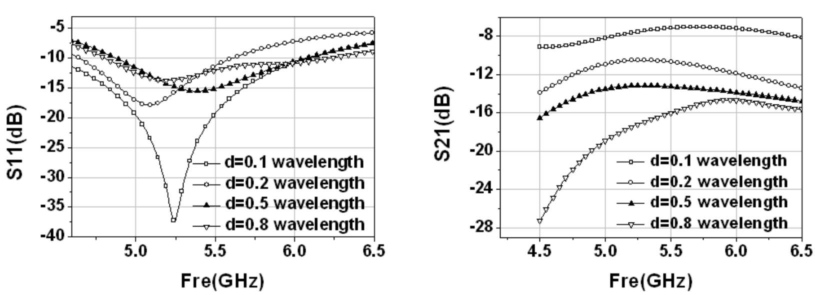
To investigate and better understand the proposed antennas presented in Section 3, the high-frequency structure simulation (HFSS.12) software was used for simulation and optimization. The prototypes were fabricated and the S-parameters were measured with Agilent 8722D vector network analyser.

4.1. Studies with Antenna Spacing

To illustrate the effects of spacing between the antenna elements on the mutual coupling, under a MIMO scheme of that in Figure 1(a), it presents the S-parameters for different antenna spacing d, as shown in Figures 2(a) and (b). From the Figure 2(a), it can be observed that there is not very much change on the bandwidth ($S_{11} < -10\,\text{dB}$) as d decreases. On the contrary, the mutual coupling (S_{21}) becomes higher when two elements become closer. The S_{21} varies from -7.6 to $-17.5\,\text{dB}$ for the spacing d from 0.1 to $0.8\lambda_o$ at 5.2 GHz as shown in Figure 2(b).

4.2. Studies with Slots

To understand the behaviour of the $\lambda/4$ slot structure, Figures 3(a) and (b) are presented to focus on the parametric studies. Figure 3(a) details the studies where slots are presented with three different slot length ($sl = 7$, 8, 10 mm) while keeping $d = 28\,\text{mm}$ ($0.5\lambda_o$), $sw = 0.5\,\text{mm}$ and $sd = 4\,\text{mm}$. It can be observed that the length of the slot obviously affect the mutual coupling of the proposed antennas. That is, with a decrease in sl, the frequency of lowest mutual coupling is quickly



(a) (b)

Figure 2. Simulated S-parameters for different antenna spacing d under a MIMO scheme of that in Figure 1(a), (a) S_{11} against frequency, (b) S_{21} against frequency.

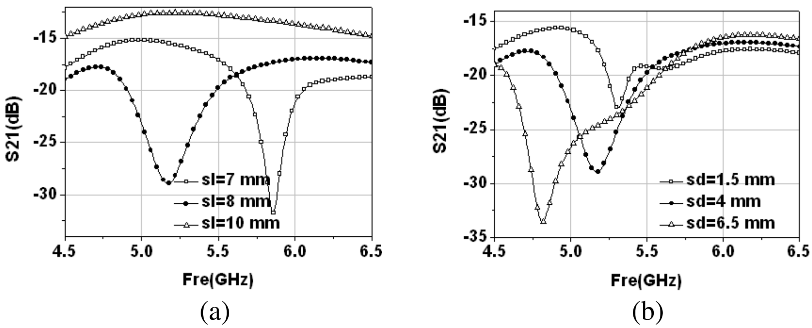


Figure 3. (a) Simulated S_{21} for different values of sl against frequency. (b) Simulated S_{21} for different values of sd against frequency.

shifted to upper frequencies. Specially, when $sl = 10\,\mathrm{mm}$, that is the ground plane is truncation, however, the mutual coupling is more than $-15\,\mathrm{dB}$ in WLAN 5.2/5.8 band. Note that the case of 8 mm is the proposed optimal design, which is approximately 0.25λ. Effects of the slot separation (sd) on the isolation are studied in Figure 3(b). Results for three different slot separation of $sd = 1.5$, 4, 6.5 mm with $sl = 8\,\mathrm{mm}$ are presented. Obvious variations in mutual coupling are also seen when sd varies. With a increase in sd, the frequency of lowest mutual coupling is shifted to lower frequencies. It can be observed that $sd = 4\,\mathrm{mm}$ is the optimal design.

4.3. Antenna Prototypes and S-parameters

Two antenna prototypes are fabricated as shown in Figure 4. The antenna with slotted ground plane has slot length $sl = 8\,\mathrm{mm}$ (approximately 0.25λ), slot separation $sd = 4\,\mathrm{mm}$ and the two antenna elements spacing $d = 28\,\mathrm{mm}$ ($0.5\lambda_o$). Then Figure 5(a) shows the measured and simulated S-parameters against frequency for the reference ground plane. Measured 10-dB impedance bandwidth is 21.5% with a 5.45 GHz centre frequency, and mutual coupling across the impedance bandwidth approximately $-13\,\mathrm{dB}$ for the reference ground plane. It was -12.5, $-14.5\,\mathrm{dB}$ at 5.2, 5.8 GHz, respectively. For comparison, Figure 5(b) presents the measured and simulated S-parameters for a ground plane containing two quarter-wavelength slots. Mutual coupling between the antenna elements is significantly reduced within the same impedance bandwidth, which was -33.3, $-21.1\,\mathrm{dB}$ at 5.2, 5.8 GHz, respectively. The lowest mutual coupling of $-33.3\,\mathrm{dB}$ was achieved at 5.2 GHz, which are 20.8 dB improvements over the reference.

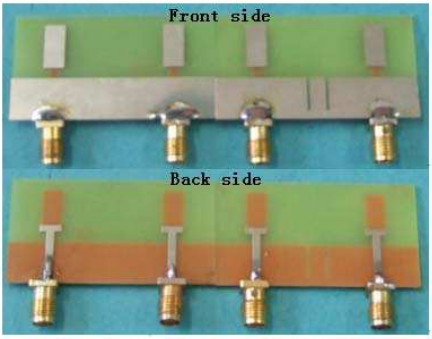


Figure 4. Prototypes of the proposed antennas.

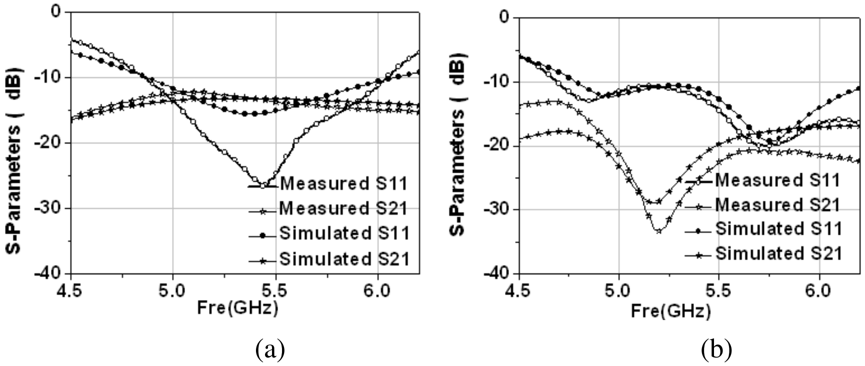


Figure 5. Measured and simulated S-parameters, (a) a reference ground plane, (b) a ground plane with two quarter-wavelength slots.

4.4. Radiation Properties

Figure 6 shows the measured radiation patterns for the two antennas at 5.2 GHz. In measurement the monopole 1 is excited and the monopole 2 is terminated by a $50\,\Omega$ impedance. In the reference in Figure 6(a), the radiation pattern is asymmetrical only in the yz plane. Monopole 1 is asymmetrically implemented related to the ground plane center and thus effects the radiation properties in the asymmetric sense. Figure 6(b) presents radiation patterns of antenna with the two slots. The same kind of behavior can be observed as in the reference case, except now the currents in $+y$ direction on the ground plane have directive behavior in yz plane, in the direction of $+60°$. Different current distributions over the slots are creating a deeper null in the direction of $-125°$.

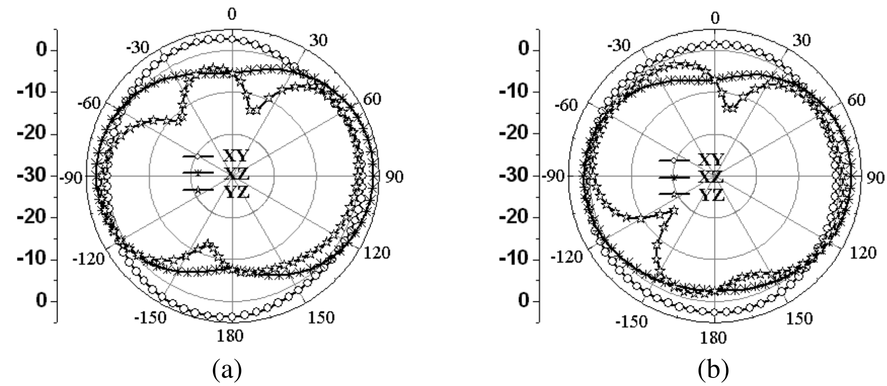


Figure 6. Measured radiation pattern at 5.2 GHz, (a) a reference ground plane, (b) a ground plane with two quarter-wavelength slots.

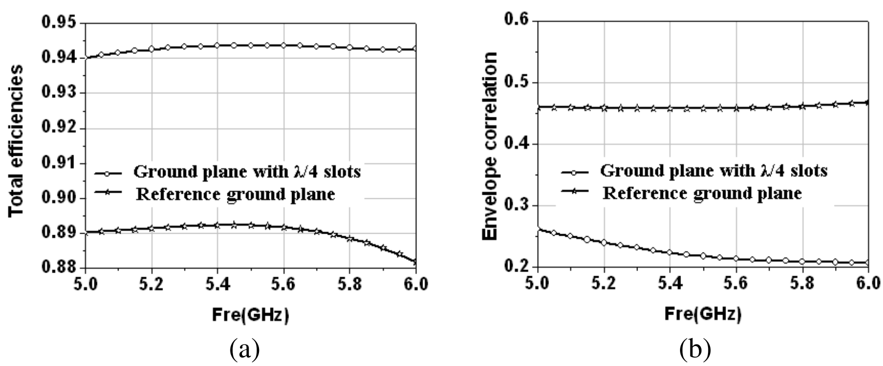


Figure 7. (a) Total efficiencies. (b) Envelope correlation.

The simulated total efficiencies are presented in Figure 7(a). Because of the fact that the structures are symmetrical, only the total efficiencies of one of the two monopoles are presented. The total efficiencies of the other radiator are assumed to be same. As expected, increasing the isolation between the two monopoles resulted in enhancing their total efficiencies. It can be seen, for the entire bandwidth under consideration, that the total efficiency of the slotted ground plane is higher than that of the reference ground. The total efficiencies are higher than 88% for the reference prototype, while 94% for the antenna structure with the two $\lambda/4$ slots.

For the two antennas analysed in this study, the computed envelope correlation coefficients are approximately obtained from the measured S_{ij} parameters according to (2) due to the total efficiencies

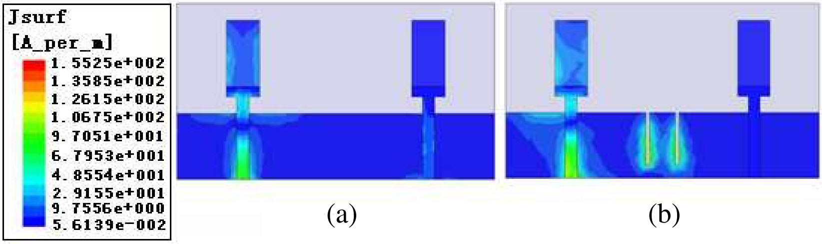


Figure 8. Simulated surface current distributions at 5.2 GHz, (a) a reference ground plane, (b) a ground plane with two quarter-wavelength slots.

are higher than 80% as illustrated in [22]. Both the antenna structures in this study exhibit an envelope correlation coefficient always below 0.5 in the WLAN 5.2/5.8 GHz system band as shown in Figure 7(b). The envelope correlation coefficient (0.25) of the slotted ground plane is always lower than the corresponding coefficient (0.45) of the reference system.

4.5. Surface Current Distributions

The simulated surface current distributions at 5.2 GHz for the proposed two antennas are presented in Figures 8(a) and (b), respectively. The pictures prove how effectively the structure with two slots reduces mutual coupling in the studied case. It is clearly seen that the two quarter-wavelength slots functions as an effective wavetrap for trapping the current of Antenna 1 from entering into Antenna 2, that is blocking the antenna's near-field radiation between the two antennas. This can explain the improved isolation obtained for the proposed design with the presence of the two $\lambda/4$ slots.

5. CONCLUSION

Isolation improvement using two quarter-wavelength slots cut into the ground plane in-between two planar coupled-fed monopoles has been demonstrated. The two quarter-wavelength slots in-between the two antennas functions as a wavetrap over the 5.2/5.8 GHz bands to effectively reduce the mutual coupling between the two antennas through trapping the current on the ground plane and blocking antenna's near-field radiation from one antenna to another. In $0.5\lambda_o$ of the antenna spacing, mutual coupling was -33.3, -21.1 at 5.2,

−5.8 GHz, respectively. The lowest mutual coupling of −33.3 dB was achieved at 5.2 GHz, which are 20.8 dB improvements over the reference. The antenna is an excellent candidate in WLAN base stations, handsets, or laptops when using multiple-input-multiple-output (MIMO) or diversity systems.

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