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Design, Development and Measurement of MIMO Antennas for Next Generation Cellular Tablets

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Abstract

A 4-elements MIMO design for cellular tablets is presented in this paper. The design comprises two pairs of MIMO antennas that are etched on a substrate board. Two antennas are designed to cover 4G Long Term Evolution (LTE) whereas, the other two antennas are covering 3G frequency bands. The antennas in each MIMO pair are identical and are symmetrically placed. Each antenna is direct fed and shaped like a monopole in altered form. The material used for the substrate board is FR-4 with a dielectric constant of 4.3-4.4 and it covers a volume of 190 x 112 x 0.8 mm3. Each element of the 4G pair occupies an area of 67.5 x 35 mm2 whereas, each antenna of the 3G pair occupies 19 x 31 mm2. The two MIMO pairs are placed in orthogonal symmetry to enhance the decoupling performance. The decoupling thus achieved is better than 15 dB. The simulation and the testing results demonstrate the design as a good candidate for the implementation in cellular tablets.

1. Introduction

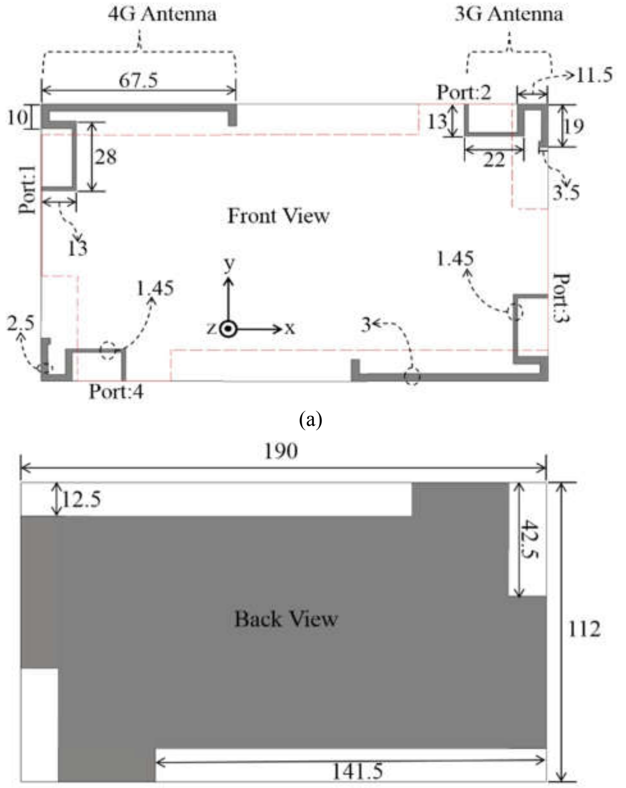
The rapid growth in the smart phones technology made it possible to have such handheld terminals through which user can access large volume data on the go. Modern handsets involve advanced communication protocols such as 4G-LTE. The number of mobile users has increased by a large proportion in the last five years [1]-[2]. The mobile handset has become a necessity of the modern day life which facilitates the users to communicate as well as enjoy large volume multimedia. The number of multimedia services provided by a handheld device has increased allowing the users to do multitasking while using mobile internet. The benefits of high-speed communication protocols such as 4G-LTE can be fully exploited by making smart antenna designs. However, certain changes in the topographical environment which involve an increase in the users of cellular devices and the certain obstacles such as large buildings degrade the quality of the communication link. It is thus necessary to employ modern antenna technologies for the improvement of communication quality.

A modern communication technology named as Multiple Input Multiple Output (MIMO) is introduced around ten years ago to address the problem of increased interference and degraded fidelity of the signal. This technology involves use of multiple antennas to increase the capacity performance and data throughput while consuming the same amount of power and bands of frequencies as that in conventional single antenna systems [3]-[11]. The execution of MIMO in mobile terminals such as mobile handsets and tablets is a challenging task due to the squeezed volume which majorly increases the far-field correlation between the antennas thus increasing the coupling. It is therefore a necessity to develop such antennas which can communicate in MIMO configuration with a good isolation and radiation performance. Few prototypes of the MIMO antennas for cellular terminals have been proposed and studied in [12]-[19]. These prototypes present novel decoupling mechanisms with modified ground planes involving slots and metallic extensions. Though the decoupling structures presented in these works are simple, however, the practical implementation of these structures is complicated. It is therefore necessary to propose such designs which can show a good isolation performance without needing any decoupling structure. One such method is presented in this paper in which antennas are placed in an orthogonal symmetry to enhance the far-field de-correlation for improving the decoupling.

In this paper, four microstrip printed antennas have been presented in MIMO configuration. The antennas are arranged in pairs for covering 4G-LTE and 3G cellular bands. Section II discusses the proposed antenna design. Section III describes the working mechanism and the radiation plots of the cellular MIMO antennas. Results are presented and debated in Section IV, followed by a conclusion.

2. Antenna Design

The computer model of the cellular MIMO design is presented in Fig. 1. The software package used for the simulations is *Computer Simulations Technology (CST)*® [20]. The design is composed of four monopoles being meandered for compact volume. The four antennas of the MIMO design are etched in pairs with each pair comprising two antennas. The antennas in each pair are placed diagonally for the improvement of isolation. The dielectric material used for the substrate possesses a dielectric constant of 4.35 whereas, the tangent delta for the substrate is 0.02. The volume of the dielectric PCB used for the design is 190 x 112 x 0.8 mm^3. Each antenna of the 4G pair occupies an area of 67.5 x 35 mm^2, whereas, each antenna of the 3G pair occupies 19 x 31 mm^2. The two MIMO pairs are placed in orthogonal symmetry to enhance the inter-pair isolation. A hardware model of the MIMO antennas is also fabricated and presented in Fig. 2. It is assumed that the tolerances in the substrate properties and the fabrication errors may lead to some discrepancies between the testing and the simulation results.



(a)

(b)

Fig. 1. Software model of the design proposed for cellular tablets (a). Front view, (b). Back view. (Units: mm)

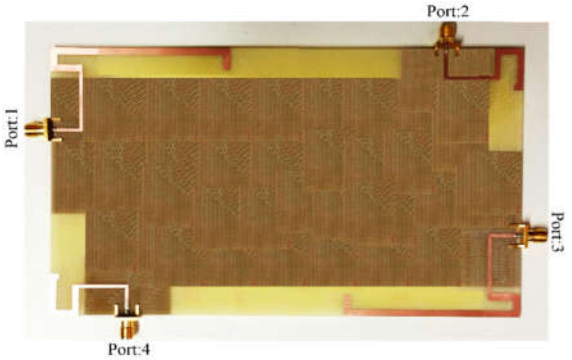
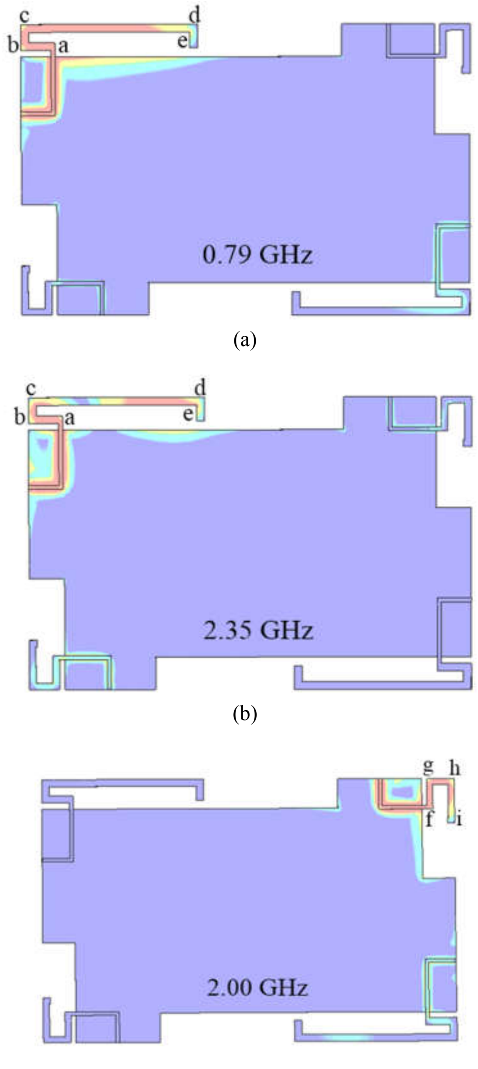


Fig. 2. Hardware model of the design proposed for cellular tablets.

3. Working Mechanism

The radiating elements shown in the paper are etched in MIMO pairs for covering 3G with one pair and 4G with the other pair. The antennas are shaped like monopoles that are altered for a compact volume. The radiating lengths at various frequencies can be calculated from the 3D distribution of the surface currents which are presented in Fig. 3.



(a)

(b)

(c)

Fig. 3. 3D current distributions of MIMO antennas (a). At f=0.79 GHz for 4G antenna, (b). At f=2.35 GHz for 4G antenna, (c). At f=2.00 GHz for 3G antenna. [Red: Maximum current; Green: Intermediate current; Blue: Minimum current]

It can be seen from Fig. 3 that at f=0.79 GHz the radiating length of the 4G MIMO antennas can be represented by the microstrip length ‘a-b-c-d’. The total radiating length of the microstrip is calculated as 88 mm which is approximately a quarter wavelength at 0.79 GHz. Likewise, at f=2.35 GHz, the conducting lengths of the 4G antennas are ‘a-b-c’ and some portions of ‘c-d’. Each length calculated out to be 30 mm which is approximately a quarter wavelength at 2.35 GHz. Lastly, at f=2 GHz, the radiating microstrip length of the 3G antennas can be represented by the microstrip length ‘f-g-h-i’. This comprises a length of 33 mm that makes up 0.25λ at 2 GHz. The decoupling between antennas is achieved by placing the antennas in each pair diagonally while the two pairs are placed orthogonally for achieving maximum far-field de-correlation. This largely enhances the decoupling thus ensuring a good pattern diversity. The simulated plots of the radiation pattern at selected frequencies (i.e. at 0.79, 2.35 and 2.00 GHz) are presented in Fig. 4. The radiation patterns of one antenna in each MIMO pair are presented. It can be seen that the antennas possess monopole like radiation patterns. This agrees with the working mechanism explained earlier.

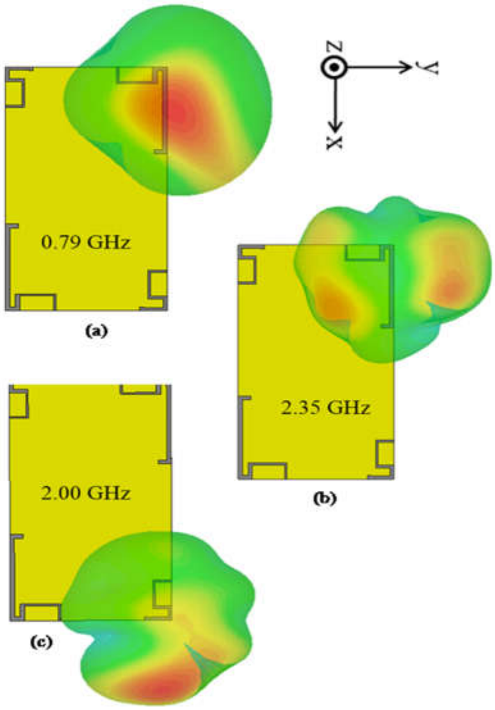


Fig. 4. Simulated 3D plots of the radiation pattern (a). At f=0.79 GHz for 4G antenna, (b). At f=2.35 GHz for 4G antenna, (c). At f=2.00 GHz for 3G antenna.

4. Measurements and Discussions

The anechoic chamber setup for the measurement of the radiation pattern of the antennas is shown in figure 5. The radiation pattern measurements were carried out in the antenna laboratory at Queen Mary University of London (QMUL). The antenna under test (AUT) is mounted on a turn table using a Styrofoam support to minimize the effect of testing setup on the measurement results the antennas. The absorbing material inside anechoic chamber is placed in all directions to eliminate the effect of reflections and noise. The measurements of only one antenna in each pair have been taken as the other antenna in each pair is identical and is symmetrically placed.

A. Scattering Parameters:

The scattering parameters (S-parameters) of the proposed cellular antennas are measured using the *Agilent Technologies* (now *Keysight*) N5230C PNA-L microwave network analyzer. Fig. 6 presents the simulation and the measurement results of the S-parameters of the proposed antennas. It can be visualized that the 4G antennas resonate in two frequency bandwidths which are 686–895 MHz and 2140–2565 MHz. Likewise, the bandwidth covered by the 3G antennas is 1685–2505 when referenced to a return loss of 6dB. The 4G pair thus covers LTE bands 5, 12, 13, 17-20, 26, 28-30 all situated in the frequency range of 698-894 MHz. Likewise, the 3G antennas cover HSDPA 1700 (1710-2170), 1900 (1850-1990), 2100 (1920-2170 MHz) and UMTS 2100 (1920-2170 MHz). Moreover, all the four MIMO antennas cover WLAN 802.11 b/g/n (2.40-2.48 GHz).

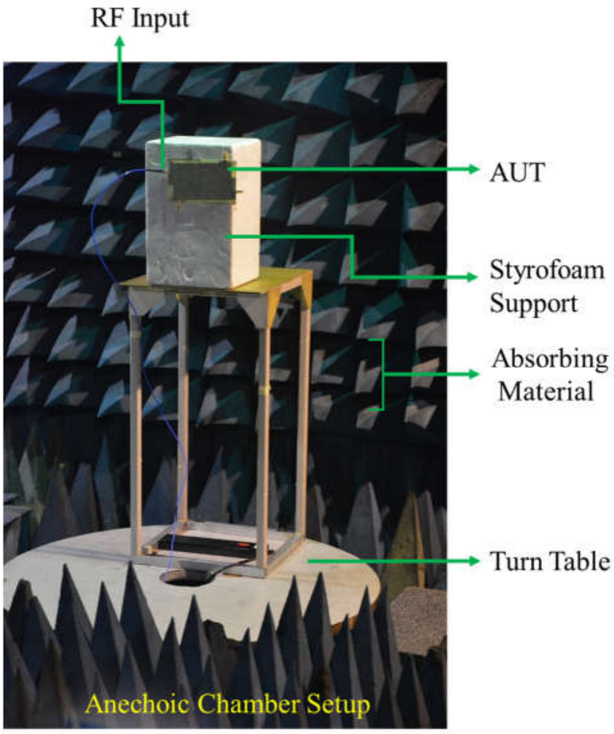


Fig. 5. Measurement Setup

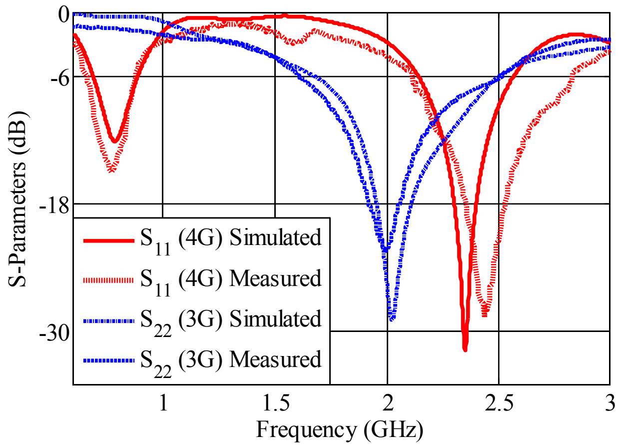


Fig. 6. Scattering parameters of the proposed cellular antennas

The measured isolation performance of the MIMO antennas is better than 15dB overall the frequency bandwidths accommodated by the antennas. The minimum value of isolation between different antennas is shown in Tab. I. The s-parameters obtained while simulation agree with those obtained from measurements however, some minor differences have occurred due to the tolerances in the substrate properties and the fabrication imperfections.

Table I. Isolation between the proposed MIMO antennas in the frequency range of 0.65 – 3.0 GHz.

S-Parameters	**Isolation (dB)**	
	Simulated	**Measured**
S_{21} / S_{12}	> 14	> 16
S_{31} / S_{13}	> 19	> 20
S_{41} / S_{14}	> 13	> 15
S_{23} / S_{32}	> 13	> 15
S_{24} / S_{42}	> 19	> 23
S_{34} / S_{43}	> 19	> 22

B. Realized Gain and Total Efficiency:

The realized gain and total efficiency values of the MIMO antennas at selected frequencies (i.e. at 0.79, 2.35 and 2.00 GHz) are highlighted in Tab. II. The measured gain is calculated using the Gain comparison method [21], whereas, for the measurement of the efficiency wheeler cap method is used [22]. The simulated and measured gain and efficiency values agree well. The total efficiency of the radiating elements largely depends on the return loss. The efficiency values at lower frequency bandwidth are smaller than the values at upper frequencies. This is due to the poorer return loss values at frequency bands below 1 GHz as compared to the frequency bands above 1.7 GHz.

Table II. The simulated (Sim) and the measured (Mea) Gain and Efficiency values for the MIMO antennas.

Freq. (GHz)	**Gain (dBi)**		**Efficiency %)**	
	SIM	**MEA**	**SIM**	**MEA**
0.79 - 4G	1.04	0.79	63	51
2.35 - 4G	3.63	2.89	89	77
2.00 - 3G	4.22	3.53	92	81

5. Conclusion

Four antennas for compact mobile tablets are presented as MIMO in this paper. The antennas are etched in pairs in the form of meandered monopoles. Two antennas make a MIMO pair for 3G cellular coverage whereas, the other two antennas make a MIMO pair for 4G-LTE coverage. The antennas cover most of the commercially available 3G and 4G cellular frequencies and WLAN. The antennas are placed in diagonal symmetry with the MIMO pairs being placed in the orthogonal configuration for achieving a better isolation performance. The isolation achieved is better than 15 dB. The results of the simulations agree well with the measurement results thus making the proposed cellular antennas a good candidate for the next generation handheld terminals. The antennas are compact and printed which make them suitable for the modern mobile tablets.

6. References

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