Spiral-shaped High Isolated Monopole MIMO/Diversity Antenna for Small Mobile Terminals

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Abstract

In this paper a spiral-shaped monopole like MIMO/Diversity antenna is proposed for mobile handsets. The proposed MIMO antenna covers the frequency bands LTE700 (777-787), GPS-L1 (1565-1595), and WLAN (2400-2480). The isolation between ports is below -20dB for LTE, -21dB for GPS-L1, and -18 dB for WLAN band respectively. The isolation between ports is achieved through DGS (Defected Ground Structure) and it is design by double rectangular ring shaped slot structure. The envelope correlation coefficient (ECC) is below 0.05 and diversity gain is almost 10 for all three bands, which meets the good diversity performances. The proposed antenna is characterized by the *S*-parameters, surface current distribution, diversity performances, and radiation patterns.

Keywords: Multiple-input multiple-output, defected ground structure, GPS L1, ECC, diversity gain.

1. Introduction

The use of multiple antennas to provide antenna diversity over a point-to-point wireless link has been studied extensively since the early 1960s. It is still a popular research topic for improving energy efficiency through the use of both transmits and receives diversity. Antenna diversity is a well-known technique to enhance the performance of wireless communication systems by reducing the multipath fading and distortion of the channel [1]. Multiple-input and multiple-output (MIMO) communication systems have received much attention as a diversity scheme in wireless mobile communication. They can substantially increase the wireless channel capacity in scattering environments without the need for additional power [2-6].

The Long-Term Evolution (LTE) service [7] can provide a better mobile communication quality than the existing GSM and UMTS services, mobile devices are desired to be able to cover the existing service bands and LTE bands at the same time. Some diversity antenna has been demonstrated for mobile terminals to cover the wireless frequency bands LTE/PCS1900/WLAN/GPS with high isolation between ports [8-10]. To realize an effective MIMO system, it is necessary to have a sufficient number of uncorrelated antennas at each end of the link. However, it is usually a big challenge to place multiple antennas within a small and slim mobile handset while maintaining good isolation between the antenna elements, because the antennas are strongly coupled with each other and even with the ground plane, they share the surface currents distributed on the ground plane.

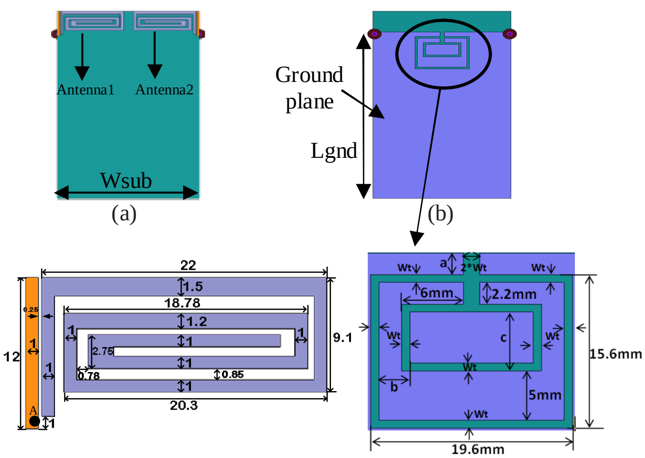
The printed monopole antennas are widely used in the MIMO communication systems for their advantages of low cost, easy fabrication, and good performance. To obtain the predicted high signal capacity, the mutual coupling between the antennas in the MIMO communication systems should be low enough, and the high isolation makes uncorrelated signals among the antennas [11]. Usually, low coupling can be obtained by separating the antennas at a distance of half a wavelength or more, but this is impractical in the mobile terminals, so a lot of methods have been studied to reduce the mutual coupling between the closely spaced monopole antennas [12-15]. Most of them used parasitic element , neutralization line, and decoupling techniques for isolation improvement, which are occupied more space on mobile circuit board. So to avoid this limitation here we use DGS for isolation improvement.

Here, we present the compact spiral-shaped monopole MIMO/Diversity antenna with high isolation between its ports for mobile handsets. The proposed antenna is formed by a coupled-fed spiral-shaped loop antenna. The antenna is design corresponding to λ/4 at lower resonating frequency 780 MHz. The total electrical length is λ/4, where λ is wavelength at lower resonating frequency. The proposed antenna are tri-band to cover the frequency band LTE700 (777-787), GPS L1 (1565-1595), and WLAN (2400-2480) with high isolation (<-20 dB) for all three desired band of operations. The isolation between its ports is achieved through DGS. It is created between two MIMO antenna elements on the ground plane, which plays a significant role in providing the high isolation by preventing the current flows on the ground plane to reach the other antenna. The envelope correlation coefficient is well below 0.05.

2. Configuration of Antenna

Figs. 1(a) and (b) shows the front and back view of the proposed on-board small size tri-band MIMO antenna for the LTE700/GPS L1/WLAN bands operation in the mobile phone. Detailed dimensions of the proposed antenna are shown in Fig. 1(c) all the dimensions in mm. Owing to the small size, the MIMO antenna is disposed on two corners only, without occupying the entire edge, of the system circuit board. These two radiating elements, which are placed at corner of circuit board regarded as Antenna1 and Antenna 2. In the study, a 0.8-mm thick FR4 substrate of relative permittivity 4.4 and loss tangent 0.024 is used as the system circuit board. The proposed monopole is printed on the no-ground portion of size 10 x 50 mm^2 on the main circuit board of the mobile phone, and the system ground plane of size 80(Lgnd) x 50 (Wsub) mm^2 is printed on the back side of the circuit board.

The antenna is mainly composed of a driven monopole and a coupled fed spiral shaped resonating strip. The driven monopole (printed on FR4) is of an I-shape, and its feeding point (point A) is connected to a 50Ω SMA (Sub Miniature version A). The driven monopole alone (that is, the coupled spiral strip is not present) can support a resonant path of about 12 mm, thus providing a quarter- wavelength resonant mode at about 6.5 GHz that is not concentrating part of our design. When the spiral-shaped monopole is couple fed with driven monopole, so the lower resonating mode is being appeared in surface current distribution plot as shown in Fig. 2(a) at frequency 780MHz. At the same time monopole antenna produces higher order modes which is responsible for GPS L1 and WLAN frequency band as shown in surface current distribution plot Fig. 2(b) and Fig. 2(c) respectively. The isolation between monopole MIMO antennas is achieved through DGS, which is design with double rectangular ring shaped slot on system ground plane as shown in Fig. 1d. Which play significant role to preventing ground surface current between MIMO antennas ports. The optimized parameters for antenna element are given in Fig 1(c).



(c) (d)

Fig.1(a)Front view (b) Back view (c) Details of single antenna element (d) Details of DGS, where **Wt**=0.8mm, **a**=3mm, **b**=3mm, c=6mm.

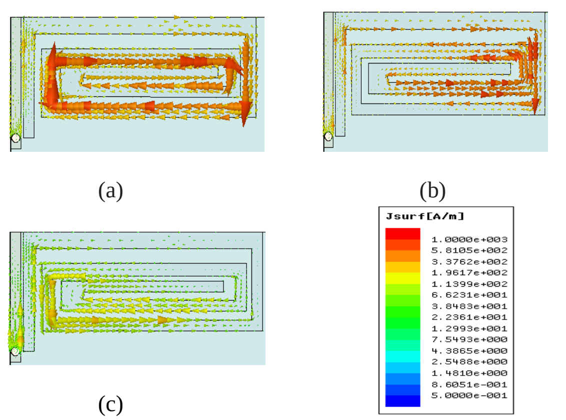


Fig. 2 Surface current distribution at (a) 780MHz, (b) 1575MHZ, and (c) 2450MHz.

3. Results and Discussion

The optimized *S*-parameters for proposed MIMO/Diversity antenna system are shown in Fig. 3. It is observed that the impedance bandwidth ($|S_{11}| < -6$ dB) can cover the LTE band 13 from 777-795 MHz, GPS L1 from 1565-1595MHz, and WLAN from 2.4-2.48 GHz and an isolation between its ports is below -20dB for LTE700 and GPS L1,-18dB for WLAN band.

3.1. *Parametric Study*

The parametric investigations have been done for optimization of the shape parameters of antenna. All the simulations have been done on HFSS (High Frequency Structure Simulation) software [16].

Fig. 4 shows the effect of rectangular ring shaped slot on ground plane. It is clear from plot without DGS the isolation between ports is -20dB for LTE700, -10dB for GPS L1, and -6dB for WLAN band. When we defect the ground plane with single rectangular ring shaped slot, the isolation improved at WLAN band only while isolation at other two bands remain same. But when the ground is defected with double rectangular ring shaped slot (proposed structure) then we found the isolation below -18dB for the all three band.

In Fig. 5, the effect of parameter **a** which is position of outer ring slot from end of the ground. It is observed that when the position are shifted down word then isolation decreases at WLAN band whereas the isolation for GPS L1 improve. The optimized position of outer ring from end of the ground plane is 3mm at which we found better isolation for entire bands of operation.

From Fig. 6, it has been observed that when thickness (**Wt**) of slots on ground plane increases then isolation between ports is increases but after a certain value it start decreasing. The optimized value of thickness of the slots is 0.8mm for this value we found high isolation between it ports.

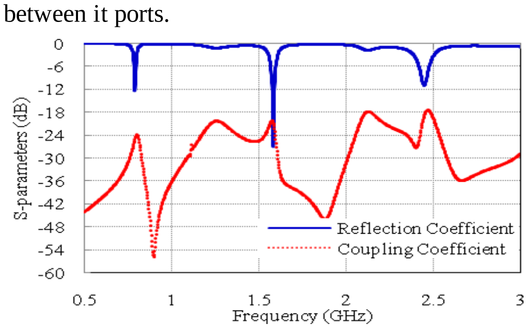


Fig. 3 Optimized *S*-parameters for proposed Antenna.

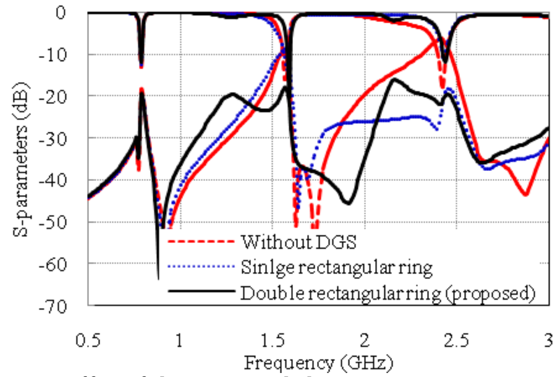


Fig. 4 Effect of slots on ground plane.

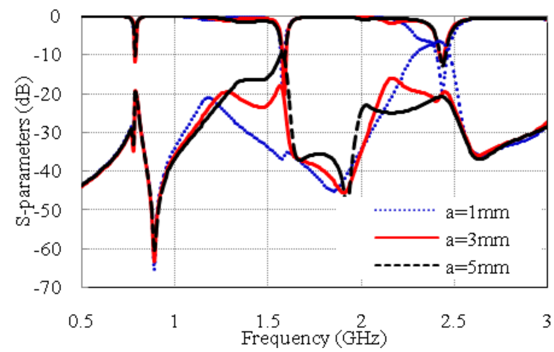


Fig. 5 Effect of parameter **a** on *S*-parameters.

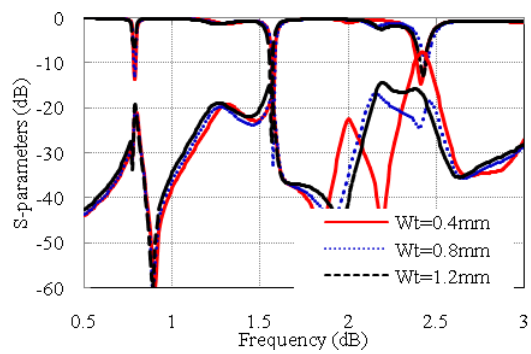


Fig. 6 Effect of slots thickness **Wt** on *S*-parameters.

3.2. *Diversity Parameters*

3.2.1 *Envelope Correlation Coefficient (ECC)*

We can calculate the correlation coefficient by using far-field pattern data [17] and the *S*–parameters [18-20] but the calculation of ECC is time consuming with the help of far field data because this involve integral equations, which are experimentally and numerically time-consuming. To make easier calculation of ECC we use *S*-parameters formula which has been derived in [18-20], i.e.

$$\rho_e = \frac{\left|S_{11}^* S_{12} + S_{22} S_{21}^*\right|^2}{\left(1 - \left|S_{11}^2 + S_{21}^2\right|\right)\left(1 - \left|S_{22}^2 + S_{12}^2\right|\right)} \quad (1)$$

Fig. 8 shows the simulated ECC versus frequency when using above equation. The simulated values of the ECC is below 0.05 which meets good diversity performances.

3.2.2 *Diversity Gain*

We will look at the relation between the correlation coefficient ρ_e and the apparent diversity gain G_{app} of a two-antenna system. The following approximate formula applies [20].

$$G_{app} = 10 * \rho_p \text{ with } \rho_p = \sqrt{1 - \left|\rho_e\right|^2} \quad (2)$$

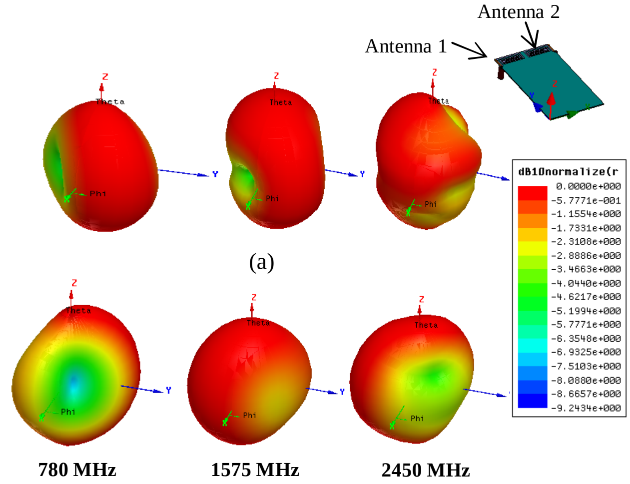
where 10 is the maximum apparent diversity gain at the 1% probability level with selection combining, and ρ_p is an approximate expression for the correlation efficiency, i.e. the reduction in diversity gain due to correlation between the signals on the two branches. This formula is not very accurate for correlations as it is close to unity when compared with the more accurate formulas in [21]. However, if we scale ρ_p with a factor 0.99, the formula becomes

$$\rho_p = \sqrt{1 - \left|0.99 * \rho_e\right|^2} \quad (3)$$

which differs from the more accurate expression for the apparent diversity gain at the 1% probability level by <0.1 dB. The envelope correlation coefficient, and diversity gain at 1% of the probability level by <0.1 dB are listed in Table 1. The calculated result in Table 1 satisfy the criteria of low correlation (ρ_e<0.5) , and good diversity performance can be expected in practical multipath environments.

3.3. *Radiation Patterns*

The radiation patterns of the proposed MIMO antenna system are simulated (HFSS) at 780MHz, 1575MHz, and 2450MHz. During the simulation only one antenna is excited whereas other antenna is matched terminated with 50-Ω load. The simulated patterns at three resonating frequency are given in Fig. 9. From the 3D radiation pattern, it has been observed that the radiation patterns not only complimentary space region but also have omnidirectional pattern. Due to complimentary space pattern, the proposed monopole MIMO antenna shows pattern diversity characteristics.



(b)

Fig. 9 3D Radiation pattern (a) Antenn1 excited (b) Antenna 2 excited.

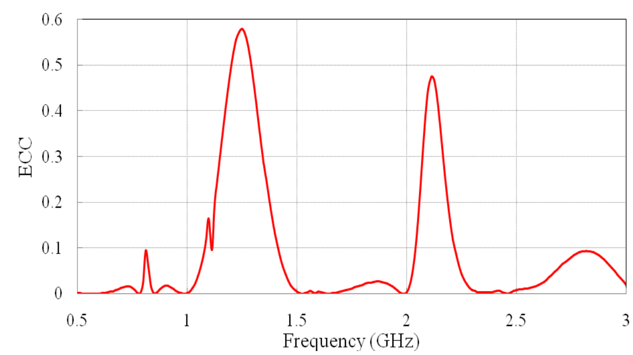


Fig. 8 Variation of ECC with frequency.

Table 1 Diversity performances of MIMO antenna.

Frequency (GHz)	Envelope Correlation Coefficient (ECC)	Diversity Gain (1%) (dB)
780	0.0008	9.999996
1575	0.002	9.999979
2450	0.0007	9.999846

4. Conclusion

A spiral shaped monopole antenna is proposed with high isolation. The proposed antenna covers the frequency band with reference to -6dB return loss LTE700 (777-787MHz), GPS L1 (1565-1600MHz), and WLAN (2.4-2.40GHz). The isolation between ports is below -20dB for LTE and GPS L1, while isolation for

WLAN band is below -18dB. The envelope correlation coefficient for proposed antenna is below 0.05 and diversity gain is almost 10 which meets the good diversity performances. The pattern of proposed MIMO antenna follow pattern diversity.

References

1. R. G. Vaughan and J. B. Andersen, Antenna Diversity in Mobile Communications, *IEEE Trans. Veh. Tech., vol. VT-36*, no. 4, (Nov. 1987), (149–172).
2. M. Karaboikis, C. Soras, G. Tsachtsiris, and V. Makios, Compact Dual-Printed Inverted-F Antenna Diversity systems for portable wireless devices, *IEEE Antennas Propag. Lett.*, vol. 3, (2004),(9–14).
3. Y. Ding, Z. Du, K. Gong, and Z. Feng, A Novel Dual-Band Printed Diversity Antenna for Mobile Terminals," *IEEE Trans. Antennas Propag.*, vol. 55, no. 7, (Jul. 2007), (2088–2096).
4. R. D. Murch and K. B. Letaief, Antenna Systems for Broadband Wireless Access," *IEEE Commun. Mag.*, vol. 40, no. 4, (Apr. 2002), (76–83).
5. G. J. Foschini, Layered Space-Time Architecture for Wireless Communication in a Fading Environment When Using Multi-element Antennas," *Bell Labs Tech. J.*, vol. 1, no. 2, (1996),(41–59).
6. J. Wallace, M. Jensen, A. Swindlehurst, and B. Jeffs, Experimental Characterization of the MIMO Wireless Channel: Data Acquisition and Analysis," *IEEE Trans. Wireless Commun.*, vol. 2, no. 2, (Mar. 2003), (335–343).
7. S. Sesia, I. Toufik, and M. Baker, LTE, The UMTS Long Term Evolution: From Theory to Practice, (Eds.. New York: Wiley), (2009).
8. M. K. Meshram, R. K. Animeh, A. T. Pimpale, and N. K. Nikolova, A Novel Quad-band Diversity Antenna for LTE and Wi-Fi Applications with High Isolation, *IEEE Trans. Antennas Propag.*, Vol. 60, no. 9, (Sep. 2012), (4360-4371,).
9. X. Zhou, X. L. Quan, and RongLin Li, A Dual-Broadband MIMO Antenna System for GSM/UMTS/LTE and WLAN Handsets, *IEEE Antennas Wireless Propag.*, Vol. 11, (May. 2012),(551-554).
10. H. S Singh, P. K. Bharti, G. K. Pandey, and M. K. Meshram, A Compact Tri-Band MIMO/Diversity Antenna for Mobile Handsets, (*IEEE CONECCT-2013, Banglore)*, (Jan. 2013), (1-6).
11. T. Svantesson and A. Ranheim, Mutual Coupling Effects on the Capacity of Multielement Antenna Systems," in *Proceedings of the IEEE Interntional Conference on Acoustics, Speech, and Signal Processing (ICASSP '01)*, (May 2001), (2485–2488).
12. X. M. Ling and R. Lin Li, A Novel Dual-Band MIMO Antenna ArrayWith Low Mutual Coupling for Portable Wireless Devices , *IEEE Antennas Wireless Propag. Lett*, Vol. 10, (2011), (1039-1042).
13. S. Cui, Y. Liu, W. Jiang and S.X. Gong, Compact Dual-Band Monopole Antennas with High Port Isolation," *Electronics Lett.* Vol. 47, No.10, (May 2011).
14. Q. Luo, J.R. Pereira and H.M. Salgado, Reconfigurable Dual-band C-shaped Monopole Antenna Array with High Isolation, *Electronics Lett.* Vol. 46, No.13, (May 2010).
15. Z. Li, Z. Du, M. Takahashi, K. Saito, and Koichi Ito, Reducing Mutual Coupling of MIMO Antennas With Parasitic Elements for Mobile Terminals, *IEEE Trans. Antennas Propag*., Vol. 60, no. 2, (Feb. 2012), (473-481).
16. Ansoft Corporation. [Online] Available: http://www.ansoft.com.
17. T. Taga, Analysis for Mean Effective Gain of Mobile Antennas in Land Mobile Radio Environments, *IEEE Trans. Veh. Technol.*, vol. 39, no. 2, (May 1990), (117–131).
18. S. Stein, On Cross Coupling in Multiple-beam Antennas, *IRE Trans. Antennas Propag.*, vol. 10, no. 5, (Sep. 1962), (pp. 548–557).
19. I. Salonen and P. Vainikainen, Estimation of Signal Correlation in Antenna Arrays," in *Proc. JINA, Nice*, (France, Nov. 2002), vol. 2, (383-386).
20. C. Blanch, J. Romeu, and I. Corbella, Exact Representation of Antenna System Diversity Performance from Input Parameter Description, *Electron. Lett.*, vol. 39, no. 9, (May 2003), (705–707).
21. M. Schwartz, W. R. Bennett, and S. Stein, Communication System and Techniques, (McGraw-Hill, New York, 1965), (470-474).