Orthogonally Polarized MIMO LTE/5G Terminal Antennas for Handsets and IoT Applications

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***Abstract* — A broadband resonant terminal antenna has been developed for handsets and IoT applications. It can cover the whole LTE band (0.7-3.8GHz), or the 5G Sub-6GHz band (3.3-7GHz) without using any matching/tuning circuits. It is covered with a thin dielectric layer to reduce its length. The new antenna does not depend on the ground plane of the terminal. It is manufactured from a thin flexible material that can be folded around the narrow sides of the terminal. This allows putting two antennas on two perpendicular sides of the handset with a high isolation between them because of the polarization diversity.**

***Index Terms* — *Antennas*, mobile antennas, omnidirectional antennas, slot antennas, ultra wideband antennas.**

I. Introduction

Multiple input multiple output (MIMO) is a technology that promises a high data rate, increased channel capacity and coverage without the need of having additional channel bandwidth. However, this technology is not very successful on mobile handsets yet due to the complications in decoupling between MIMO antennas that appear when dealing with a small volume of the mobile handset. In addition, wireless terminals are getting more and more compact with a capability to support multiple cellular voice and data communication services. It is, therefore, necessary to develop new MIMO antennas for small wireless terminals to support voice and data communications over a high data rate. Several designs of MIMO antennas presenting different decoupling mechanisms for mobile handsets have been proposed recently. However, the used decoupling techniques in handsets have limited frequency bands and most of them only work at frequencies above 1800MHz [1]-[2].

In this paper, a broadband resonant antenna has been developed for terminal devices. The new antenna covers the whole LTE band (0.7-3.8GHz) or the 5G Sub-6GHz band (3.3-7GHz) for handsets and IoT applications without using any matching/tuning circuits. Matching circuits are frequency dependent and, therefore, they reduce the bandwidth. The losses in matching circuits significantly reduce the efficiency, which also results in reducing the mobile battery lifetime. The new antenna is self-contained and does not require an extended ground plane. So, it does not need to use the ground plane of the handset. It has a thin narrow size and it is manufactured from a flexible material that can be bent and/or folded around itself and/or around any part of the frame of the handset including the narrow sides of its chassis. This allows putting two of these antennas on two perpendicular sides of the handset, or on the back, with a high isolation between them because of the polarization diversity. So, one of these two antennas can be used as a primary antenna while the other one can be used as a MIMO antenna. This MIMO antenna configuration covers the LTE band (0.7-3.8GHz) or the 5G Sub-6GHz band (3.3-7GHz) with a polarization diversity over the whole band. This provides the maximum isolation and minimum correlation coefficient between the primary and the diversity antenna.

II. A Single Antenna Covers The Whole LTE/Sub-6GHz Band

A broadband antenna technology was developed before by the authors of this paper where two antennas were used together to cover the whole LTE band (0.7-3.8GHz) [3]. The first antenna covers the lower part of the LTE band (0.7-1.5GHz), while the second antenna covers the upper part of the band (1.7-3.8GHz). However, one of the challenging problems in this dual antenna configuration is the isolation between the two primary antennas and their corresponding MIMO antennas. With the limited sizes of mobile handsets, one of the best techniques to increase the isolation between the primary and MIMO antennas is the polarization diversity. However, covering the required frequency band by a dual antenna configuration results in using a total of four antennas for the primary and MIMO coverage. Therefore, it is not possible to get a good polarization diversity between all of them. The optimum solution for this problem is to be able to cover the whole LTE/Sub-6GHz frequency band with a single resonant antenna, which is successfully achieved in this project.

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Actually, this process was tried before as shown in reference [4]. However, this trial had some drawbacks, especially the length of the antenna. The length of the LTE antenna was about 16 cm, which is not suitable for the proposed MIMO configuration with a polarization diversity. Different techniques have been tried to solve this problem. In this paper, the most successful solution is presented, where the antenna is completely covered with a very thin layer of a dielectric material. Different dielectric materials with different thicknesses are tried and optimized with all the other design parameters where the length of the LTE antenna is reduced from 16 to 10 cm. Moreover, the length of the LTE antenna can be further reduced by folding the antenna along its length.

The new antenna consists of three arms, two of them are directly fed while the third arm is fed by coupling as shown in Fig. 1. The performance of the new antenna is numerically analyzed with the moment method using IE3D software from Zeland. A sample configuration of the new LTE single-antenna technology is selected, optimized, manufactured and tested. The reflection coefficient is measured using a vector network analyzer while the efficiency and the radiation patterns are measured using a Satimo Compact Range [5]. The detailed dimensions of the new LTE antenna are shown in Table. 1. The thickness of the used dielectric cover is 0.02cm with a dielectric constant 4.4 (FR4). So, the overall length of the selected LTE antenna configuration is 10.04cm. The overall width of the antenna is 0.34cm and its overall thickness is 0.34cm. Thus, the new LTE antenna has an overall volume of 0.34x0.34x10.04 = 1.16cm^3. This is the total volume of the antenna because it does not require any additional ground planes or matching circuits. Furthermore, the new antenna can be bent by 90°, 180°, or by any other angle in any direction. It should be noted that bending the antenna does not have any significant effect on its performance.

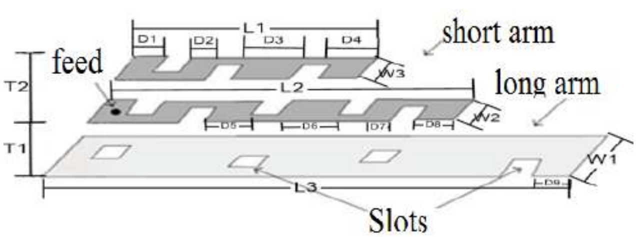

Fig. 1. Geometry of the new antenna

TABLE I

THE DIMENSIONS OF THE NEW ANTENNA (all in cm)

D1	D2	D3	D4	D5	D6	D7	D8	D9
0.3	0.25	0.5	0.5	1.3	2.1	2.1	0.3	0.3
W1	W2	W3	L1	L2	L3	T1	T2	
0.3	0.3	0.3	3.2	7.1	10	0.2	0.1	

The measured reflection coefficient of the new LTE antenna is shown in Fig. 2. It is better than -6 dB over the whole LTE band (0.7-3.8GHz). On the other hand, Fig. 3 shows the measured reflection coefficient of the new antenna while it is mounted on a mobile handset and handheld next to the human head. It is clear that the human body has a negligible effect on the new LTE antenna.

The measured efficiency of the new antenna is shown in Fig. 4 as a function of frequency. The minimum efficiency is 40%, which only happens at very few frequencies. The efficiency exceeds 90% at some other frequencies. The radiation pattern around the axis of the new antenna is presented in Fig. 5 at 800MHz as a sample frequency.

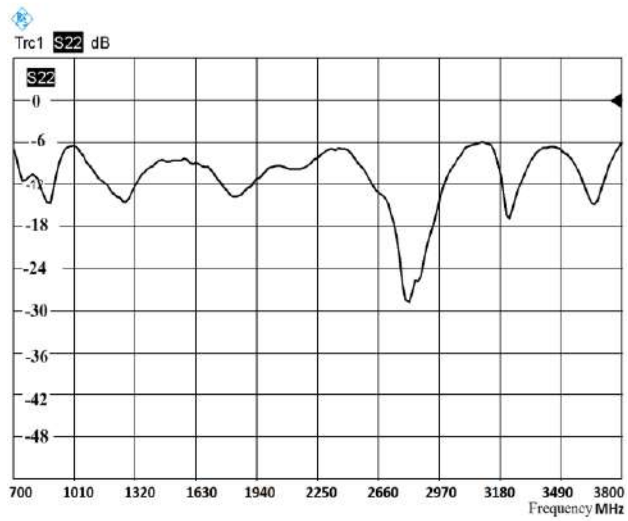

Fig. 2. Reflection coefficient of the new LTE antenna

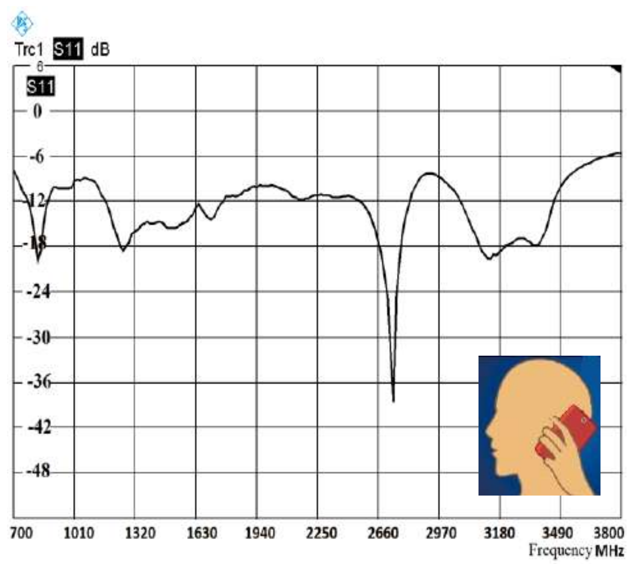

Fig. 3. Reflection coefficient of the new LTE antenna while it is handheld next to the human head

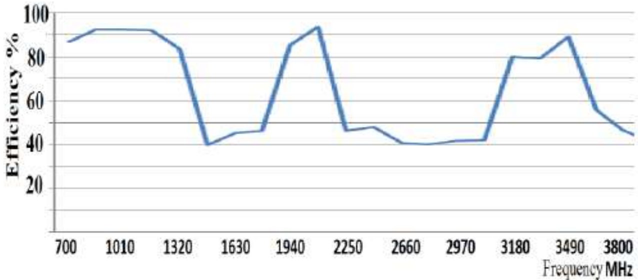

Fig. 4. Efficiency of the new LTE antenna

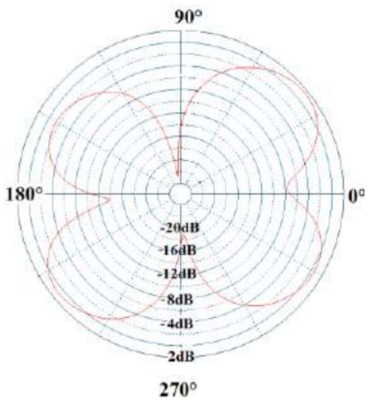

Fig.5. The radiation pattern of the new LTE antenna at 800MHz

The dimensions of the above configuration of the new LTE antenna are scaled down such that the antenna resonates at the Sub-6GHz band of 5G (3.3-7GHz). The scaled antenna has an overall volume of 0.16x0.16x3.2 = $0.082cm^3$. The reflection coefficient of the scaled antenna is better than -7 dB over the whole frequency band, which is slightly better than that of the LTE antenna. This is because the bandwidth of the 5G sub-6GHz band is less than that of the LTE band. This also results in a higher efficiency, which is better than 75% over the whole band of the 5G Sub-6GHz antenna (3.3-7GHz). Moreover, the reflection coefficient can be further improved by slightly increasing the width and the thickness of the 5G Sub-6GHz antenna to make it, physically, equal to those of the above LTE antenna. Hence, the increased size 5G sub-6GHz antenna has an overall volume of 0.3x0.3x3.2 = $0.288cm^3$. However, it should be noted that in terms of wavelengths, the increased width and thickness of the 5G Sub-6GHz antenna are larger than those of the LTE antenna. The reflection coefficient of the increased size 5G Sub-6GHz antenna is better than -10 dB over the whole frequency band (3.3-7.0GHz) as shown in Fig. 6. On the other hand, Fig. 7 shows the measured reflection coefficient of the 5G Sub-6GHz antenna while it is mounted on a mobile handset and handheld next to the human head. The human body still has a negligible effect on the new 5G Sub-6GHz terminal antenna.

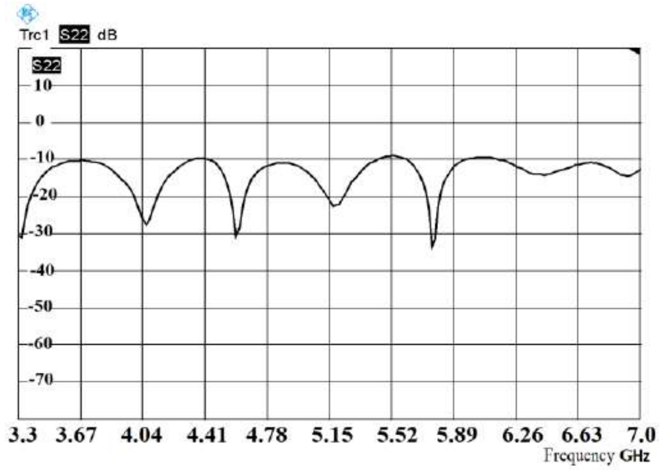

Fig. 6. Reflection coefficient of the 5G Sub-6GHz antenna

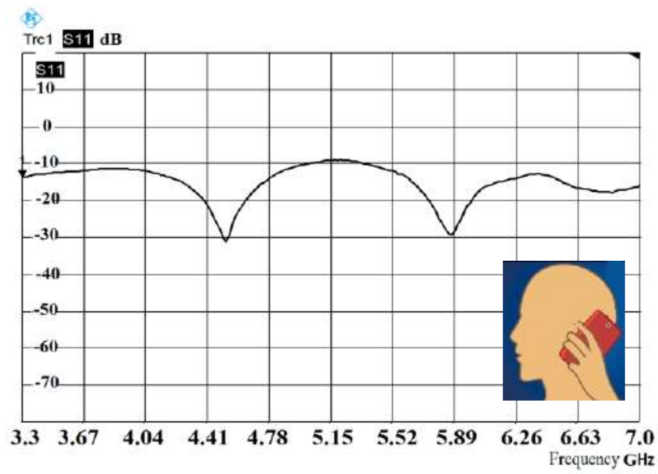

Fig. 7. Reflection coefficient of the 5G Sub-6GHz antenna while it is handheld next to the human head

III. A DISTINGUISHED MIMO CONFIGURATION

As explained above, the new antenna is thin, narrow, and manufactured from a flexible material that can be bent and/or folded around the narrow sides of the handset. Hence, two perpendicular antennas can be mounted on the sides or on the back of the handset (Fig. 8) with a high isolation between them because of the polarization diversity. So, one of them can be used as a primary antenna while the other one can be used as a MIMO antenna. The isolation between the LTE antennas is shown in Fig. 9. As shown in the figure, the isolation is always better than 20dB. This MIMO antenna configuration is very distinguished since it covers the whole LTE band (0.7-3.8GHz) with a polarization diversity over the whole band. It provides the maximum isolation and minimum correlation coefficient between the MIMO antennas over the whole LTE band. Similar results are obtained for the isolation between two perpendicular 5G Sub-6GHz antennas as shown in Fig. 10.

Fig. 8. Different configurations of MIMO antennas with a polarization diversity

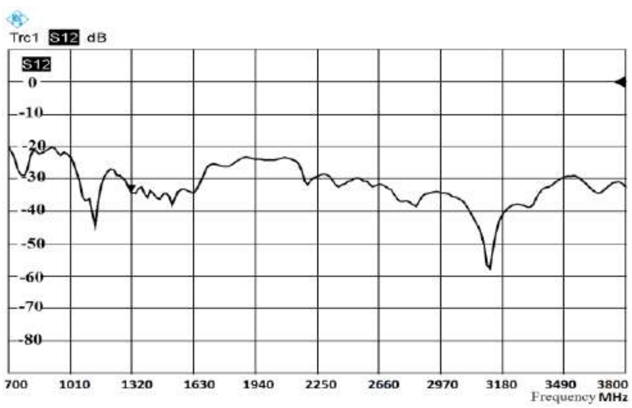

Fig. 9. The isolation between the LTE MIMO antennas

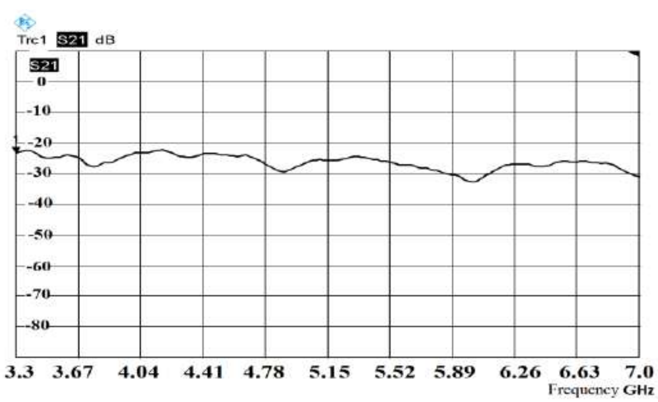

Fig. 10. The isolation between the 5G Sub-6GHz MIMO antennas

IV. Conclusion

A new broadband antenna has been developed for mobile handsets and IoT applications. A single resonant antenna could cover the whole LTE spectrum (0.7-3.8GHz) or the whole 5G Sub-6 GHz spectrum (3.3-7GHz) without using any matching/tuning circuits. The antenna was covered by a thin layer of dielectric material to reduce its length. The new antenna did not require an extended ground plane. So, it could be mounted anywhere on the handset. It had a thin and narrow size and it was manufactured from a flexible material that could be folded around the narrow sides of the chassis. The length of the antenna could also be further reduced by folding the antenna along its length. All that allowed putting two of these antennas on two perpendicular sides of the handset frame with a very high isolation between them because of the polarization diversity. So, one of these two antennas could be used as a primary antenna while the other one was used as a MIMO antenna. This MIMO antenna configuration was very distinguished since it covered the whole LTE band (0.7-3.8GHz) or the whole 5G sub-6 GHz band (3.3-7GHz) with a polarization diversity over the whole band. This provided the maximum isolation and minimum correlation coefficient between the primary and the diversity antennas.

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