Dual-Band MIMO Balanced Antenna for C-Band and WLAN Applications

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Abstract

Two closely spaced MIMO balanced antennas consist of four printed U-shaped folded arms developed to operate over dual-band spectrum of C-band and WLAN. The two-element MIMO antennas are printed over 1.6mm FR4 substrate. The present MIMO design occupies a volume of 60 x 23 x 1.6 mm3. The two MIMO balanced antennas are placed over a ground plane dimension of 120mmx60mm2. To enhance the isolation between the antenna element, an I-shaped slot is generated on the ground plane, which presents a high isolation of around -20dB at both bands. This antenna also shows promising performances in terms of envelope correlation coefficient, channel loss, power gain, efficiency and current surfaces. This makes the present design a suitable candidate for future MIMO systems.

1 Introduction

The technology of Multiple-Input and Multiple-Output (MIMO) has been considered as a promising approach to significantly accomplish an increase in wireless channel capacity and reliability. This is because of its high data rate and high-spectrum efficiency without the need for additional power or spectrum particularly in rich scattering environments. However, a prominent and recurring issue that face MIMO applications lies in the coupling or so called leakage current while MIMO is being deployed in a limited space, such as mobile handsets. In this case, the correlation coefficients between MIMO antenna elements are very high in which leads to a severe drop in the antenna efficiency. Lately, a large number of MIMO antennas along with numerous techniques for reducing mutual coupling between the MIMO antenna elements in compact mobile handsets have been proposed [1-8]. However, all these MIMO antennas are made with unbalanced structure, which are ground plane independent, and as a result, are sensitive to user hand held effects [9]. In other word, these unbalanced antennas and their ground planes are a part of the radiator assembly whereby there are large currents induced on both the radiator and the antenna ground structure. This will severely impact system performance, particularly when the antenna is being held by the user’s hand.

This has motivated the antenna designers to investigate an alternative approach to overcome such an issue, such as opting for balanced antenna syntheses. These kind of antennas are based on symmetric feed structures with two wires having exactly the same current and being 180 degrees out of phase. Several balanced antennas have been recently reported [10-15], but these are still using a single radiating element in both the transmitter and receiver side, and consequently are limited in the amount of data throughout and reliability that they can offer to cater for a truly broadband experience that next generation handsets should offer.

Until recently, very few MIMO balanced antennas have been demonstrated [16-17]. Thus, in the scope of this work we aim to deal with the above-mentioned issues by proposing a compact and closely spaced printed balanced MIMO antenna that operates over dual-band spectrum. As design targets, we aim to reduce the degree of correlation between antenna elements to below -15dB, while achieving good performances in terms of envelope correlation coefficient (ECC), channel capacity (CC), power gain and efficiency.

2 MIMO Antenna Structure and Concept

The present antenna elements consist of four U-shaped folded arms on each side that are printed over 1.6mm FR4 substrate, dielectric constant $\varepsilon_r = 4.4$ and loss tangent $\tan \delta = 0.017$ as seen in Figure 1. These two elements are separated by a distance of 8 mm for optimal mutual coupling suppression. The two elements MIMO structure are suspended over a ground plane with dimensions of 120mmx 60mm i.e., used as reference mobile ground as depicted in Figure 1. The proposed MIMO synthesis is fed by a balanced voltage source. The width of the folded printed arms is 1mm. To further shrink the mutual coupling between the antenna elements; an approach of employing the I-shaped slot over the ground plane was used. In principle, inserting the I-shaped slot on the ground plane introduces an opposite coupling, which aims to decrease the mutual coupling. This antenna was built using the HFSS software package [18]. The full dimensions of the whole antenna system are detailed in Table 1.
To meet the optimum heights of recent smart phones, the height of the antenna over the ground plane is deemed as a vital factor that should be investigated. Therefore, the height of the present MIMO antenna was studied and analysed. This analysis is started by mounting the antenna at 3mm over the ground plane, as shown in Figure 2; although the antenna demonstrates good isolation between the two elements, there is impedance mismatching at both target band, namely at 4GHz and 5GHz. When the antenna is fixed at 5mm over the ground plane, the structure exhibits also high isolation, but again there is mismatching at the higher band of WLAN5GHz as indicated in Figure 2.a. In the case of 7mm and 9mm, the proposed antenna provides good performance in terms of S11 and S21, however the 7mm height was selected as the best choice since it keeps the volume of the antenna at minimal size.

| Parameters | Value in mm |
|------------|-------------|
| L1         | 23          |
| L2         | 12          |
| W1         | 12          |
| W2         | 6           |
| W3         | 6.25        |
| S          | 2           |
| S1         | 2           |
| S2         | 2           |
| d          | 8           |
| h          | 7           |
| Sw         | 8           |
| Sl         | 23.25       |
| L          | 120         |
| W          | 60          |

Table 1: The full dimension of the antenna.

To further understand the contribution of the slotted I-shape on the ground plane in reducing the mutual coupling between the two elements, the best slot size should be carefully selected. Thus, four different slot lengths (Sl) were investigated against the variations of S11 and S21, as depicted in Figure 3. It can be seen, when the length of the slot is set at 2.2mm and 9.25mm, the antenna shows good S11 performance with a return loss exceeding -15dB at both desired bands (C-band 4GHz and WLAN5GHz), but with low
isolation of 8 dB at the first band of 4GHz. On other hand, when the length of the I-slot is set at 16.25mm and 23.35mm, the antenna illustrates good S11 and S21 performance, however, the length of the 23.25mm was chosen as the ideal one since it shows better isolation (S21) of around -20 dB as illustrated in Figure 3.

Figure 3. The influence of the I-shaped slot length against the S parameters

3 Results and Discussions

The Sparameters of the proposed MIMO antenna are depicted in Figure 4. It can be seen that in the case of the antenna without slot on the ground plane, the antenna operates over the dual band of 4GHz and 5GHz, however, the coupling exhibited between the antennas at the first band (4GHz) is quite high (-7dB). Thus, the embedded slot approach was exploited that significantly mitigates the coupling between the elements: approximately -17 dB at the 4GHz and showing further reduction in coupling to around -20dB at the second band (5GHz), while preserving the dual band properties at 4GHz and 5GHz.

Figure 4. Simulated S parameters of the antenna with and without I-shaped slot on ground plane

For proof of concept, the antenna with slotted ground was fabricated and measured. The antenna prototype including the slot over the ground plane is depicted in Figure 5. The folded U-shaped arms were printed over 1.6mm FR4 substrate. The manufactured antenna was fed through coaxial cables as shown in Figure 5. The ground plane was fabricated from 0.15mm copper sheet. A slot with dimensions of 23.25mm x8mm was introduced on the ground as indicated in Figure 5a.

Figure 5. The antenna prototype, (a) 3D view, (b) ground view

The measured S parameters of the prototyped design is presented in Figure 4. It is clear that the I-shaped slot introduced on the ground plane effectively contributed towards enhancing the isolation between the antenna elements. The S11 performance is approx. -16dB and -12dB at the dual operational band of 4GHz and 5GHz, respectively, whilst achieving an isolation of -14dB and -17dB at the targeted band respectively. This agrees well with the simulated analysis in Figure 4.
To further validate the effectiveness of the I-shape slot over the ground plane as an approach to enhancing the isolation between the two elements of the MIMO antenna, the current surfaces of the antenna with and without the I-shaped slot are investigated in Figure 6. In particular, Figure 6(a) plots the surface current distributions at the dual targeted bands without the I-shaped slot, while the port of antenna 1 is excited and the port of antenna 2 is terminated by 50 Ω loads. At 4GHz, the surface current flows from antenna 1 to antenna 2, which presents very low isolation between the two elements, but at 5GHz, the structure shows very low induced current on antenna 2 that leads to high isolation. In Figure 6(b), that includes the I-shaped slot on the ground plane, the current only exists on antenna 1, while it is very weak on antenna 2. This verifies that the I-shaped approach introduced an opposite coupling preventing the current flowing through to antenna 2, which leads to a significant reduced mutual coupling. These investigations prove the outcome in Figure 4.

![Figure 6](image)

Figure 6. The current surfaces at 4GHz and 5GHz, (a) antenna without I-shaped slot, (b) antenna with I-shaped slot

To validate the MIMO system diversity, the correlation between signals that are received at the same side of a wireless link by the separate antennas is deemed as a significant factor for the entire system. Generally, the envelope correlation coefficient (ECC) is exploited to estimate the diversity capability of the system that consists of multi-antennas. The ECC could be calculated from three-dimensional (3D) radiation patterns [19], however, this avenue is difficult. Assuming that a multiple antenna operates in a uniform multipath environment, its ECC can alternatively be [20].

\[
\rho_e = \frac{|S_{11}^a S_{12}^b + S_{21}^b S_{22}^a|^2}{(1-|S_{11}|^2)(1-|S_{22}|^2)}
\]

In order to investigate the performance of the MIMO antenna, the calculated ECC is illustrated in Figure 7.a. It is noticeable, that the ECC of the proposed two-element antenna is kept below 0.01 at the dual desired bands of 4GHz and 5GHz. This is comparable to the results obtained from [1-2], which suggests good diversity performance.

![Figure 7](image)

Figure 7. The proposed MIMO antenna characteristics: (a) Envelope correlation coefficient, and (b) Capacity loss.

The other paramount factor is the channel capacity. In principle, increasing the number of MIMO antenna elements will lead to channel capacity enhancement. However, loss of channel capacity may exist when Rayleigh-fading MIMO...
channels are present. This loss can be calculated from the correlation matrices given in [21,22]. In a 2×2 MIMO system scenario, by supposing that only the receiving antenna patterns are correlated and supposing the worst scenario where high SNR is occurring, the capacity loss $C_{\text{loss}}$ can be estimated by using the following equation [20,21]:

$$C_{\text{loss}} = \log_2 \det(\psi^R)$$  \hspace{1cm} (2)

where $\psi^R$ is the receiving antenna correlation matrix that is given by:

\begin{equation}
\psi^R = \begin{bmatrix}
\rho_{11} & \rho_{12} \\
\rho_{21} & \rho_{22}
\end{bmatrix}, \quad \rho_{ii} = 1 - (|S_{ii}|^2 + |S_{ij}|^2),
\end{equation}

and

$$\rho_{ij} = - (S_{i}^* S_{ij} + S_{j}^* S_{ij}), \text{ for } i, j = 1 \text{ or } 2$$  \hspace{1cm} (3)

Figure 7.b displays the capacity losses of the present MIMO antenna. In particular, the capacity loss at 4GHz is around 0.2 bps/Hz, while at the second band of 5GHz is 0.17 bps/Hz. This indicates good impedance matching and isolation between the two antennas elements leading to low capacity loss.

The power gains and radiation efficiencies of the present MIMO antenna are shown in Figure 8. The present antenna demonstrates power gain values of 4.8dBi and 5.2dBi at the desired bands of 4GHz and 5GHz respectively, while the power gain drastically drops before and after both bands as depicted in Figure 8.a. On other hand, the curve of the antenna efficiencies agree with the performances of the antenna gain, where the efficiency values are -0.90 dB and -0.80 dB , which are equivalent to 90% and 91% that were achieved over the two operating bands at 4GHz and 5GHz correspondingly, as indicated in Figure 8.b.

4 Conclusions

A compact printed folded arms balanced MIMO antenna has been developed and analysed. This antenna covers dual-band operation, namely at 4GHz and 5GHz. To enhance the isolation between the antenna elements, a simple method of generating an I-shaped slot on the ground plane has been implemented. This shows a significant increase in the isolation between the antenna elements. The present MIMO antenna design has size of $0.8\lambda_0 \times 0.3\lambda_0 \times 0.002\lambda_0$, with a spacing distance between the two antennas of 8mm that equates to $0.10\lambda_0$, where $\lambda_0$ is the wavelength of the lowest operating frequency (4GHz). The antenna design geometry could be tuned/reconfigured to cover additional long-term evolution (LTE) bands for use in future smart applications.

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