Full Band MIMO Monopole Antenna for LTE Systems

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***Abstract*─** A novel printed planar monopole antenna for LTE multi-input and multi-output (MIMO) application is proposed. By adding six ellipticals on top of the antenna, we enhance the lower frequency bandwidth. The idea for this is gotten from [1, 2]. These papers designed by using log periodic technique with the number of rectangle and flare elements . Also, by cutting E-shaped slots in the ground plane, additional resonance is excited, and hence much wider impedance bandwidth can be produced. The proposed antenna provides all of the LTE bands between 0.65 GHz to 4 GHz. In order to provide low mutual coupling and envelope correlation, two of the antennas are combined with orthogonal polarizations. The mutual coupling and envelope correlation coefficient (ECC) of the antenna are lower than -21 dB and 0.002 across the operation bands, and total active reflection coefficient (TARC) is less than 0.35. The designed antenna has small size area of 55 × 94 mm^2, which has a small size with respect to recently reported antennas.

Index Terms - Long term evolution (LTE), multi-input and multi-output (MIMO), monopole antenna, and mutual coupling.

I. INTRODUCTION

Nowadays, there is an increased interest in research on multi-input and multi-output (MIMO) systems in the wireless communication. This technology is probably the most established to truly reach the promised transfer data rates of 4G communication [3]. To be more precise, the fourth mobile-phone generation is set to be the long term evolution (LTE) and is scheduled to operate in different bands from 400 MHz to 4 GHz [4]. This antenna has the ability to increase the capacity of channel using the spatial properties of multipath. It is necessary to have a number of uncorrelated antennas at each end of the communication link. So it seems to be very essential to design adequate antenna due to use in MIMO systems. As revealed in many literatures [5-12], both of non-printed MIMO antennas such as planar-inverted F antennas (PIFAs) and printed MIMO antennas are proposed. However, among the antennas which are used for MIMO application, printed antennas are more appropriate due to their low cost, easy fabrication, and their capability of easily being integrated to small terminal devices.

A number of planar monopoles to improve the impedance bandwidth have been investigated [13-15]. Moreover, in [15] fractal monopole antenna using the Sierpinski carpet geometry is described that caused to wideband, broadband, and multiband antenna. In this paper a novel multiband

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printed planar monopole antenna for LTE MIMO application is presented. First by adding six ellipticals on top of the antenna, the bandwidth in lower frequency is improved. In the proposed structure, by cutting a pair of E-shaped slots in the ground plane, additional resonance is provided. As a result, the designed antenna covers all of the LTE bands. Two elements of such antennas are used for MIMO applications. The size of the proposed antenna is smaller than the antennas reported recently [5, 6]. The proposed structure obtains low mutual coupling and envelope correlation due to the orthogonal polarization. Also, good return loss and radiation pattern characteristics are obtained in the frequency band of interest. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for LTE systems.

II. ANTENNA DESIGN

The base structure of the proposed MIMO antenna is shown in Fig. 1, which is printed on an FR4 substrate with relative permittivity 4.4 and thickness of 1.6 mm. The monopole is rectangular with width 2 mm and length 54 mm. The antenna is fed by a microstrip line with width 2 mm to match 50 Ω SMA connector for signal transmission. The antenna has two layers, the top layer and the bottom layer. On the top layer there is monopole antenna with 6 elliptical elements. On the bottom layer there are grounds with E-shape slots. The geometrical parameters of ellipticals described in Fig. 2 and Table 1. The two identical antenna elements have the same structures and dimensions. The two antenna elements are spaced with a gap "Gap1".

Figure 1 shows that this kind of monopole antenna covers a little frequency band. However, only the monopole antenna cannot cover more LTE bands. Then 6 ellipticals and E-shaped slots are added. As illustrated in Fig. 2, 6 ellipticals are used to control the impedance bandwidth and return loss level by modifying the capacitance between the patch and ground plane in a lower frequency bandwidth. To further enhance the matching, we use a pair of E-shaped slots in the antenna's ground plane. These slots create an additional path for the surface current, which produce an additional resonance, and as a result, increase the bandwidth. The optimal dimensions of the designed antenna are specified in Fig. 3 and Table 1.

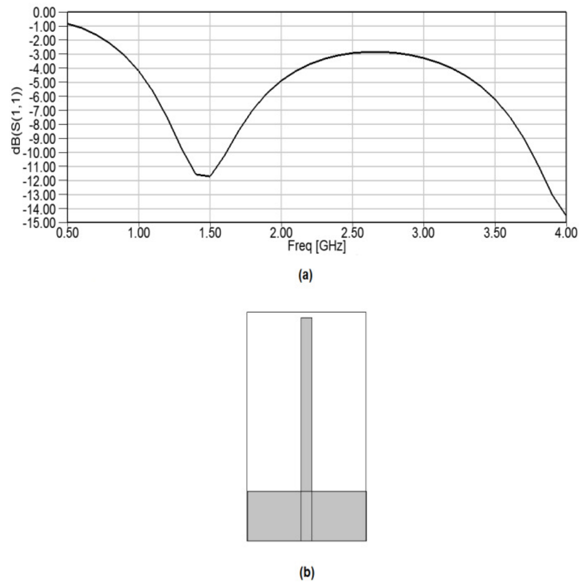


Fig. 1. (a) S(1,1) and (b) the base structure of the antenna.

In addition to the traditional antenna parameters, such as radiation pattern, and reflection coefficients, new parameters and aspects have to be included in the design for MIMO systems. MIMO coupling between antenna elements is a key factor to achieve high antenna performance in the MIMO antenna configuration. For a low mutual coupling, antennas must be far away from each other, but the space for the internal antenna is not enough to obtain low correlation and mutual coupling. In this paper we present a structure for the MIMO antenna elements in which the identical two antenna elements are orthogonally placed. As a result, the two antenna elements have orthogonal polarization, which can reduce the mutual coupling between the two antennas. Figure 4 shows the simulated 3D radiation patterns of the two antenna elements. It can be seen that the two antenna elements have orthogonal polarizations.

III. RESULTS AND DISCUSSION

In this section, the MIMO monopole antenna with various design parameters was constructed, and the experimental results are presented and discussed. The parameters of this proposed antenna are studied by changing one parameter at a time and fixing the others. The simulated results are obtained using the Ansoft simulation software High Frequency Structure Simulator (HFSS) and measured in an anechoic chamber. For understanding well the operation of the proposed MIMO antenna, first we studied a single monopole antenna, because the MIMO structure consists of two identical antenna with orthogonal polarizations. Then we studied the MIMO antenna characteristics.

Tabel 1: The geometrical parameters of the elliptics (cw = clockwise and ccw = counter clock wise).

	Major Radius	Ratio	Center of elliptic	Degree of rotation to x-axis
Ellip-1	**14**	**0.6**	**(20.86,32.43)**	**15(ccw)**
Ellip-2	**14**	**0.6**	**(9.14,32.43)**	**15(cw)**
Ellip-3	**10**	**0.8**	**(8.55,43.62)**	**15(ccw)**
Ellip-4	**10**	**0.8**	**(21.45,43.62)**	**15(cw)**
Ellip-5	**8**	**0.1**	**(26.64,20.52)**	**15(ccw)**
Ellip-6	**8**	**0.1**	**(3.36,20.52)**	**15(cw)**

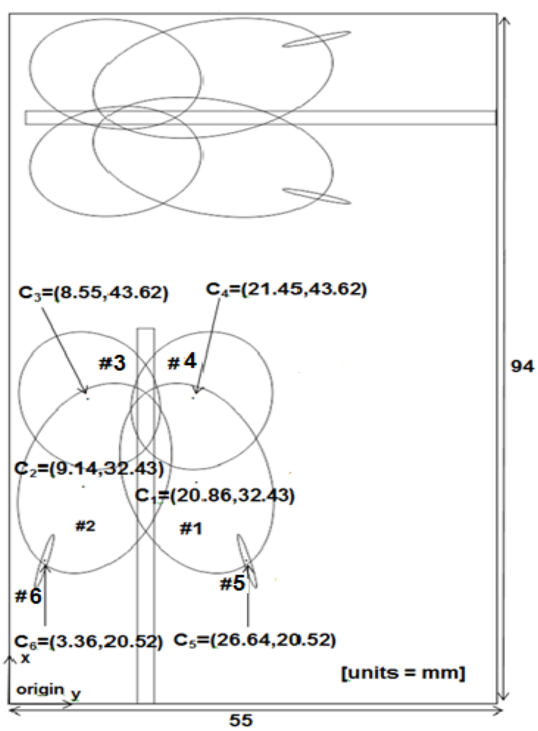


Fig. 2. The top view of the proposed antenna.

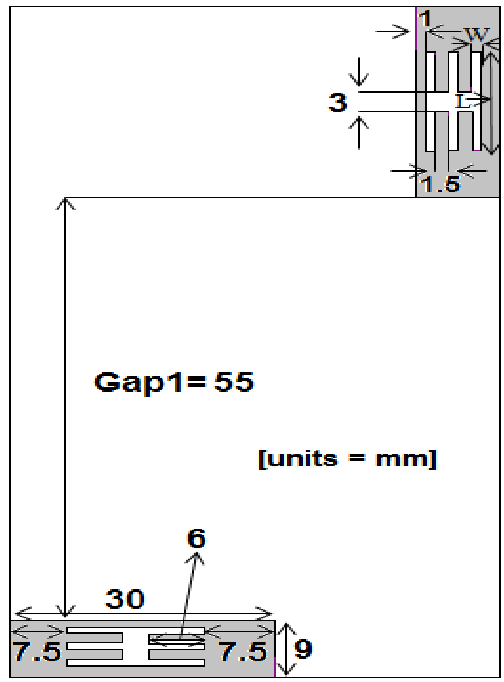
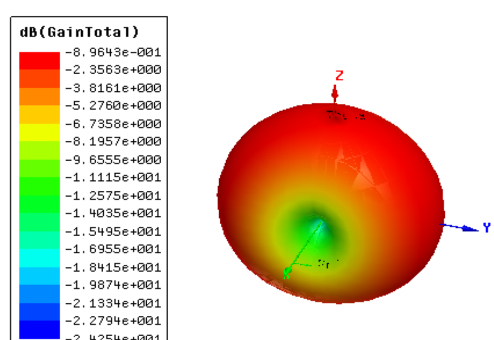


Fig. 3. The bottom view of the proposed antenna.

To design a novel antenna, and also in order to increase the frequency bandwidth, simple monopole is loaded with 6 ellipticals as displayed in Fig. 2. These ellipticals play important role inimpedance matching of this antenna because they can control the electromagnetic coupling effects between the patch and the ground plane and improve the band width. Figure 5 shows the structure of various antennas used for performance simulation studies. Return loss characteristics for simple monopole [Fig. 5 (a)], simple monopole with 2, 4, and 6 ellipticals [Fig. 5 (b)- (c)- (d)], and with two E-shaped slots in the ground plane [Fig. 5 (e)] are compared in Fig. 6. As shown in Fig. 6, in order to generate a new resonance (3.4 GHz), we use a pair of E-shaped slots in the center of the ground plane.



(a)

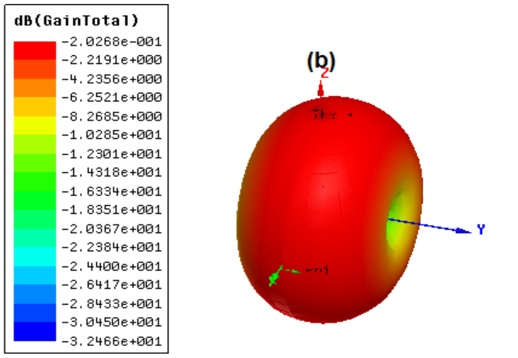


Fig. 4. 3D radiation patterns of two antenna elements.

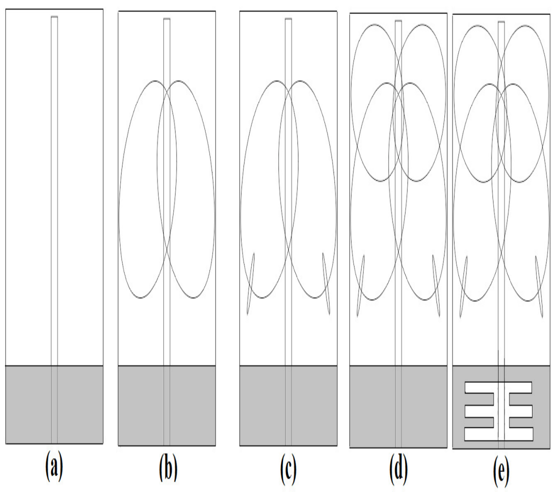


Fig. 5. (a) Basic structure, (b) with 2 elliptics, (c) with 4 elliptics, (d) with 6 elliptics, and (e) with 6 elliptics and E-shaped slots.

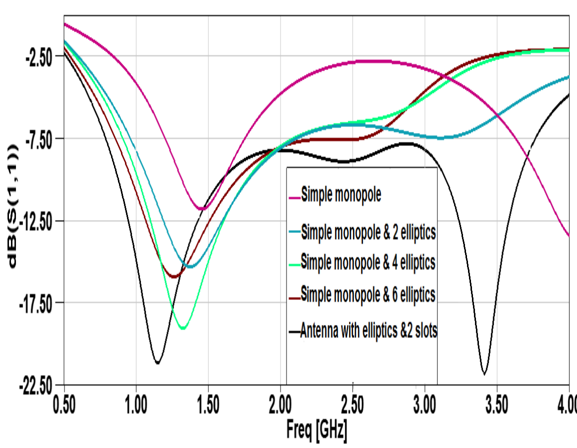


Fig. 6. Simulated return loss for basic structure without and with elliptics and E-shaped slots.

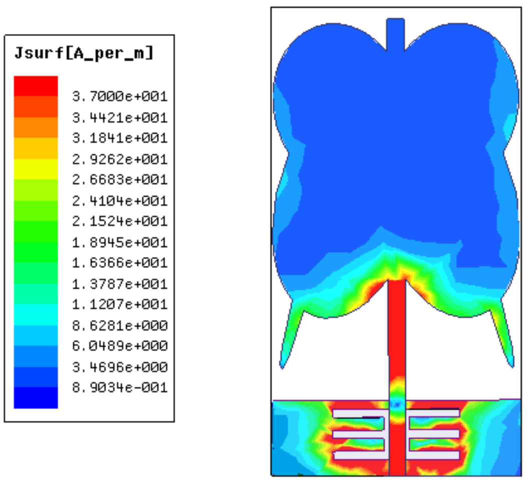
To understand the effects of these slots, the simulated current distribution on the radiating patch and ground plane is presented in Fig. 7 (a). It can be observed from Fig. 7 (a) that the current is concentrated on the edges of the interior and exterior of the E-shaped slots at 3.4 GHz. Therefore, the antenna impedance changes at this frequency due to the resonant properties of the E-shaped slots. Figure 7 (b) shows the effects of L and W on impedance matching and second resonance. After comparison the best case is selected.

A prototype of the proposed MIMO antenna as shown in Fig. 8 was constructed and tested. Figure 9 shows the simulated and measured return loss. The measured -6 dB S(1,1) and S(2,2) are not equal because the structure is not symmetrical. The mutual coupling between the two ports is less than -21 dB across the common bandwidth, as shown in Fig. 9 (c). As shown in Fig. 9, there exists a discrepancy between measured data and simulated results. This could be due to the effect of the SMA port. In order to confirm the accurate return loss characteristics for the designed antenna, it is recommended that the manufacturing and measurement process be performed carefully.

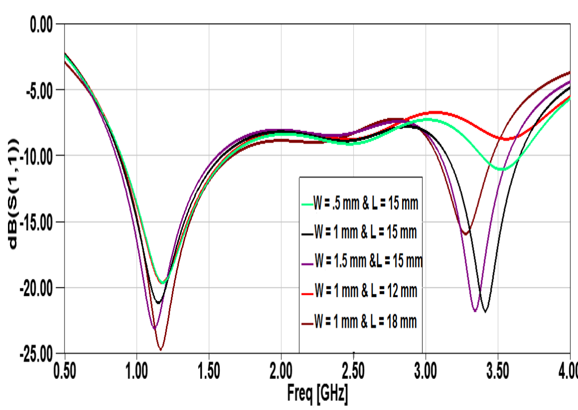
Figures 10 and 11 show the radiation patterns of antennas 1 and 2, respectively. Antenna 1 has an omnidirectional vertically polarized pattern in the x-z plane and antenna 2 generates horizontally polarized in the y-z plane. As shown in Figs. 10 and 11 the omnidirectional properties, particularly at low frequencies are not good. This is mostly due to the small ground plane effects and the change of excited surface current distributions on the system ground plane at low frequencies. The omni-directional patterns can enhance and increase the channel capacity [9]. In general, when two linearly polarized antenna are orthogonally located to each other, they can provide polarization diversity by reducing the mutual coupling between them. Therefore, these orthogonal radiation patterns and high isolation (> 21 dB) give the lower ECC (< 0.002), which is less than a recommended value [9] of 0.5, as shown in Fig. 12. The ECC is obtained by using the far field radiation patterns [10]. However, this process requires complex and advanced calculation. Assuming that an antenna operates in a uniform multipath environment, the correlation coefficient can be calculated by S-parameters [16],

$$\mathrm{ECC}=\frac{|S_{11}^{*}S_{12}+S_{21}^{*}S_{22}|^{2}}{(1-|S_{11}|^{2}-|S_{21}|^{2})(1-|S_{22}|^{2}-|S_{12}|^{2})}\,. \quad (1)$$

Array's total active reflection coefficient (TARC) for a two port antenna as described in [17], can be showed in Fig. 12. Thus the proposed antenna is more attractive for MIMO application. The isolation between two polarizations will increase by increasing the dimension of spacing Gap1. Figure 13 shows the effect of Gap1.



(a)



(b)

Fig. 7. (a) Simulated current distribution on the radiating patch and ground plane at 3.4 GHz and (b) simulated return loss characteristics of the antenna with different values of L and W.

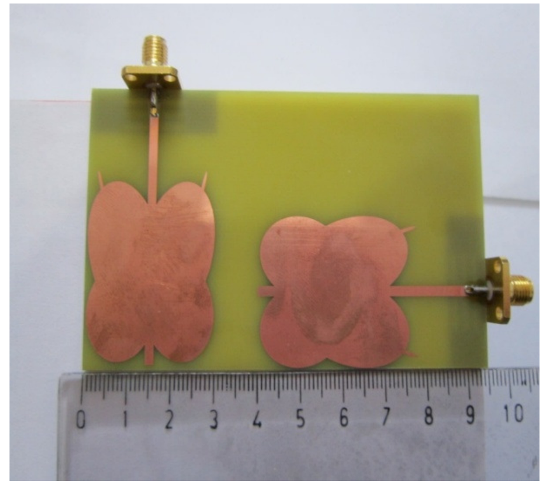
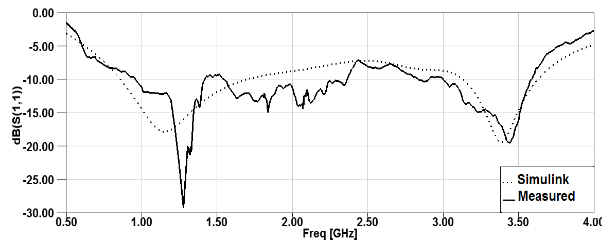
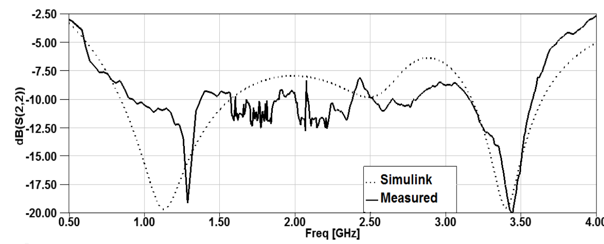


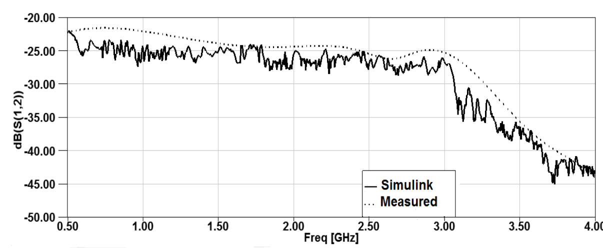
Fig. 8. Photograph of the constructed antenna.



(a)



(b)



(c)

Fig. 9. Simulated and measured (a) S(1,1), (b) S(2,2), and (c) S(1,2) (when S(1,1) of one port is measured, the other port ended with 50 Ω load).

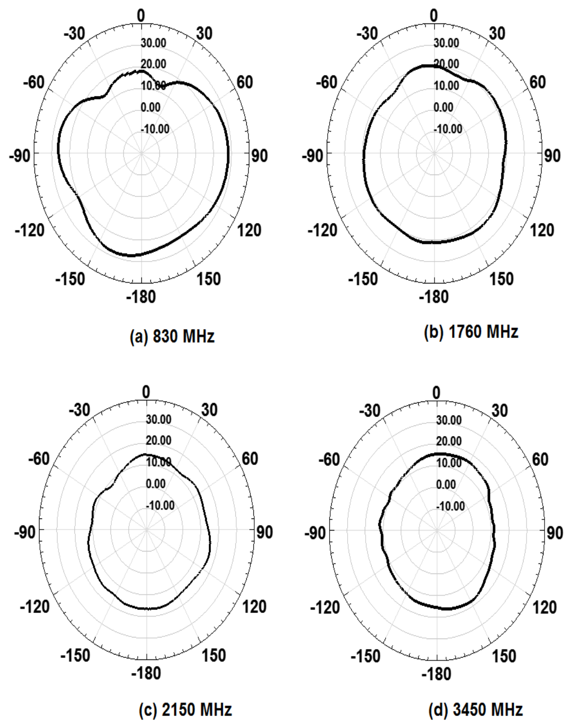


Fig. 10. Measured radiation patterns of antenna 1 in the x-z plane [unit : dB].

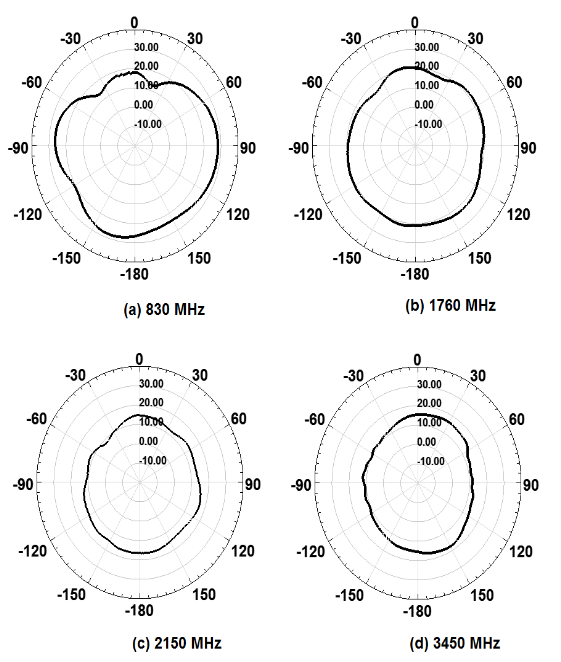


Fig. 11. Measured radiation patterns of antenna 2 in the y-z plane [unit : dB].

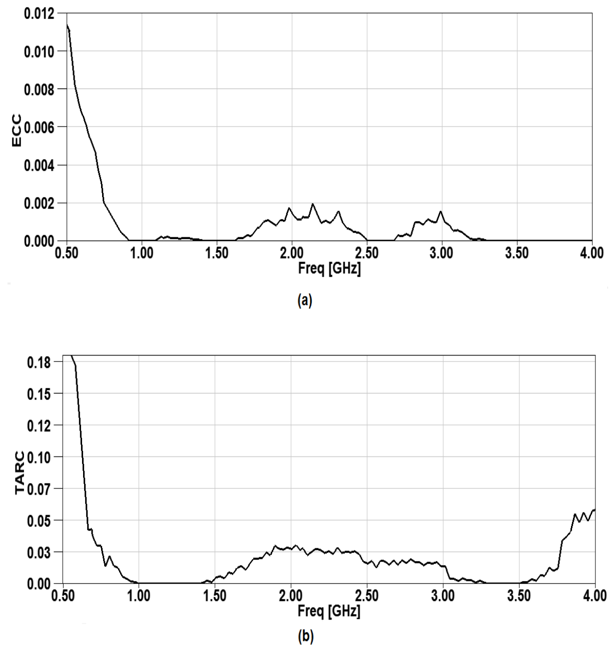


Fig. 12. (a) ECC and (b) TARC.

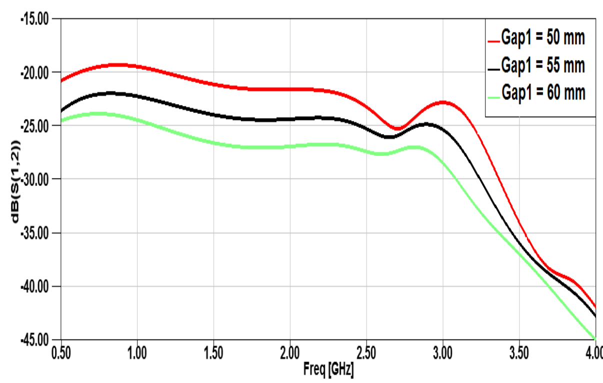


Fig. 13. Simulated S(1,2) with different value of Gap1.

IV. CONCLUSION

In this paper a novel planar monopole antenna for LTE MIMO system has been proposed and implemented. Simulated and measured results showed that the antenna can cover all of the LTE frequency bands. By adding 6 ellipticals, the lower frequency bandwidth is improved and by cutting two E-shaped slots in the ground plane, additional resonance are excited and hence wider impedance bandwidth can be produced. Good return loss and radiation pattern characteristics are obtained in the frequency band of interest. The antenna has high isolation (> 21). Moreover, low ECC and TARC is achieved by a pattern diversity. The designed antenna has a small size. Simulated and measured results show that the proposed antenna will provide better propagation channel and enhance the capacity of MIMO antenna for LTE applications.

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