Design of Immensely Isolated 2×2 MIMO Antenna for Dual-Polarized Triple-Frequency Applications

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***Abstract*—This paper represents the design and implementation of dual-polarized-triple-frequency 2×2 Multiple-Input-Multiple-Output (MIMO) antenna with extremely high isolation capabilities having total dimensions of 50×155mm^2. Proposed antenna succeeds triple band frequency operations including GSM (IEEE-802.21), WiMAX (IEEE-802.16) and WLAN (IEEE-802.11n) bands of modern wireless communication system. Circular polarization has been hosted in WiMAX and WLAN bands with ≤ 3dB axial ratio (AR) while GSM band obeys linear polarization; hence dual-polarized operation has been accomplished with the same geometry. Highly isolated structure has been investigated by means of inverted ground planes and integration of parasitic strips amongst the radiating antennas. Fabricated 2×2 MIMO antenna achieves triple band operations that is, GSM (1.78-1.82 GHz), WiMAX (3.3-3.7 GHz) and lower edge of WLAN (5.15-5.35 GHz) with S_{11}, S_{22} ≤ -10dB for aforementioned bands and attains S_{21} ≤ -42dB isolations within electrifying ports. Designed antenna fulfills directional radiation patterns along E-plane and omnidirectional in H-plane with highest -49dB cross polarization levels. Antenna has simulated on MOM based CADFEKO software. Simulated peak gain of 4dBi has been acquired with 78% of peak efficiency. Designed 2×2 MIMO antenna has linear and constant group delay with superior time domain response for a Gaussian pulse.**

Keywords*—*2×2 MIMO antenna,CADFEKO, dual polarization, highly isolated structure, inverted ground plane, parasitic strips, triple frequency.

I. INTRODUCTION

Multiple-Input-Multiple-Output (MIMO) technology is one of the most effective way for increasing reliability and channel capacity of modern wireless communication systems [1]. Now a days grabbing of digital streams are more likely to be essential for modern radio receivers. MIMO offers significant advantages including multiplexing of digital streams, multiplexing gains, diversities in the frequencies and polarization patterns improving bit-error-rates satisfying the higher data rates. Due to its compressive features listed in [2], allows full adoption of radio spectrum.

Advanced wireless system necessitates integration of multiple application standards by same antenna in order to accommodate them within travail space-introducing multi-antenna systems [3]-[4]. Multiband antenna system provides advanced filtering features to send radios at desired frequencies and specifications [5]. Integration of different application bands into same antenna has carried out and such antennas are capable to operate at multiband wireless environments which avoid the need for replications of same antenna elements for each individual application band. Circular polarized (CP) antennas were found beneficial due to asymmetrical orientations between transmitting and receiving sections. While using a CP antenna system, the antenna placements does not have any significant effects on radiating properties. CP in [6]-[8] has been yielded by using two orthogonal feeds, adopting external polarizers, stacked configurations, chopping the radiating corners. The antennas with dual polarizations features achieves multiband operations with negligible mutual corresponds between radiating bands [9]-[11], giving a superior quality of reception.

MIMO communication systems includes multiple elements and require high degree of isolation between the radiators [12]. However, integration of multiple antennas closely in a small and compact device with maintenance of good isolation between the antenna elements is rather complicated since the antenna elements couple strongly to each other as demonstrated in [13]-[15]; also due to common ground plane, sharing the surface currents on it. Isolation performance of MIMO antenna system can be represented by the factor of correlation coefficients [16], which must be adequately small and indicated by scattering parameters between elements on same geometry [17]-[18] given by (1).

$$\sigma = \frac{|S11*S12+S21*S22|^2}{(1-(|S11|^2+|S21|^2))(1-|S22|^2+|S12|^2))} \quad (1)$$

Mutual coupling within MIMO elements can be controlled by differing the spaces between elements- spacing's can be varied in accordance with operating wavelengths[19], defecting the ground planes- which discretizes the direct current interactions [20], implementing resonators with individual ground plane for each radiating element [21], inclusion of EBG structures for reducing modal current interactions[22], altering the orientations of radiating elements by offering least current correlations [23]; while merging above comparable mechanisms approaches to achieve highly isolated arrangement is illustrated in [24].

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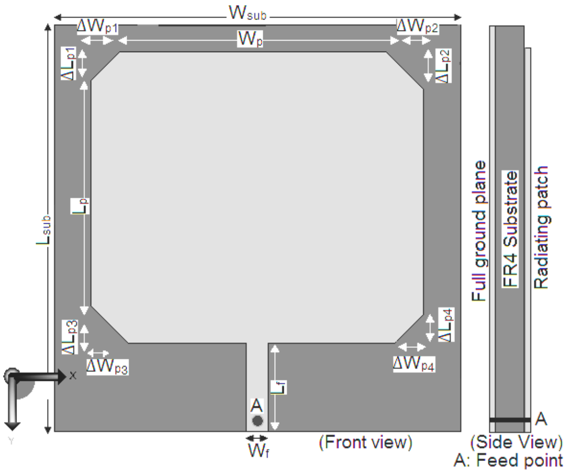
In this letter, two-port planar MIMO antenna is proposed for the 1.8-GHz GSM, 3.5-GHz WiMAX and 5.3-GHz WLAN band. Amongst aforementioned three bands, 3.5-GHz WiMAX and 5.3-GHz WLAN bands inhabits CP behavior with ≤3dB AR; while 1.8-GHz GSM assists linear polarization (LP) of radiations having > 3dB AR, proposing dual polarized system. Patch truncations over the radiating coroners has been explored in order to achieve a CP operation. To fulfill highest isolations between radiating ports, inverted ground planes and parasitic elements are integrated over a same configuration to neutralize the effects of mutual currents from the radiating antennas.

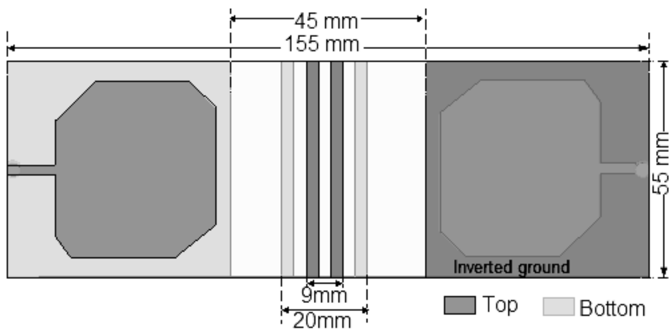
II. Antenna Design

Fig. 1 (a) shows the basic geometrical details of single element antenna. Antenna is modeled on FR-4 substrate with relative permittivity (εr)=4.4, loss factor (tanδ)=0.02, height (h)=1.6 mm. Designed antenna parameters are optimized for lower edge frequency fr=1GHz [25], with Ws=Ls=55 mm, Wp=45 mm, Lp=39.5 mm, Wf=3 mm, Lf=13 mm.

To acquire CP with triple band operations, antenna has truncated at four radiating corners and optimized as described by table I. Proposed antenna is excited with microstrip feed line having λ/8 mm length, which reduces the total size of antenna for MIMO formation, offering 50 ohm of matched impedances. Designed 2×2 MIMO antenna simulated and fabricated prototype is shown in Fig. 1. MIMO antenna has total geometry of 55×155 mm^2. Antennas on common ground plane are separated with distance of 45 mm.



(a)



(b)

(c)

Fig. 1. Proposed antenna geometry: (a) Single element antenna, (b) 2×2 MIMO antenna with inverted ground plane and parasitic strips, (c) Fabricated prototype.

Table I. Patch Truncation Dimensions

W_{p1}	W_{p2}	W_{p3}	W_{p4}
9.12mm	13.16mm	14.12mm	9.12mm
L_{p1}	**L_{p2}**	**L_{p3}**	**L_{p4}**
6.45mm	8.40mm	8.5mm	6.45mm

To deal with excessive isolations amongst the radiating MIMO elements, inverted ground plane arrangement for individual element has been investigated. Proposed antenna has simulated over angular displacements of 270^0, 90^0 and 90^0, 270^0 along the axis of radiating geometry. Due to angular displacements within antennas, mutual coupling can be significantly reduced. While, parasitic-absorbing strips are positioned in between the antenna elements to suppress effect of mutually induced currents to and from the radiating antennas. Due to inverted ground planes for each antenna on a common geometry, movement of currents from neighboring radiating element have opposite direction and hence it makes cancellations when they exposed to each other, posing very less current correlation factors among them. Parasitic strips of 3×55 mm are positioned on and above to substrate and also in between the resonating elements.

The parasitic strips acting as an absorber to mutually coupled current in between the radiating antennas over the same geometry. The leaky current is allow to pass through parasitic strips from top to bottom of substrate, nevertheless these strips are open ended, they does not allow path for flow of current, hence cancel outs the spurious radiations caused by mutual current due same as like discharging effect of capacitance mid them and hence mutual currents from neighboring elements are suppressed greatly. This makes antennas to be operated over the negligible MC and provides immense isolations within the radiating ports.

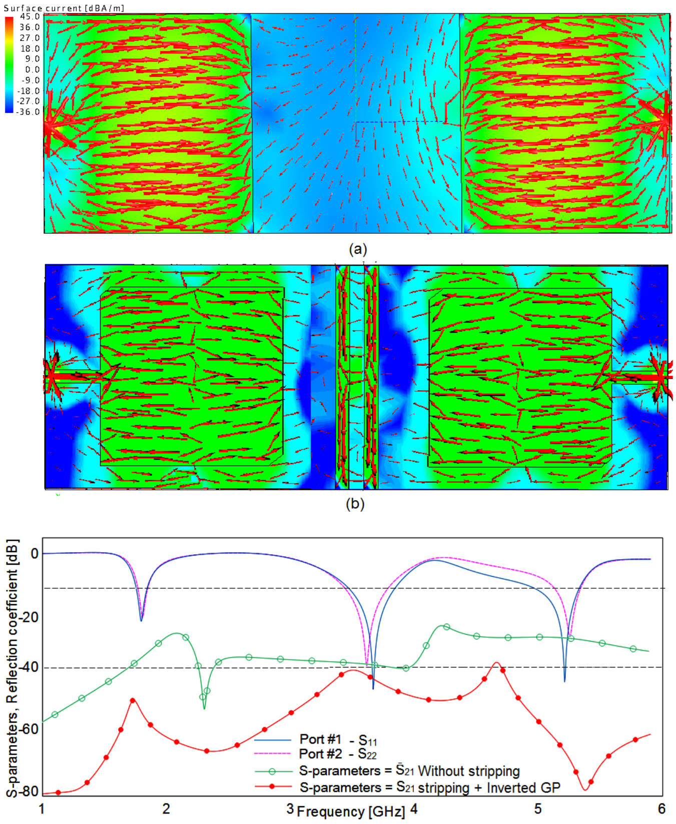
III. Simulation And Measurement Results

Proposed 2×2 MIMO antenna has been simulated by CADFEKO antenna design tool and fabricated over FR-4 substrate [26]-[27]. In subsequent sections, the S-parameters, dual polarized operations, radiation patterns, efficiency and gain, impedance matching and time domain analysis of proposed MIMO antenna has been demonstrated.

A. S-Parameters

The S-parameters are examined by using Agilent N9916A 2-port vector network analyzer [28]. Simulated 2×2 MIMO antenna S-parameters with respect to port 1 and 2 has been illustrated in Fig. 2 (c). From simulated results, it is noticed that designed 2×2 antenna occupies return loss S_{11}, $S_{22} \leq$ -10dB at center frequencies of 1.8-GHz GSM, 3.5-GHz WiMAX and 5.3-GHz WLAN bands, where mutual coupling factor S_{21} is below to -42dB for all over the three mentioned bands. In measured results, return loss S_{11}, S_{22} and mutual coupling fragments S_{21} confirms good agreements to simulation results. Peak isolations of -48dB at GSM, -42dB at WiMAX and -68dB at WLAN band has been effectively achieved with the deployment of inverted ground plane and integration of parasitic elements between two radiating ports.

When antenna is excited, amount of mutually coupled currents passes from immediate parasitic strips to adjacent antenna over top side of geometry with equal magnitudes. As adjacent antenna have inverted ground plane, it receives same magnitudes of current vectors with opposite trajectories within them. As an effect, coupled current cancellations on both top-bottom sides takes places as both ground planes appears themselves in inverted fashion with respect to single one. While, parasitic strips on both sides of geometry are open ended, they does not allow to pass any infrequent escaped currents through them and cancel outs by the phenomenon of capacitor discharging. This effect allows reducing total coupling levels henceforth improving the isolations between antennas. Instantaneous current distributions of 2×2 MIMO antennas without stripping are shown in Fig. 2. (a), illumes, current densities have more dominant in between the elements.



(c)

Fig. 2. Simulated current density and S-parameters relationship with/without inverted ground plane and parasitic elements striping.

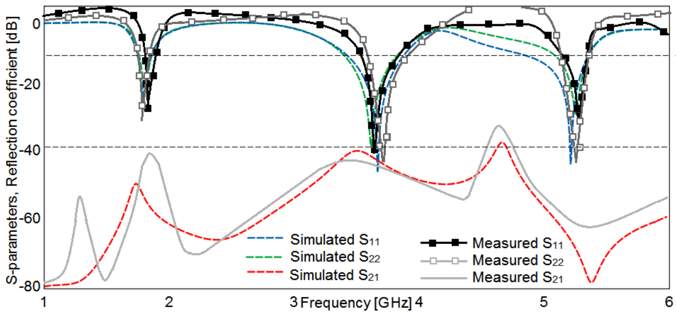


Fig. 3. Simulated/measured S-parameters relationship with inverted ground plane and parasitic elements striping.

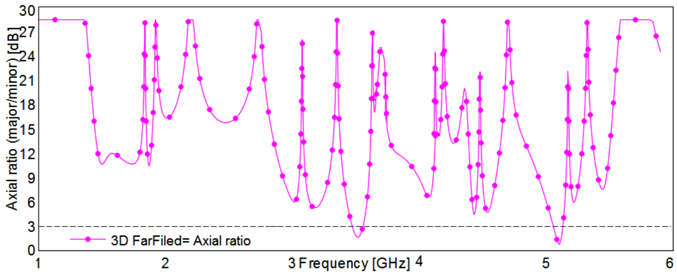


Fig. 4 .Axial ratio versus frequency plot of proposed 2×2 MIMO antenna.

Highest isolations were found and verified by bearing with the current distributions from integrating the absorbing-parasitic strips shown by Fig. 2 (b).

B. Daul Polarized Operation

Proposed 2×2 MIMO antenna dual polarized operation is displayed by the graph of axial ratio versus frequency in Fig. 4. Truncation along the patch widths integrates CP in a proposed MIMO antenna. From the simulation, axial ratio (AR) is lower than 3dB from 3560 to 3682 MHz for WiMAX and from 5150 to 5270 MHz for WLAN band, giving 122 MHz and 120 MHz axial ratio bandwidths (ARBW) at aforementioned two bands, confirming pure CP operations at these bands. Greater than 3dB ARBW clear-outs the LP operation at GSM band; henceforth dual polarized behavior is come to an agreement from the proposed 2×2 MIMO antenna. From the simulated antenna current distributions shown in Fig. 2 (a), linear directions of arrows are observed validating LP, while in Fig.(b) current vectors are divided in to two distinct planes along the metallic geometry having orthogonal arrow directions (arrivals), which validates CP behavior, as orthogonal currents are created on a same geometry.

C. Radiation Patterns

Fig. 5 shows radiation patterns of designed 2×2 MIMO antenna, obtained at simulation frequencies of 1.8 GHz, 3.5 GHz and 5.3 GHz. It is observed that, designed antenna offers almost directional patterns shaped as integer letter eight (8) along E-plane, where omnidirectional patterns are observed along H-plane. Cross polarization heights of proposed MIMO antenna is obtained lower than -49dB at 1.8 GHz, about -40dB at 3.5 GHz and -48dB at 5.3 GHz, showing that designed antenna is good candidate for faded wireless environment.

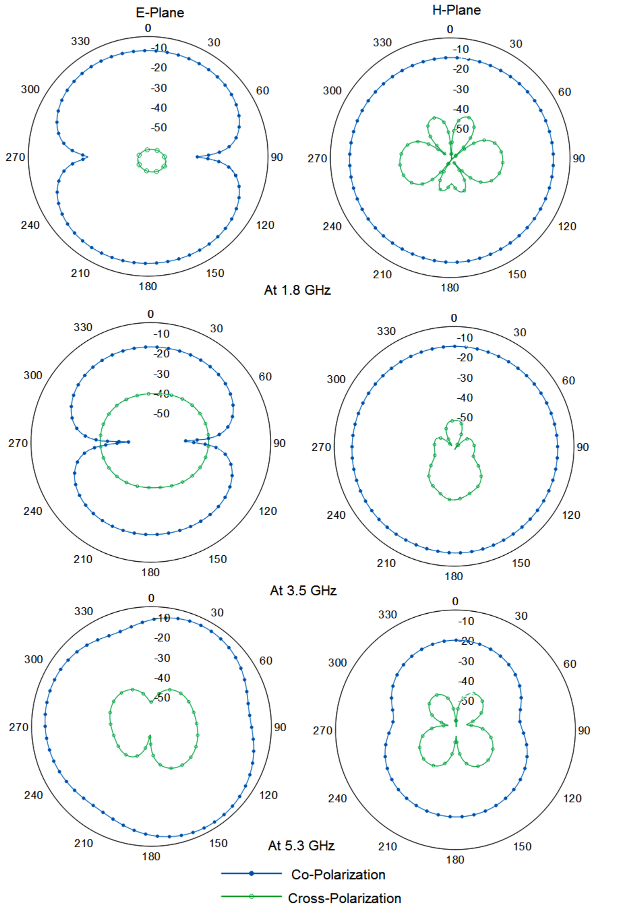


Fig. 5. Simulated 2-D radiation patterns of proposed 2-element antenna at 1.8 GHz, 3.5 GHz and 5.3 GHz.

D. Efficiency and Gain

Fig. 6 shows efficiency plot of designed antenna in relation to single and 2×2 MIMO antenna. By means of single antenna configuration, effectiveness has been doubled by the adoption of proposed 2×2 MIMO realizations. At the center of resonance frequencies in working bands, peak efficiency of 76% at GSM band, 78% at WiMAX band and 54% at WLAN is observed.

Isotropic gain of designed 2×2 MIMO antenna is shown in Fig. 7. It is correspondingly obtained at simulated frequencies of 1.8 GHz, 3.5 GHz and 5.3 GHz. Designed antenna provides peak gain of 4dBi at GSM and WiMAX bands and 3dBi at WLAN band.

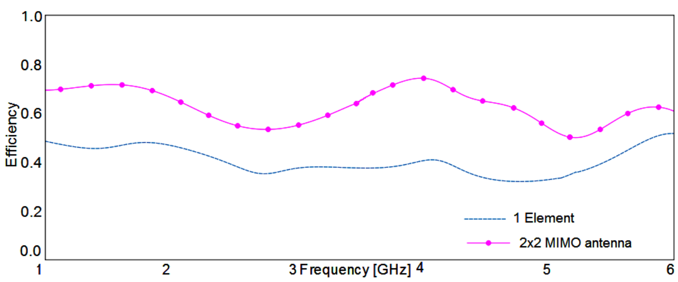


Fig. 6. Efficiency of designed 2×2 MIMO antenna.

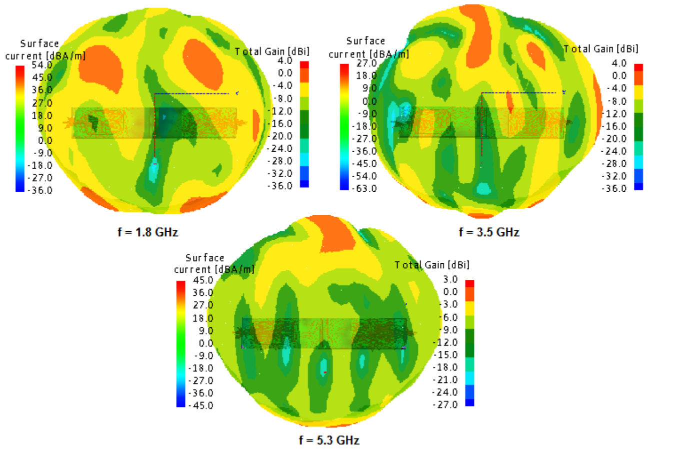


Fig. 7. 3-D gain of designed 2×2 MIMO antennas for simulating frequencies at 1.8 GHz, 3.5 GHz and 5.3 GHz

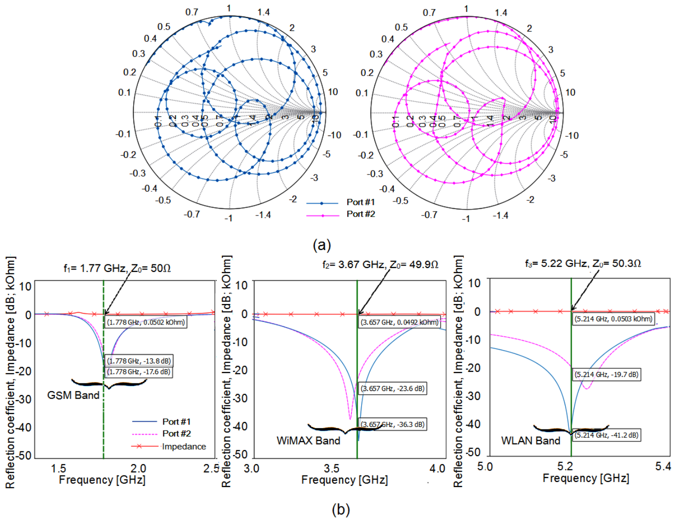


Fig. 8. Simulated 2×2 MIMO antenna (a): Schmitt chart patterns, (b): Complete impedance matching characteristics.

E. Impedance Matching

Simulated antenna impedance matching's at two respective ports is shown in Fig. 8. Proposed 2×2 MIMO antenna gives best impedance matching as each circle on schmitt chart having coordinates centered nearly at points 0 (0.1 to 0.5) which having approximately radius equal to 0.5 hence matched impedances, as waves at both ports having nearly zero reflection coefficients as shown in Fig. 8 (a). Complete impedance characteristics are shown for GSM, WiMAX and WLAN bands with center frequencies at 1.8 GHz, 3.5 GHz and 5.3 GHz in Fig.8. (b). Proposed antenna offers 50 Ω, 49.9 Ω and 50.3 Ω impedances at respective application band.

F. Tme Domain Analysis and Performance

Time domain analysis has significant vital role in broad band high-data rate communication. Group delay index embraces important factor of phase-synchronization between the transmitted and received pulses by antennas. If phase vector of transmitting antenna is unbalanced, then it compromises to larger group delay variations at receiving side.

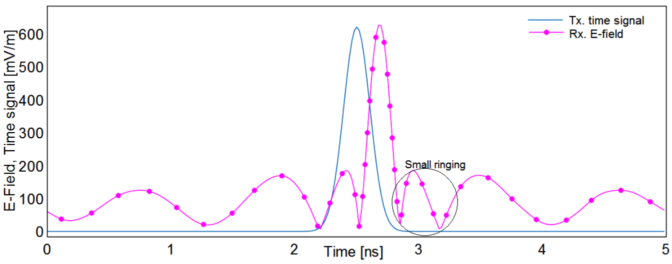


Fig. 9. Time-domain Gaussian-pulse response of proposed antenna.

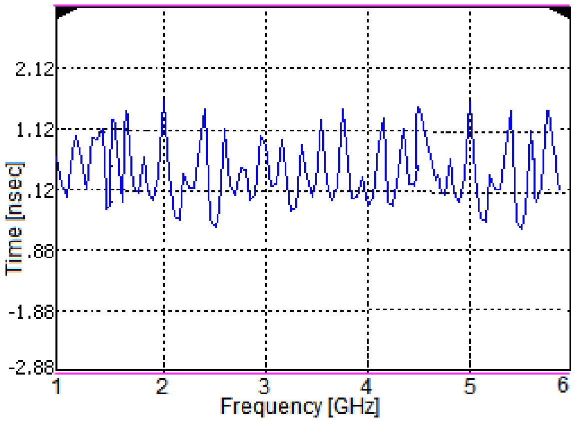


Fig. 10. Measured group delay of proposed antenna.

Simulated antenna time domain exploration is shown in Fig. 9. Gaussian pulse with total signal duration (sd) of 5ns is applied to input of antenna as a transmitted pulse. Proposed antenna has upright time domain Gaussian response with very small amount of acceptable ringing levels at received pulse, which implies that proposed MIMO antenna has negligible time crosstalk between transmitted and received signals and providing very small amount of bit-error-rates for digital transmission.

Proposed antenna group delay measurements has been carried out by using Gwinstek AFG-2225 arbitrary function generator and digital storage oscilloscope by considering the distance of 30 cm among the pair of antennas, where line of sight arrangement has been considered between them [29]. Designed antenna shows impressively constant and linear group delay about 2ns over the operating frequency range of 1 GHz to 6 GHz as displayed in Fig. 10.

IV. Conclusion

In this paper, a design and fabrication of dual polarized triple frequency operated 2×2 MIMO antenna for GSM (1.78 - 1.82GHz), WiMAX (3.40-3.78GHz) and WLAN (5.15-5.35GHz) applications is presented. Antenna is fabricated over FR-4 substrate with total geometry of 55×155 mm^2. To introduce triple band operations along with dual polarization characteristics, patch truncations alongside of width has been carried out. Greater than 3dB axial ratio at GSM band and less then 3dB axial ratios at WiMAX and WLAN band realizes dual polarized operations. To achieve highest isolations among the radiating ports, inverted ground planes and integration of open ended parasitic elements between them are introduced. Inverted ground planes cancels out the self-mutual couplings from distinct neighboring antenna element where open ended parasitic strips acts as barrier to infrequent flow of mutual current. Measured results validates that, the investigated mutual coupling reduction methodology attains S_{11}, $S_{22} \leq$ -10dB and $S_{21} \leq$ -42dB at aforementioned bands. Consequently, antenna approaches peak gain of 4dBi at GSM, WiMAX band and 3dBi at WLAN band, providing 78% of peak efficiency. Proposed MIMO antenna shows stable radiation patents and good impedance matching performance at dedicated three bands. A time domain analysis shows the effectiveness of proposed 2×2 MIMO antennas in regards with linear and constant group delays offering phase-synchronized behavior to existing wireless channel. Proposed 2×2 MIMO antenna shows beneficial potentials for development of traditional broad band communication systems.

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