Miniaturized Dual-Layers LTE MIMO Printed Antenna with Hybrid Decoupling Elements to Improve Isolation

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***Abstract*—A miniaturized multilayer internally multiple-input multiple-output (MIMO) printed antenna system combined with hybrid decoupling elements to improve isolation between two antennas at triple Long-Term Evolution (LTE) bands is presented in this paper. To reduce the single antenna size, the meander lines are stretched perpendicularly on the two respective layers that its overall dimensions are 14 × 15 × 3.2 mm^3 . Two different mechanisms are introduced for enhancing the port isolation at two different frequency bands. The isolation within three desired bands could be improved to all below -20 dB.**

***Keywords*—LTE antennas, mobile antennas, multiple-input multiple-output (MIMO), mutual coupling.**

I. Introduction

In recent years, the increasing demand for wireless communication quality has induced the development. Thus, the multiple-input multiple-output (MIMO) system was used. In a MIMO antenna system [1]-[2], high antenna coupling would let current leakage from one antenna to another. It will probably deteriorate antenna performance by closely element with strong coupling. To do that, low mutual coupling or high isolation between adjacent antennas is a key factor. However, the spacing between antennas is usually limited, especially in mobile communication devices.

Many studies have been carried out to enhance the port isolation of strongly coupled antennas. For example, polarization decoupling method had been investigated in many kinds of different configurations in [3]. The port isolation in [3] shows the lower mutual coupling when the polarization of two antennas is orthogonal to each other. Another method to enhance the port isolation is to introduce coupling element or slit system ground for reducing the mutual coupling between antenna [4]-[5]. In [6], a neutralization line is connected to the antenna for improving isolation. This line delivers to the other antenna in order to cancel out the existing mutual coupling. A decoupling technique using the transmission line analysis combined with array conception for enhance isolation between two closely spaced antennas at the same frequency band has been proposed in [7].

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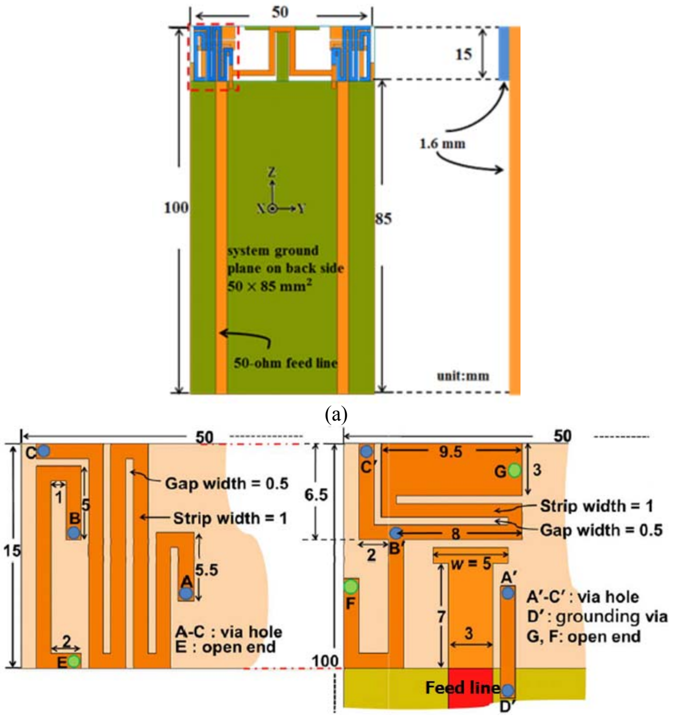
On the other hand, Long-Term Evolution (LTE) is latest standard in mobile network technology. Frequency spectrum allocated for LTE applications ranges from 400 MHz to 4 GHz. Not only compact antenna structure with difficult work but also the achievement of high isolation design between antennas becomes a serious technical challenge, especially in low frequency [8]-[9]. A multi-band antenna for LTE operation has been proposed in [10], but the area of antenna is too large which is not suitable for MIMO design. In order to achieve small size antenna structure as possible, some research used magnetic dielectric materials. However, the additional magnetic loss will be introduced by using the material with high permeability [11]-[12]. In [11], it shows a compact application so that two antennas separation in far distance as possible, but isolation is still not enough. In [12], a meander line used for decoupling structure nears the feeding position in order to get high isolation in MIMO antenna system was presented.

In this paper, we present a miniaturized dual-antenna MIMO system with decoupling elements for decrease mutual coupling between antennas for triple band operations is proposed. For single antenna element, the two-layer with orthogonal meander layout is presented. To improve the port isolation between antennas, a hybrid decoupling architecture is proposed in this paper.

II. Proposed Antennas Design

Fig. 1(a) shows the geometry of the proposed LTE MIMO antenna system with decoupling elements for triple band operations (LTE700: 698 ~ 862 MHz, LTE2300: 2300 ~ 2400 MHz and LTE2600: 2500 ~ 2690 MHz) of mobile devices. The antenna array is mounted at the top edge of mobile devices.

It was fabricated on two 1.6-mm-thick FR-4 substrate with a permittivity of $\varepsilon_r = 4.4$, loss tangent $\tan\delta = 0.02$. The upper one (50 × 15 mm^2) is contacts the under one (50 × 100 mm^2) very closely, the main array fabricate on the top layer and 2nd layer, by using vias (AA', BB' and CC') to connect antennas strip, where the system ground is on the back side of the lower substrate as the 3nd layer in the study. The dimension of a single antenna occupies only $14 \times 15 \times 3.2$ mm^2, which is



(b) (c)

Fig. 1. The Geometry of proposed LTE antenna with decoupling elements (a) with system ground, (b) top layer and (c) second layer.

about 0.035 wavelength of LTE700 as the minimum dimension. The distance of two antennas is 0.06 wavelength (26 mm) in LTE700 band. The proposed antenna is shorted to the system ground trough a shorting via (D'). Finally, a neutralization line connected to the nearby shorting via and T-shape resonator connected to the ground plane. .

Fig. 1(b) shows the top layer of the single antenna. To reduce the antenna size, the width of gap between strip B-E and A-C is chosen as 0.5mm, and the width of metal strip is 1 mm. The lengths of strip B-E and strip A-C are 21.5 and 64 mm. The point A, B and C are shorting vias with 0.2 mm radius which to connect with the second layer. According dual-layer structure, it probably strongly electromagnetic interference so that antenna cannot be successful excitation in desired operation. In order to improve this problem, the orthogonal layout has been proposed in this case. The top layer of proposed antenna is given a vertical layout as possible as we can. Fig. 1(c) shows the 2nd layer of the single antenna. As the above description, the width of gap and metal width are chosen 0.5 mm and 1 mm. The length of strip A'-D', strip C'-B', strip B'-F' and strip B'-G' are 7.5, 8, 16, and 33mm, respectively. Note that the radiating strip D'-G can be successfully to generate 1/4λ at 760 MHz and the higher mode of 2650 MHz in 5/4λ operation. The lengths of strip D'-F is used to produce a resonant point at 2360 MHz in this design as the 3/4λ operation. In order to ensure that the higher modes could be excited and to cover wide band operation, the strip B-E is also proposed in the top layer to achieve better impedance matching.

For enhancing the port isolation between two closely multi-band antennas, a neutralization line and a T-shape resonator has been added between two antennas. The geometry of the proposed hybrid decoupling structure is shown in Fig. 2. There

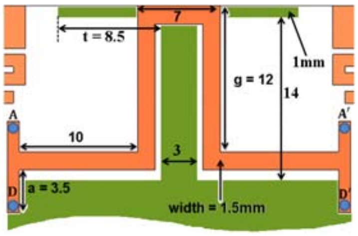


Fig. 2. The geometry of proposed hybrid decoupling elements.

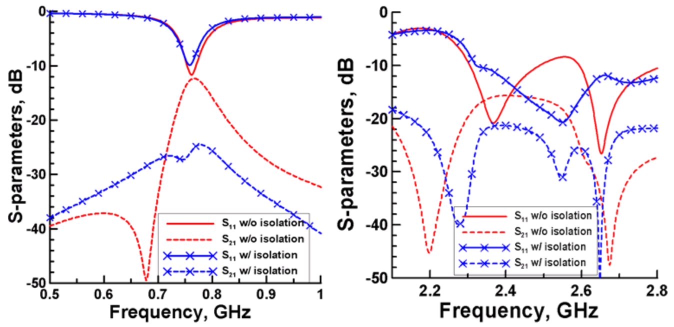
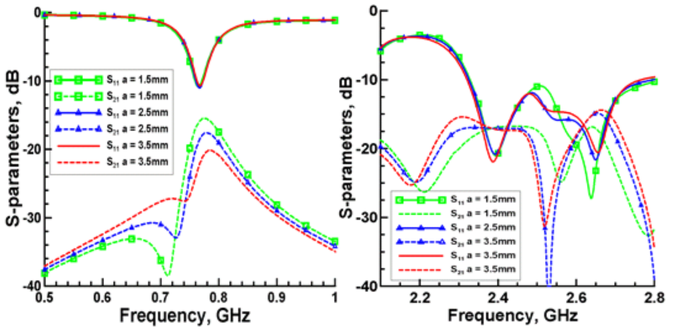


Fig. 3. The simulated reflection coefficient S_{11} and isolation S_{21} with and without the decoupling elements at (a) lower and (b) higher bands.

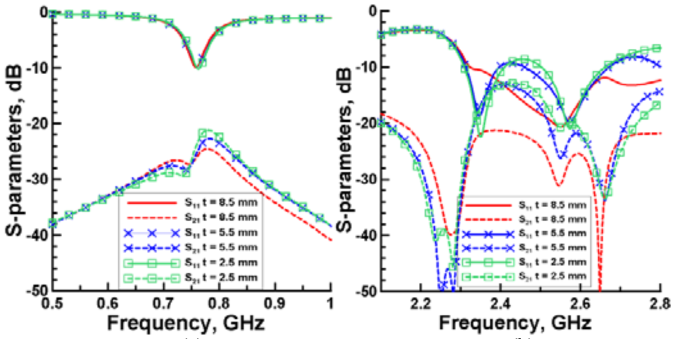
are two different mechanisms for enhancing the port isolation at two different frequency bands. At the lower frequency, the proposed neutralization line can be introduced current from coupled antenna, which could cancel out the energy from one antenna to another. At higher frequency band, the mechanism of the proposed T-shape resonator is a 1/4λ resonator. The energy that radiated from one antenna could be trapped by the proposed resonator. Finally, the isolation of two antennas could be improved. The detail parameter will be addressed to verify these behaviors in next section.

III. Results and Discussions

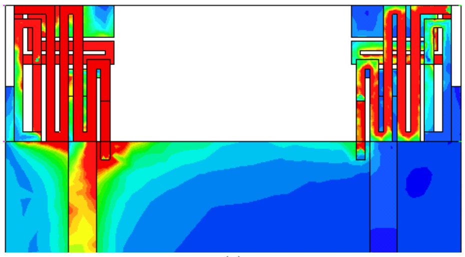
Fig. 3 depicts the simulated of a comparison of with/without decoupling elements. In Fig. 3(a), it exhibits the bandwidth about 53 MHz (from 733 to 786 MHz) by the definition of -6 dB reflection coefficient but with the poor isolation about -7 dB as the antenna without decoupling elements. According to the result, there are still remained that the poor of isolation in desired frequencies. Thus, the isolator is still needed for decreasing the mutual coupling between two antennas. It is hard to get wide band isolation enhancement especially the bandwidth of the higher frequency (from 2.3 to 2.69 GHz). In order to solve the problem, a hybrid decoupling is proposed. The bandwidth is slightly shifted to lower frequency about 40 MHz (from 740 to 780 MHz), and port isolation could be improved more than -20 dB in operation frequency. The higher two frequencies are also shown in Fig. 3(b), both of the with and without proposed hybrid decoupling elements exhibit full LTE2300 operation (from 2.3 to 2.4 GHz) in S_{11} with the worst isolation about -13 dB, and full LTE2500 operation (from 2.5 to 2.69 GHz) in S_{11} from 2.5 to 2.69 GHz with the worst isolation about -16 dB. The simulated S-parameter of the proposed antenna with varying the connected position of the neutralization line is shown in Fig. 4. By adjusting the connected position (a) of the neutralization line, the port isolation of two antennas could be improved at lower band. We also examined the effect of the length of the



(a) (b)
Fig. 4. The simulated S-parameter of the proposed antenna with different connected position of neutralization line at (a) lower and (b) higher bands.



(a) (b)
Fig. 5. The simulated S-parameter of the proposed antenna with different length of resonator at (a) lower and (b) higher bands.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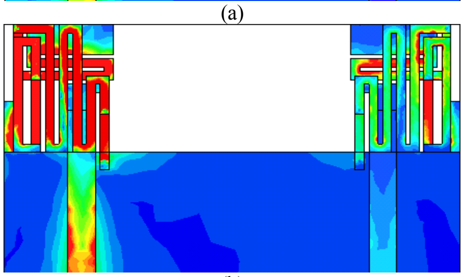
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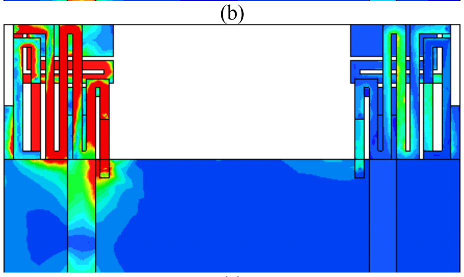
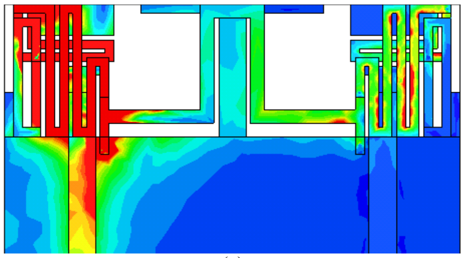

(c)
Fig. 6. Simulated current distributions with Port 1 excitation without decoupling elements at the best matching point in three bands, respectively.
(a) 760 MHz (b) 2361 MHz (c) 2653 MHz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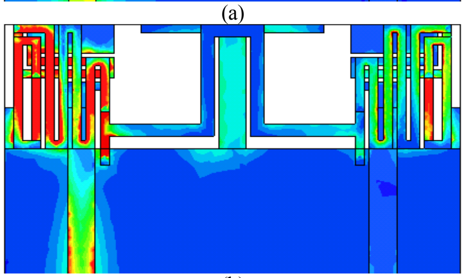
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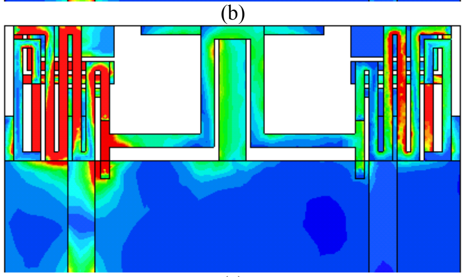
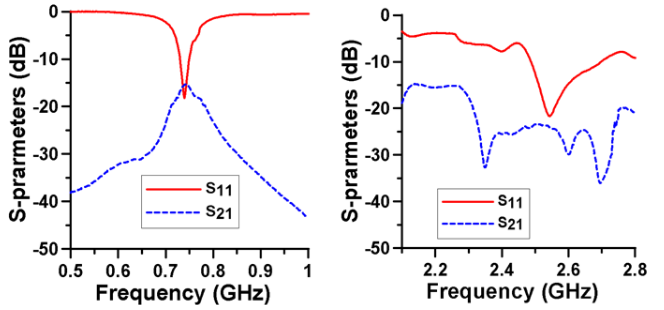

(c)
Fig. 7. Simulated current distributions with Port 1 excitation with decoupling elements at the best matching point in three bands, respectively. (a) 760 MHz (b) 2400 MHz (c) 2544 MHz.

resonator (t), the simulated results of varying its value are shown in Fig. 5. It can be seen that the port isolation could be improved at higher band. In this paper, the connected of the neutralization line a = 3.5 mm and the length of resonator t = 8.5 mm are chosen for better port isolation.

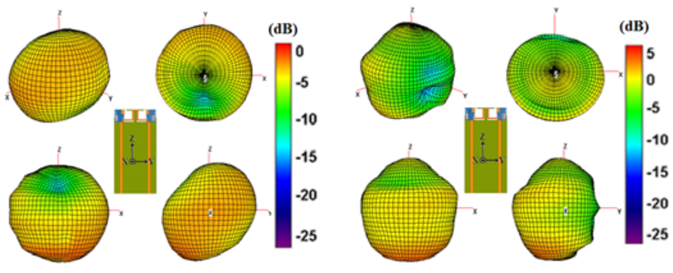
The simulated current distributions of the proposed antenna with Port 1 excitation and Port 2 terminated without decoupling elements are shown in Fig. 6. In order to easily compare the effect of the proposed resonator, we fixed all of the current density in the same scale. All of the simulated current distribution exhibits significantly coupling from antenna 1 to antenna 2. The simulated current distributions of the proposed antenna with decoupling element at three resonant frequencies are shown in Fig 7. When Port 1 is excited, the current from the radiator tending to couple to Port 2 has been blocked by the decoupling structure and reduce flow to the other radiator through the free space radiation and common ground plane at all these frequencies. Note that in Fig. 6(c), the current distribution of the Port 2 is stronger due to the additional decoupling elements which slightly decrease isolation.

The measured S-parameter are plotted in Fig. 8. It is observed that the reflected coefficient covers upper band (2.3-2.69 GHz), and cover 718 to 758 MHz in lower band. The measured isolation is lower than -16 dB in LTE700 band and -20 dB over higher band. The three-dimensional radiation pattern, antenna gain, and efficiency of the proposed antenna were measured in order to determine the radiation



(a) (b)

Fig. 8. The measure reflection coefficient S_{11} and isolation S_{21} with and without decoupling elements at (a) lower and (b) higher bands



(a) (b)

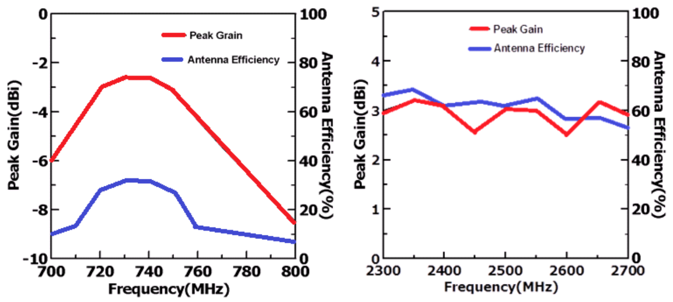
Fig. 9. Measured three-dimensional radiation pattern at (a) 730 MHz and (b) 2500 MHz

characteristics of the proposed antenna within the operation bands. Fig. 9 shows the measured radiation pattern at 730 MHz and 2500 MHz, respectively. It exhibits LTE700 operation radiation patterns are closed to the dipole-like radiation pattern, and omnidirectional radiation characteristics are observed. Similar performance is observed at 2500 MHz, for the middle of two resonance frequencies, with the addition of a null point in comparison to the pattern shown in Fig. 8. The radiation pattern shown in Fig. 9(b) demonstrates that the nullpoint will occur in the X-Y plane. The direction of the maximum gain is toward the ground plane (-Z direction), according to higher-order resonances at 2500 MHz. .

The measured antenna gain and efficiency within the operation bands are shown in Fig. 10. The measured maximum antenna gain at lower and higher bands is approximately -2.5 and 3.2 dBi, respectively. In addition, the efficiency is approximately 30% at the lower band (720~760 MHz) and approximately 60% for the higher band. The radiation characteristic of the proposed miniaturized printed antenna means it is suitable for wireless communication in handheld devices. The use of a material without a high permeability would allow the radiation performance to be enhanced further by avoiding material loss in a high permeability material.

IV. Conclusion

In this letter, a miniaturized dual-layer MIMO antenna design with decoupling elements for triple LTE bands had been proposed antenna could cover LTE700 (740~780 MHz), LTE2300 (2.3 to 2.4 GHz) and LTE2600 (2.5 to 2.69 GHz) operation by the definition of 3:1 VSWR. In order to improve



(a) (b)

Fig. 10. Measured antenna gain and antenna efficiency of the proposed antenna versus frequency at (a) lower and (b) higher bands.

the port isolation within three bands, operation by the definition of 3:1 VSWR. In order to improve the port isolation within three bands, a hybrid decoupling elements for isolation enhancement has also been proposed. The mechanisms of the proposed isolator within both lower and higher bands have been analyzed. Finally, the port isolation of two strongly coupled antennas is greatly enhanced by using the proposed decoupling element. The proposed MIMO antenna system is suitable for compact mobile phone applications.

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