A Novel LTE MIMO Antenna with Decoupling Element for Mobile Phone Application

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***Abstract*—A novel multiple-input and multiple-output (MIMO) antenna system combined with decoupling element for enhancing the port isolation between two antennas at triple Long-Term Evolution (LTE) bands is presented in this paper. For compact single antenna, an orthogonal strip layout design is used to build a single antenna with its dimension 14 × 15 × 3.2 mm^3 only. A spiral decoupling structure is added between two strongly coupled antennas to enhance the port isolation. The isolation within three desired bands could be improved to all below -20 dB. With the aid of the proposed decoupling element, the interference between two antennas could be minimized.**

Keywords—antenna, multiple-input and multiple-output (MIMO), decoupling element, Long-Term Evolution (LTE).

I. Introduction

Future wireless communication systems should provide the ability to deliver much higher data rates than the traditional system. Thus, the multiple-input and multiple-output (MIMO) systems are used. In a MIMO antenna system [1]-[3], high antenna coupling would let signal leakage from one antenna to another. It probably decreases the antenna efficiency due to the power absorbed by closely element with strongly coupling. In order to reduce the leakage between two strongly coupled antennas, the port isolation between two antennas could be improved by increasing the antenna spacing. However, the spacing between antennas is usually limited, especially in mobile communication devices.

Recently, many researchers have been focused on enhancing the port isolation of strongly coupled antennas. Many kinds of decoupling methods to enhance the port isolation have been published. A polarization decoupling method had been investigated in many kinds of different configurations in [4]. The port isolation in [4] shows the lower mutual coupling when the polarization of two antennas is orthogonal to each other. Another method to enhance the port isolation by introducing an additional coupling path to neutralize the coupling between two antennas and split system ground totally for improving isolation were studied in [5]. A decoupling technique using the transmission line analysis combined with array conception for improving the isolation between two closely spaced antennas at the same frequency band has been proposed in [6]. Furthermore, there are few studies to decoupling to a wide band or dual band isolation. In [7] and [8], a greatly wide isolation in ultra-wideband antenna was studied.

On the other hand, Long-Term Evolution (LTE) is the 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 multiple bands operation in a small area is a difficult work but also the achievement of high isolation design between antennas becomes a serious technical challenge, especially in low frequency bands [9]-[11]. Recently, reactive component are more and more popular to use in antenna design due to miniature antenna is a tendency and it is usually easy to embed in the mobile devices. A compact broadband antenna design had been addressed in [12]. However, the wideband operation is only achieved at lower frequency band, which is not suitable for multi-standard application. A dual-band antenna for LTE operation has been proposed in [13], but the area of antenna is too large which is not suitable for MIMO design. In [14] and [15], two-element antenna array composed by a meander monopole antenna were designed with port isolation enhancement methods at LTE700 operation. 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 [16]-[17]. In [16], it shows a compact application so that two antennas separation in far distance as possible, but isolation is still not enough. In [17], 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, a compact dual-antenna MIMO system with decoupling element for enhancing the port isolation for triple band operations is proposed. For single antenna element, the two-layer with orthogonal meander layout is presented for antenna miniaturization. For enhancing the port isolation between two closely placed antenna, a mushroom-type resonator , which is connected to the ground, is proposed in this paper. By using the proposed resonator, the coupling between two closely placed antenna could be isolated significantly. The operating mechanism of the resonator will be discussed and analyzed.

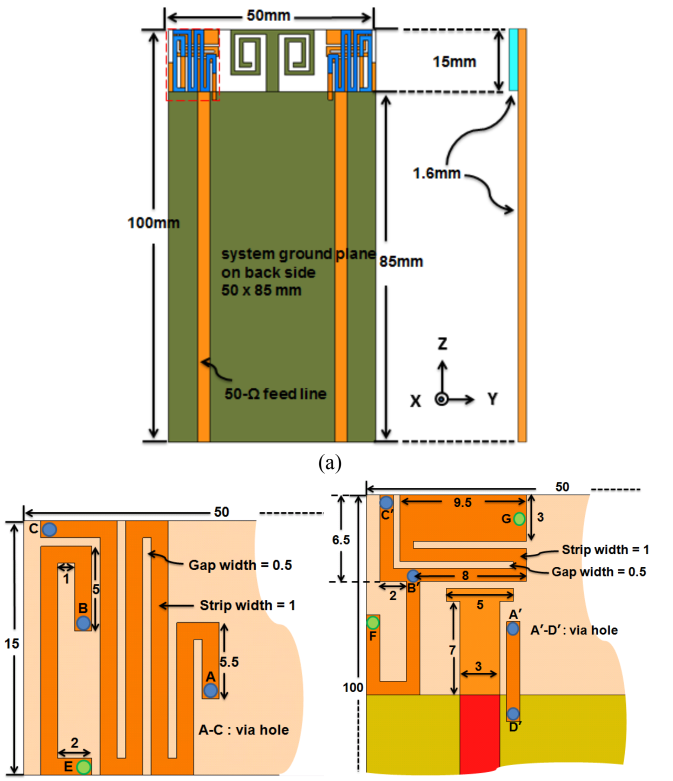


Fig. 1. The geometry of the proposed LTE MIMO antenna with decoupling element (a) with system ground, (b) top layer and (c) second layer.

II. Proposed Antenna with Isolation Enhancement

Fig. 1 shows the geometry of the proposed LTE MIMO antenna system with decoupling element for triple band operations (LTE700: 698 ~ 862 MHz, LTE2300: 2300 ~ 2400 MHz and LTE2500: 2500 ~ 2690 MHz) of mobile phone application. The antenna array is mounted at the top edge of the mobile device. There are two FR-4 substrates, with its relative permittivity ε_r = 4.4, loss tangent tanδ = 0.02 and thickness is 1.6 mm, in antenna design. 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 to connect antennas strip, where the system ground is on the back side of the lower substrate as the 3rd layer in the study. The dimension of a single antenna occupies only 14×15×3.2 mm^2, which is about 0.035 wavelength of LTE700 as the minimum dimension. The distance between two antennas is 26 mm, which is about 0.06 wavelength in LTE700 band. Owing to the antenna is a multi-layer structure, the strips are connected from top to 2nd layer by using three via-holes (AA', BB' and CC'). The proposed antenna is shorted to the system ground through a shorting via (D'). Finally, a mushroom-type resonator, which connected to the ground plane, is placed between two antennas on the 3nd layer.

Fig. 1(b) shows the top layer of the single antenna. In order to reduce the antenna parameter, the width of gap is chosen to be 0.5 mm between strip B-E and strip A-C. the width of the metal strips is chosen to be 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 2nd layer. According to PCB dual-layer structure, it probably produces 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 A-G can be successfully to generate 1/4λ at about 700MHz and the higher mode of LTE2500 in 5/4λ operation. The lengths of strip B-F is used to produce a resonant point at LTE2300 in this design as the 3/4λ operation. In order to ensure that the higher modes could be excited successfully and to cover wide band operation, the strip B-E is also proposed in the top layer to achieve better impedance matching.

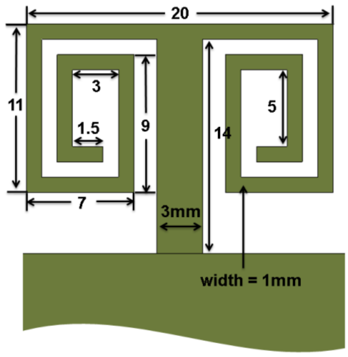


Fig. 2. The geometry of proposed mushroom-type decoupling element.

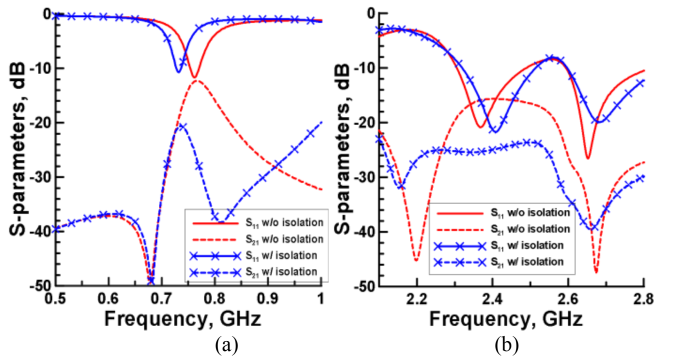
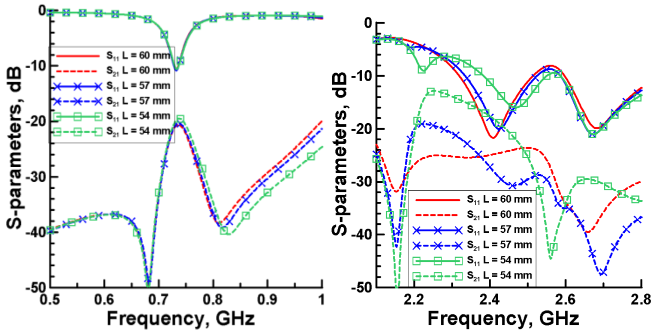


Fig. 3. The simulated reflection coefficient S_{11} and isolation S_{21} with and without the decoupling element, (a) lower band. (b) higher band.

For enhancing the port isolation between two closely placed antennas, a mushroom-type resonator has been added between two antennas. The geometry of the proposed resonator is shown in Fig. 2. There are two different mechanisms for enhancing the port isolation at two different frequency bands. At the lower frequency, the proposed resonator is worked as a shielding effect, which could shield the energy from one antenna to the other. At higher frequency band, the mechanism of the proposed resonator is a half-wavelength resonator. The energy that radiated from one antenna could be trapped by the proposed resonator. Finally, the isolation of two antennas could be improved at both lower



(a) (b)

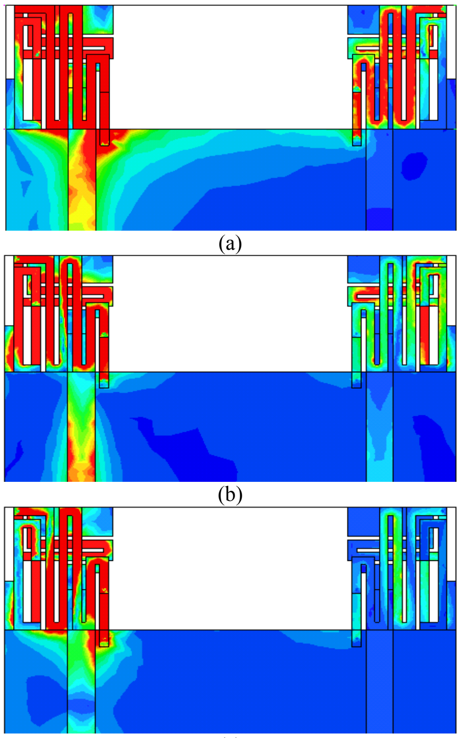
Fig. 4. The simulated S parameter for different length of the proposed decoupling element, (a) lower band. (b) higher band.

and higher frequency bands. The detail parameter will be addressed to verify these behaviors in next section.

III. Result and Discussion

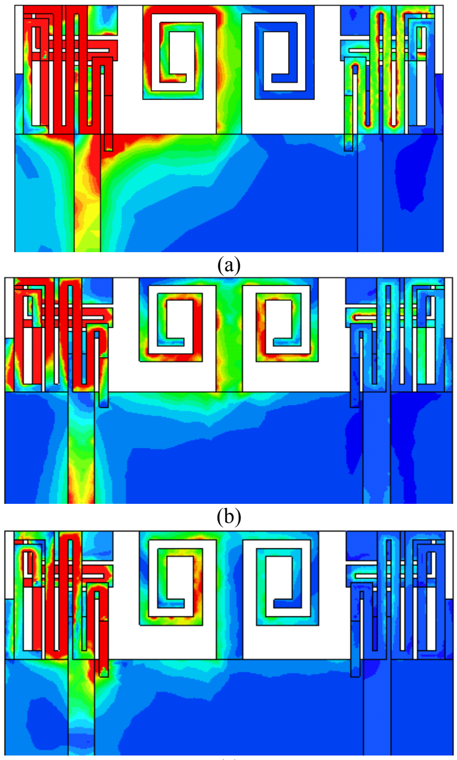
Fig. 3 depicts the simulated of a comparison of with/without decoupling element. In Fig. 3(a), it exhibits the bandwidth about 53 MHz in LTE700 band (from 733 to 786 MHz) by the definition of -6 dB reflection coefficient (S_{11}) but with the poor isolation (S_{21}) about -7 dB as the antenna without proposed resonator. According to the result, there are still remained that the poor of isolation in desired frequencies. Thus, the decoupling element is still needed for enhancing the port isolation between two strongly coupled 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 mushroom-type resonator is proposed. The bandwidth is slightly shifted to lower frequency about 40 MHz (from 752 to 712 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 decoupling element 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. Although the resonance frequency is shifting to higher as the resonator embedded, the average isolation can be improved to be lower than -24 dB, but it is still remained to cover full band in two higher frequencies. The simulated S-parameter of the proposed antenna with varying the length of the decoupling element *L* is shown in Fig. 4. By adjusting the length of the decoupling element L, the port isolation of two antennas could be improved to below -20 dB within the operation bands. In this paper, the length of the decoupling element *L* = 60 mm is chosen for better port isolation.

The simulated current distributions of the proposed antenna with Port 1 excitation and Port 2 terminated without decoupling element are shown in Fig. 5. 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 6. When Port 1 is



(a) (b) (c)

Fig. 5. Simulated current distributions with Port 1 excitation without decoupling element at the best matching point in three bands, respectively. (a) 760 MHz. (b) 2361 MHz. (c) 2653 MHz.



(a) (b) (c)

Fig. 6. Simulated current distributions with Port 1 excitation with decoupling element at the best matching point, respectively. (a) 732 MHz. (b) 2405 MHz. (c) 2666 MHz.

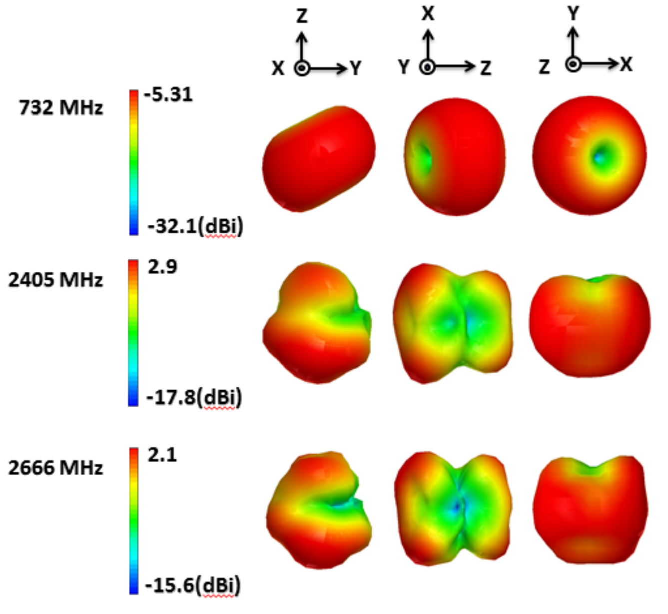


Fig. 7. The simulated of 3D patterns with decoupling element at 732 MHz, 2405 MHz, and 2666 MHz, respectively .

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 the current distribution of the proposed resonator in lower frequency is shown as an shielding effect, and higher two frequencies are controlled by the 3/4λ operation.

To verify the radiation characteristics of the proposed antennas with decoupling element, the simulated 3-dimensional radiation patterns are shown in Fig. 7. It exhibits LTE700 operation radiation patterns are closed to the half-wavelength dipole antenna like. At two higher frequencies at 2405 MHz and 2666 MHz, the obtained radiation pattern shows others dips or nulls in there and the patterns are close to those of the dipole antenna at its higher-order resonant modes. The new nulls are toward to y-axis direction. The resonant points at those frequencies are third-order and fifth-order mode. Due to the antenna is too small that the main radiation is dominating by the ground so that the pattern is focused in y-axis direction.

IV. Conclusions

A miniature dual-layer MIMO antenna design with decoupling element for triple LTE bands has been presented in this paper. The operating bandwidth of the proposed antenna could cover LTE700 (712~752 MHz), LTE2300 (2.3 to 2.4 GHz) and LTE2500 (2.5 to 2.69 GHz) operation by the definition of 3:1 VSWR. The miniature antenna is achieved by using the orthogonal strips layout between two different layers. In order to improve the port isolation within three bands, a mushroom-type resonator for isolation enhancement has also been proposed. The mechanisms of the proposed resonator 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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