International Journal Of Advancement In Engineering Technology, Management and Applied Science (IJAETMAS)

ISSN: 2349-3224 || www.ijaetmas.com || Volume 04 - Issue 09 || September-2017 || PP. 85-93

A Compact Dual Element PIFA Array for Wireless MIMO Advanced TDD LTE Applications

Manish Kumar Soni M.E. Scholar[1], Garima Saini Assistant Professor[2]

[1] *Department of Electronics & Communication Engineering*
National Institute of Technical Teachers' Training & Research Chandigarh, UT, India
[2] *Department of Electronics & Communication Engineering*
National Institute of Technical Teachers' Training & Research Chandigarh, UT, India

Abstract— MIMO systems have been developing in recent past as a solution to high speed and reliable data communication problems. Reducing the separation between antenna terminals while not compromising at the same time with the performance parameters of the system, is a key area of research in MIMO technology. In this paper, a compact dual-element PIFA array is presented for MIMO LTE applications. The MIMO system is designed to operate in advanced Time Division Duplexed (TDD) LTE bands LTE B 42 and LTE B 43. The design uses a dual layer substrate with the two rectangular radiating elements are present on the top substrate layer and are shorted to the ground plane by two shorting plates of 4.5mm width. The overall dimensions of the antenna are 45mm x 43mm x 7.9mm. Performance analysis of the designed MIMO system is done with respect to Return Loss, Isolation, TARC, ECC and Capacity Loss. The proposed system resonates at 3.6 GHz providing a 10 dB TARC bandwidth of 330 MHz ranging from 3.4 GHz to 3.73 GHz. An isolation of better than -11.5 dB is obtained in the frequency band of interest. The system offers good MIMO performance parameters with TARC better than -10 dB, ECC of almost zero and Channel Capacity Loss of less than 0.5 bps/Hz in the desired LTE bands. The size of the MIMO design and its performance indicators are compared with the existing designs covering TDD LTE bands. The proposed design provides a compact and efficient MIMO system that finds its applications in advanced TDD LTE bands for high data rate communication devices.

Keywords—PIFA; Long Term Evolution; MIMO; Total Active Reflection Coefficient; Envelope Correlation Coefficient; Channel Capacity Loss

I. INTRODUCTION

Long Term Evolution is a technology which is used in advanced mobile communication networks to provide high speed broadband services to the users. Also, LTE systems have the advantages of improved capacity and efficiency [1]. LTE bands from 1 to 22 are kept for FDD and from 33 to 41 are kept for TDD. TDD LTE is popularly employed in closed networks and ISP where there is data centric use rather than voice. This technology is particularly suitable to build private LTE networks that may include Internet of Things (IOT). MIMO technology has been evolving in recent decades to meet the demand of quality high speed data communication. A MIMO system uses multiple communication channels to increase the capacity of the system without needing additional radiation power. MIMO technology can be used to increase data rate and capacity linearly with the number of radiating elements. The design of MIMO systems, however, on small platforms with more radiating elements is difficult owing to increased mutual coupling between closely spaced elements [2]. High mutual coupling between antenna elements due to small spacing between them degrade the performance of the system. In fact, there is always a trade-off between compactness of MIMO antenna elements and relative isolation between them.

Design of MIMO systems with small size and less separation between the elements has been key area of research. Less spacing between antenna elements lead to high mutual coupling resulting in higher correlation coefficients and lower efficiencies. The separation between two adjacently placed radiating antenna elements is generally required to be large in

ISSN: 2349-3224 || www.ijaetmas.com || Volume 04 - Issue 09 || September-2017 || PP. 85-93

order to significantly reduce mutual coupling [3]. To achieve best isolation of the order of 20 dB, the spacing between antenna terminals should be greater than one half wavelength. Also, to realize a fairly good isolation of 10 dB, which implies low enough correlation and mutual coupling, a separation of a quarter of a wavelength is still required [4].

Planar Inverted F Antenna (PIFA) has emerged as a suitable candidate for MIMO applications because of its small dimensions, easy fabrication, light weight and low profile. PIFA finds its origin in Linear Inverted F Antennas in which wire structures forming an F shape are constructed above a metallic ground plane. In order to enhance the bandwidth conducting strips replaced wires and these strips have now been substituted with a single patch to form present version of PIFA [5]. PIFA is used in wide range of applications including MIMO systems, Ultra Wide Band systems, RFID, Wireless Sensors, wearable device communication systems etc.

Existing literature points out that significant research work has been done on MIMO antennas for wireless communication applications. These works, however, do not particularly focus on advanced LTE bands and these band are either being included in Ultra Wide Band or multiband antenna designs thereby giving an average performance in them. In [6] a two element MIMO reconfigurable antenna for UWB applications is proposed and the design performs well in advanced LTE bands but the dimensions of the antenna with supporting structure are large. Also the MIMO performance characteristics in terms of TARC and ECC is not satisfactory in the above mentioned bands. In [7] a wideband MIMO PIFA is proposed in 2.35 -3.25 GHz band which covers LTE 41 band. The MIMO performance of the design is good in terms of nearly zero ECC in LTE 41 band but return loss and isolation are relatively less. In [8] a UWB MIMO antenna with two identical PIFA elements connected by T shaped structure is proposed. The design covers Advanced LTE bands but has the limitation of small gain and comparatively large dimensions. In [9] a wideband printed dipole MIMO antenna is presented which uses V-shaped ground branches. The design has good performance in Advanced LTE bands except that its gain is limited to only 2.5 dB. In [10] a two element PIFA array is proposed that covers Advanced LTE bands but its overall dimensions and ECC in above mentioned bands are comparatively high. In [2] a dual band MIMO system is proposed that has eight elements in its design and covers a part of advanced LTE band but the size of the design along with ECC is higher. In [11] a four element partially grounded monopole MIMO antenna with SRR is designed that covers Advanced LTE band but the gain of the antenna is less.

The proposed work is arranged as follows: Section II describes the MIMO performance parameters based on which a MIMO system is analysed. Section III presents the antenna configuration and the selected design parameters to realize the proposed PIFA MIMO array. In section IV obtained simulation results are discussed, analysed and compared with the existing design. Finally, section V concludes the conducted work and the results obtained.

II. MIMO PERFORMANCE PARAMETERS

The MIMO antenna system is evaluated for its performance in terms of various parameters that include Envelope Correlation Coefficient, Total Active Reflection Coefficient and Channel Capacity Loss.

A. Total Active Reflection Coefficient (TARC):

Evaluation of the performance of a MIMO system cannot be done merely from scattering matrix parameters. For a MIMO antenna, TARC may be considered as overall return loss. The bandwidth of the MIMO antenna design is characterized from TARC curve. Also,

ISSN: 2349-3224 || www.ijaetmas.com || Volume 04 - Issue 09 || September-2017 || PP. 85-93

smaller the value of TARC, better is the radiation performance of a MIMO design. In an antenna system with two ports, TARC is given as the square root of reflected power to the incident power. Mathematically, it is given as:

$$\Gamma_a^t = \frac{\sqrt{\left(\left(|S_{11} + S_{12}e^{j\theta}|^2 + |S_{21} + S_{22}e^{j\theta}|^2\right)\right)}}{\sqrt{2}} \qquad (1)$$

Where θ is the Gaussian random input feed phase and it ranges from 0 to π. TARC is a parameter that considers both random signal phase and the mutual coupling between antenna terminals [12]. For MIMO systems, VSWR can be evaluated from TARC as:

$$VSWR_{MIMO} = \frac{1 + \Gamma_a^t}{1 - \Gamma_a^t} \qquad (2)$$

B. Envelope Correlation Coefficient (ECC):

It describes the performance of a MIMO system in terms for its diversity. ECC is the parameter that signifies how much of isolation or correlation exist between communication channels and how much the radiation pattern of different antenna elements affects each other. ECC can be computed from S parameters and considers the isolation between antenna elements in MIMO system. It is given as:

$$\rho = \frac{|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}|^2}{\left(1 - \left(|S_{11}|^2 + |S_{21}|^2\right)\right)\left(1 - \left(|S_{22}|^2 + |S_{21}|^2\right)\right)} \qquad (3)$$

Smaller the value of ECC, less correlated and hence more isolated are the antenna terminals. Lesser value of ECC indicates higher diversity gain of MIMO system. For satisfactory performance ECC should be less than 0.5 [12].

Diversity gain may also be computed from ECC as:

$$DG = 10\sqrt{1 - |ECC|^2} \qquad (4)$$

C. Channel Capacity Loss (CCL):

Theoretically, in case of uncorrelated Rayleigh fading environment, as the number of antenna terminals increases, capacity also increases. In practice, however, correlated environment causes degradation in channel capacity [12]. The losses incurred in 2x2 MIMO system, assuming high SNR and correlation in receiving antennas only, can be computed as:

$$C_{loss} = -log_2^{\det(\psi^R)} \qquad (5)$$

Where ψ^R is the correlation matrix associated with receiving antenna and is given as:

$$\psi^R = \begin{pmatrix} \rho_{11} & \rho_{12} \\ \rho_{21} & \rho_{22} \end{pmatrix} \qquad (6)$$

$$\rho_{ii} = 1 - \left(|S_{ii}|^2 + |S_{ij}|^2\right); \quad \rho_{ij} = -\left(S_{ii}^{*}S_{ij} + S_{ji}^{*}S_{jj}\right) \qquad (7)$$

Where i,j = 1 or 2.

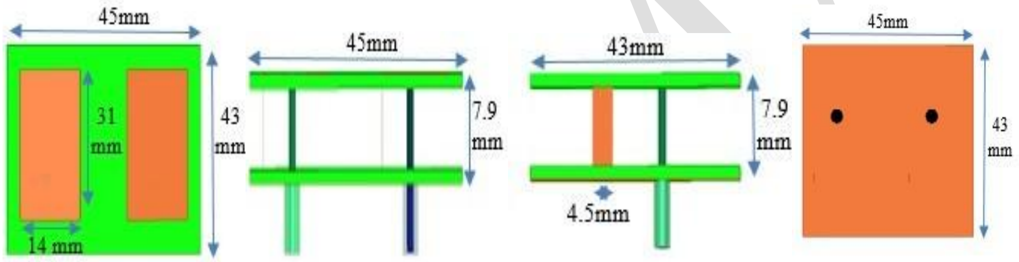
A loss of 0.5 bps/Hz in channel capacity is generally acceptable in MIMO systems.

ISSN: 2349-3224 || www.ijaetmas.com || Volume 04 - Issue 09 || September-2017 || PP. 85-93

III. Antenna Design and Configuration

PIFA is generally designed with a radiating planar element, a metallic ground plane and a narrower shorting plate. The geometry of a PIFA is represented in Fig. 1. The shorting plate is smaller compared to the shortened side of the radiating element.

The proposed MIMO system is designed using dual layer substrate. The two substrate layers are separated from each other by an air gap of 5.9mm. The material selected for both substrate layers is FR4 which offers a relative permittivity value of 4.4, a loss tangent value of 0.02 and thickness of 1mm. The geometry of the proposed array is shown in Fig. 1. The metallic ground of the structure has rectangular shape with dimensions Lg and Wg as 45m and 43mm respectively. One of the substrate is placed above the ground plane with same dimensions as that of the ground. The second substrate, having same dimensions, is located above the bottom substrate at an air gap height of 5.9mm. Two rectangular radiating elements of dimensions 14mm x 31mm are placed on the surface of top substrate with an edge to edge separation of 11mm between them. Both elements are fed by 50Ω coaxial cable separately and are connected to the ground by two shorting plates of 4.5mm width each.



Top view | Front view | Bottom view | Side view

Proposed MIMO Design

ISSN: 2349-3224 || www.ijaetmas.com || Volume 04 - Issue 09 || September-2017 || PP. 85-93

The two radiators are mounted collinearly on the substrate top. The dimensions of the ground plane, radiating patches and separation between the patches are optimized so as to obtain resonance at desired frequency of 3.6 GHz. The positions of coaxial feeds are optimized to obtain good impedance matching.

IV. SIMULATION RESULTS AND DISCUSSIONS

The proposed MIMO PIFA array has been designed and simulated in Ansys High Frequency Structure Simulator (HFSS) software. The desired resonance at 3.6 GHz is obtained by varying various key parameters of the MIMO antenna like dimensions of radiating patch and ground, width of shorting pin, separation between two radiating elements, positions of coaxial feed points etc. The design is setup with a solution frequency of 3.6 GHz with maximum number of passes and delta S being 10 and 0.02 respectively.

The schematic is designed with the optimized dimensions listed in Table 1.

TABLE I
DESIGN SPECIFICATIONS

Parameter	Dimensions
Ground Length	45mm
Ground Width	43mm
Patch Length	14mm
Patch Width	31mm
Shorting plate width	4.5mm
Substrate thickness	1mm

The design is then simulated and analysed for its performance characteristics like return loss, isolation, TARC, VSWR, ECC and Channel Capacity Loss.

Fig.2 depicts the return loss S11 of the MIMO design. The antenna resonates at 3.6 GHz with a good return loss value of -20dB. The return loss for port 2, i.e. S22 is -28 dB (Fig.3). Fig.4 shows the isolation between the two radiating elements of the MIMO design is always better than -11.5 dB in the entire band of interest that covers LTE B 42 and LTE B 43. At the lower frequencies in the band of interest, an isolation of -11.7 dB is achieved which increases to a value of -16 dB at higher frequencies. Thus the proposed design is well capable of providing good isolation and hence low mutual coupling for advanced TDD LTE bands.

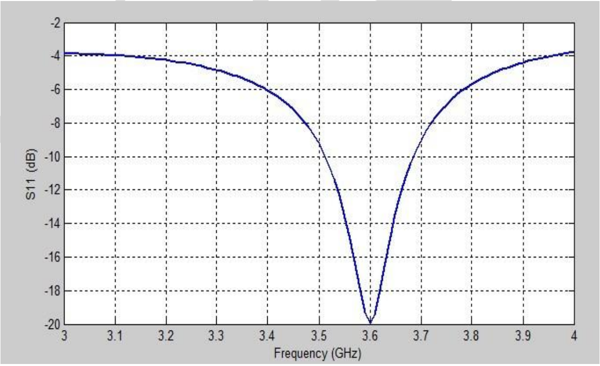


Fig. 2. Return Loss S11

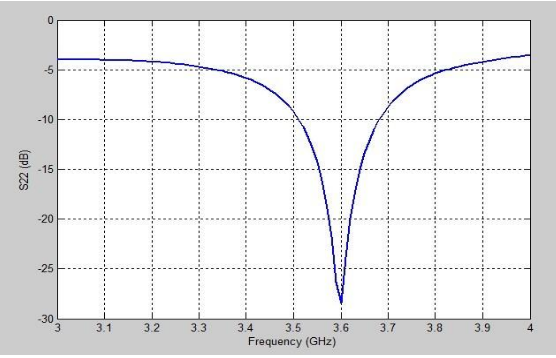


Fig. 3. Return Loss S22

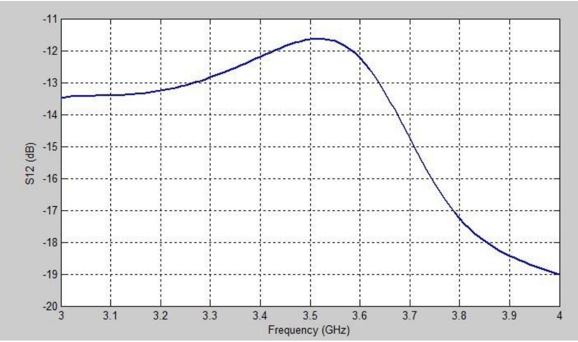


Fig. 4. Isolation S12

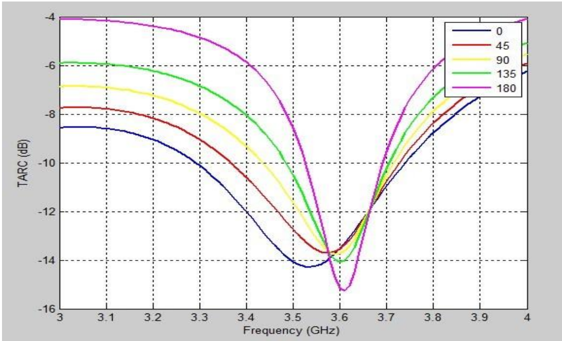


Fig. 5. TARC Characteristics

The MIMO performance analysis is done with the help of TARC, ECC, Channel Capacity Loss and VSWR. Fig.5 depicts the plot of TARC against frequency for various random input feed phases. The TARC is always better than -10 dB which is required for good MIMO performance. Average value of TARC is also plotted against frequency in Fig.6 It can be seen that the TARC has a minimum value of nearly -13.8 dB in the desired frequency band. VSWR for the designed MIMO antenna is calculated from the TARC curve and is plotted and shown in Fig.7.

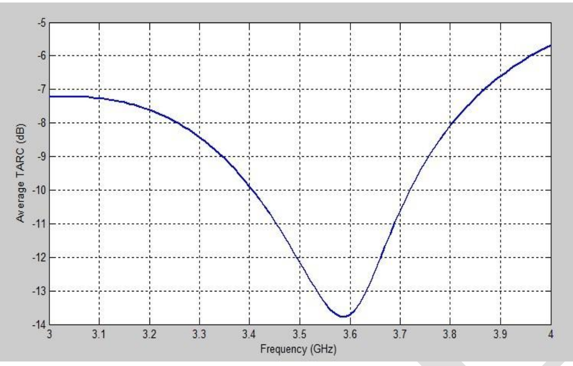


Fig. 6. Average TARC

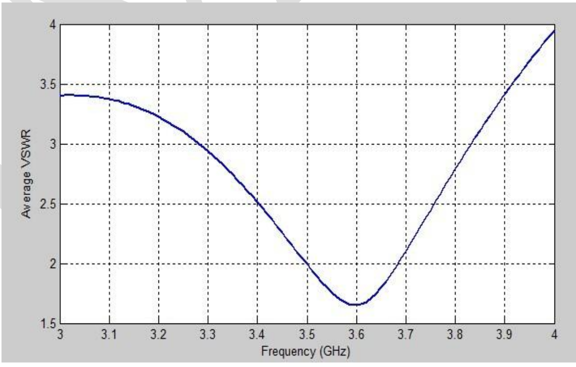


Fig. 7. Average VSWR

The channel capacity loss in bps/Hz is plotted against frequency and is shown in Fig.8. It has a minimum value of nearly 0.15 bps/Hz at a frequency of 3.6 GHz. Finally, the ECC isalso calculated and plotted for various values of frequencies. The plot inn Fig. 9 shows that the ECC reduces to a value of nearly zero in the desired band of frequencies.

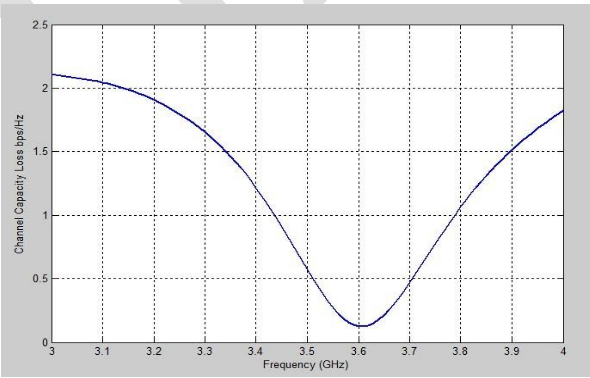


Fig. 8. Channel Capacity Loss

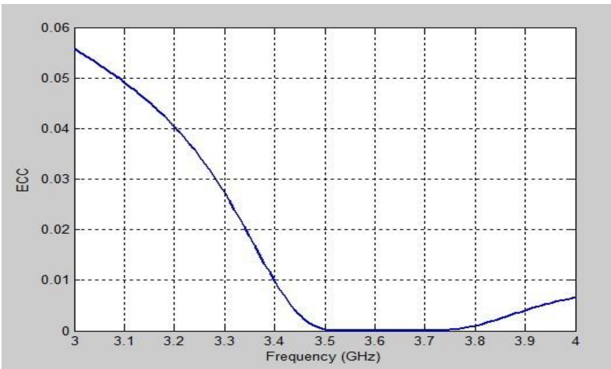


Fig. 9. Envelope Correlation Coefficient

ISSN: 2349-3224 || www.ijaetmas.com || Volume 04 - Issue 09 || September-2017 || PP. 85-93

Fig.10 represents the 3D gain plot for the designed MIMO antenna. As shown in the figure, the peak gain observed at 3.6 GHz is found to be 7.91 dB.

Performance and comparative analysis of the designed PIFA MIMO antenna system with other MIMO designs in the existing literature, is done next. In Table 2 the proposed PIFA MIMO design is compared with the MIMO design presented in [6] in terms of size, TARC, ECC and CCL. The proposed MIMO antenna is then compared with other designs for its size using a bar chart.

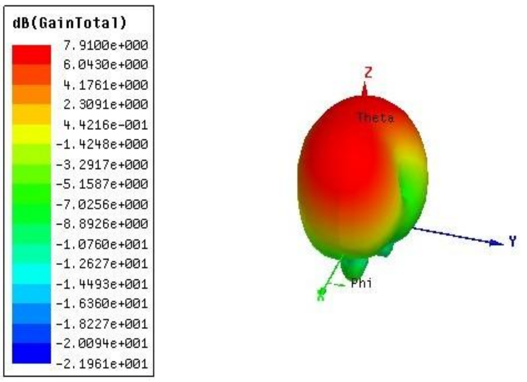


Fig. 10. 3D Gain Plot

TABLE II
PERFORMANCE ANALYSIS

Design	Size of MIMO design (mm3)	Min. TARC (dB)	ECC	Channel capacity loss (bps/Hz)
Ref. [6]	38 x 40 x 20	-10	<0.01	< 0.5
Proposed	45 x 43 x 7.9	-13.8	<0.01	< 0.5

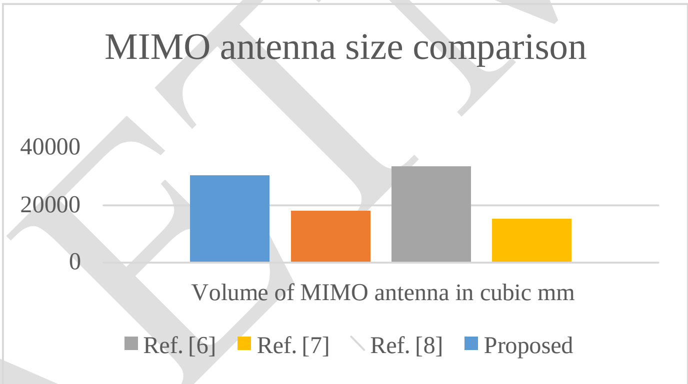


Fig. 11. Size comparison in cubic mm for various MIMO antennas

From the above table and bar graph it is seen that the size of the proposed PIFA MIMO system is only 45mm x 43mm x 7..9mm occupying a total volume of 15286.5 mm^3 compared to a size of 38mm x 40mm x 20mm (30400 mm^3) [6], 100mm x 40mm x 4.5mm (18000 mm^3) [7] and 50mm x 90mm x7.5mm (33750 mm^3) [8]. The proposed system therefore offers a compact PIFA MIMO antenna for LTE B 42 and LTE B 43 applications. The value of TARC is less than 0 dB in the entire range of frequency and attains a minimum value of -13.8 dB. Another advantage of the proposed design is that the value of ECC, as shown in Fig.10, is nearly zero in the LTE bands of interest. The channel capacity loss observed is also within the limit of 0.5 bps/Hz which is required for good MIMO performance of the system.

Fig.10 shows that the peak gain of the proposed PIFA MIMO design is 7.91 dB which is fairly good when compared with the gains of already existing PIFA structures. The isolation achieved with the proposed design is better than -11.5 dB for the frequency band of interest which is fairly good for an MIMO design. As the bandwidth of the MIMO design is also characterized from the TARC curve it can be inferred from Fig.6 that the design offers a TARC value of less than -10 dB from 3.4 GHz to 3.73 GHz thereby providing a bandwidth of 330 MHz. This frequency range covers advanced TDD LTE bands of LTE B 42 and LTE B 43 and therefore the proposed design finds its applications in advanced LTE terminals for high speed data communication.

V. Conclusion

In this paper a compact PIFA MIMO antenna using two Planar Inverted-F Antenna elements is proposed. The performance analysis of the proposed MIMO antenna is done in terms of ECC, TARC and Channel Capacity Loss. The proposed antenna is designed to operate in the advanced TDD LTE bands, LTE B 42 and LTE B 43. The designed MIMO antenna offers a small size with good gain, isolation and other MIMO performance indicators. The peak gain of the MIMO antenna array is found to be 7.91 dB with an isolation of better than -11.8 dB. The value of TARC obtained, in the frequency bands of interest, is well below 0 dB level with a minimum value of -13.8 dB. The observed value of ECC in the advanced TDD LTE bands is nearly zero. The channel capacity loss is also below a value of 0.5 bps/Hz which is marked for good MIMO performance. The MIMO performance of the proposed system is also compared with the existing MIMO designs whose operation range includes advanced TDD LTE bands.

References

[1] B. Mun, C. Jung, M. J. Park and B. Lee, "A Compact Frequency-Reconfigurable Multiband LTE MIMO Antenna for Laptop Applications," IEEE Antennas and Wireless Propagation Letters, Vol. 13, pp. 1389-1392, 2014.

[2] G. Li, H. Zhai, Z. Ma, C. Liang, R. Yu and S. Liu, "Isolation-Improved Dual-Band MIMO Antenna Array for LTE/WiMAX Mobile Terminals," IEEE Antennas and Wireless Propagation Letters, Vol. 13, pp. 1128-1131, 2014.

[3] Mustafa K. Taher Al-Nuaimi, "Mutual Coupling Evaluation of Dual-Miniaturized PIFA Antenna Array for MIMO Terminals," European wireless conference 2011, pp. 618-621, 2011.

[4] S. Zhang, B. K. Lau, Y. Tan, Z. Ying and S. He, "Mutual Coupling Reduction of Two PIFAs with a T-Shape Slot Impedance Transformer for MIMO Mobile Terminals," IEEE Transactions on Antennas and Propagation, Vol. 60, No. 3, pp. 1521-1531, 2012.

[5] J. A. Ray and S. R. B. Chaudhuri, "A review of PIFA technology," 2011 Indian Antenna Week (IAW), Kolkata, pp. 1-4, 2011.

[6] S. I. Jafri, R. Saleem, M. F. Shafique and A. K. Brown, "Compact reconfigurable multiple-input-multiple-output antenna for ultra wideband applications," IET Microwaves, Antennas & Propagation, Vol. 10, No. 4, pp. 413-419, 2016.

[7] S. Al Ja'afreh, Y. Huang and L. Xing, "Low profile and wideband planar inverted-F antenna with polarisation and pattern diversities," IET Microwaves, Antennas & Propagation, Vol. 10, No. 2, pp. 152-161, 2016.

[8] C. H. See, H. I. Hraga, J. M. Noras, R. A. Abd-Alhameed and N. J. McEwan, "Compact multiple input and multiple output/diversity antenna for portable and mobile ultra-wideband applications," IET Microwaves, Antennas & Propagation, Vol. 7, No. 6, pp. 444-451, 2013.

ISSN: 2349-3224 || www.ijaetmas.com || Volume 04 - Issue 09 || September-2017 || PP. 85-93

[9] H. Wang, L. Liu, Z. Zhang, Y. Li and Z. Feng, "A Wideband Compact WLAN/WiMAX MIMO Antenna Based on Dipole with V-shaped Ground Branch," IEEE Transactions on Antennas and Propagation, Vol. 63, No. 5, pp. 2290-2295, 2015.

[10] H. S. Singh, M. Agarwal, G. K. Pandey and M. K. Meshram, "A Quad-Band Compact Diversity Antenna for GPS L1/Wi-Fi/LTE2500/WiMAX/HIPERLAN1 Applications," IEEE Antennas and Wireless Propagation Letters, Vol. 13, pp. 249-252, 2014.

[11] R. Anitha, P. V. Vinesh, K. C. Prakash, P. Mohanan and K. Vasudevan, "A Compact Quad Element Slotted Ground Wideband Antenna for MIMO Applications," IEEE Transactions on Antennas and Propagation, Vol. 64, No. 10, pp. 4550-4553, 2016.

[12] A. Sharma and A. Biswas, "Wideband multiple-input–multiple-output dielectric resonator antenna," IET Microwaves, Antennas & Propagation, Vol. 11, No. 4, pp. 496-502, 2017.

[13] Kin-Lu Wong, “Planar Antenna for Wireless Communication,” John Wiley & Sons, Inc., Chapter 2, pp. 26-65,2003.