Dual Polarized Triple Band 4×4 MIMO Antenna with Novel Mutual Coupling Reduction Approach

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Abstract—**A 4-port Multiple-Input-Multiple-Output (MIMO) antenna with tri-band frequency operation covering GSM (IEEE-802.21), WiMAX (IEEE-802.16) and WLAN (IEEE-802.11n) bands for modern wireless broadband communication applications has been designed and investigated. Proposed MIMO antenna has linearly polarized (LP) GSM band and circularly polarized (CP) WiMAX, WLAN bands poses ≤ 3dB axial ratios (AR), demonstrating dual polarized operations amongst existing three bands. Proposed 4×4 MIMO antenna attains reflection coefficient magnitudes S_{11}, S_{22}, S_{33}, S_{44} ≤ -10dB at mentioned three bands. The proposed antenna is fabricated on a low cost FR4 substrate and has total geometry of 165×165 mm^2. Presented antenna accomplishes 96 MHz axial ratio bandwidth (ARBW) at WiMAX and 201 MHz at WLAN band. With novel mutual coupling reduction approach of integrated parasitic strips and inverted ground plane structure a highest isolation of S_{21}, S_{31}, S_{41}, ≤ -45dB has been achieved. Deployment of inversions in ground planes does not affect the intended polarization properties when numbers of antenna elements are increased for MIMO applications.**

Keywords—4×4 multiple input multiple output (MIMO) antenna, dual polarization, isolations, parasitic strips, triple band.

I. INTRODUCTION

In recent years, MULTIPLE-INPUT-MULTIPLE-OUTPUT (MIMO) technology becomes researchers pivot for modern wireless multi-band systems due to its comprehensive features of enrichments in capacity and hence permitting extreme bit stream transmissions due to spatial multiplexing capabilities, ultimately providing a rich solution for multipath radio environments [1]-[2]. As digital streams from multi-antennas are to be combined and sent over a common channel, MIMO antenna is an essential solution due to its ability of grabbing many signals, allowing it to transmit over a same media, henceforth utilizing maximum radio spectrum [3].In order to avoid antenna duplications for each application bands, multi-band antenna systems have been proposed [4]. Conventionally MIMO antennas were using a multi-antenna configuration on a common substrate in order to achieve higher performance parameters. Nevertheless, antennas on same substrate must be separated by at-least half of its operational wavelength; providing good isolation [5]-[10]. In regards with miniaturizations of MIMO antenna systems, antennas at receiving end are kept much immediate to each other thus they sustain with electromagnetic phenomenon by which some of transmitted RF energy is coupled to neighboring radio transducers in the form of spurious EM-influences due to the interactions of leaky-escaped currents to and from the radiating ports located on the same periphery [11]. The radiating properties of MIMO antennas fluctuates the overall performance of communication system when antennas are placed much nearer to each other. Whenever the spacing between antennas is less then overall geometry will be compact but offers small isolations between radiating ports and hence presence of mutual coupling (MC), narrow BW and offers relatively high correlation coefficients, which must be small and indicated by scattering parameters in terms of microwave frequency network analysis [12]-[13]. Thus a quantitative analysis of MIMO antenna suggests that there should be negligible contributions of turbulences in terms of MC, indicating best isolations through the radiating ports thus posing a stable MIMO wireless system. The unexpected interactions of EM fields within multi-element MIMO antennas can be controlled by various configurations and methodologies described in [14]-[18].

In order to support mobility function from radio receivers, circular polarization (CP) plays an important role as it provides orthogonal field distributions of EM-waves along the propagation path. Deployment of orthogonally polarized antenna supporting digital modulation techniques for adoption of smart radio broadcasting system intends maximization in total throughput of channel [19]-[21]. In CP radiation the revolving angle of transmit and receive antennas has negligible importance in accordance with the power received, as E-field vector obeys equal amplitudes and phase variation correspondence of ±90^o as described in (1) and (2) [22].

CP can be accomplished with the orthogonal dual-feed as well by adopting the external polarizer network [23]-[26], which is more cumbersome and tedious to implement. A

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remedy is to implement a single-diagonal-feed structure with slotted or truncated patch geometry along the radiating corners [27]. Antennas with dual polarizations characteristics accomplish multiband operations and negligible mutual corresponds between nearly radiating bands, giving a superior quality of receptions.

In this paper, 4×4 dual polarized MIMO antenna for broadband modern wireless applications covering triple band operations has been presented. Proposed work was initiated by considering a triple band single element antenna, which operates in GSM-1800-DCS (1.71 GHz-1.88 GHz), WIMAX (3.3 GHz-3.7 GHz) and WLAN (5.15 GHz-5.35 GHz) bands of frequencies. Single-feed-dual polarized antenna operation has been carried out by truncating the corners of the radiating patch antenna. Designed antenna shows LP behavior at GSM band and CP radiating operations at WiMAX, WLAN bands. A 4×4 MIMO antenna configuration is then proposed with parametric evaluations to achieve dual polarized operation and reducing the effect of MC between the radiating elements over a common substrate is investigated. Inverted planar ground plane structures with mutual current absorbing parasitic strips are examined between neighboring elements to achieve peak isolations between the radiating antennas in terms of reduction in MC effect.

II. Proposed Antenna Element Design

The structure of proposed basic triple band antenna for the MIMO antenna configuration with patch truncated geometry is shown in Fig. 1. Antenna element has been designed by cavity model analysis of MSA with selected resonance frequency of 1GHz and overall dimensions of 55x55 mm^2 has computed by considering equations given in [28]-[29]. Due to chopping geometry along the patch corners, simulated antenna exhibits into three different distinct radiating modes of radiations covering GSM-1.8GHz, WiMAX-3.5GHz and WLAN-5.15GHz bands. Symmetry of truncations on patch integrates the CP in same antenna. Designed antenna parameters has optimized for fr = 1GHz with relative permittivity of substrate

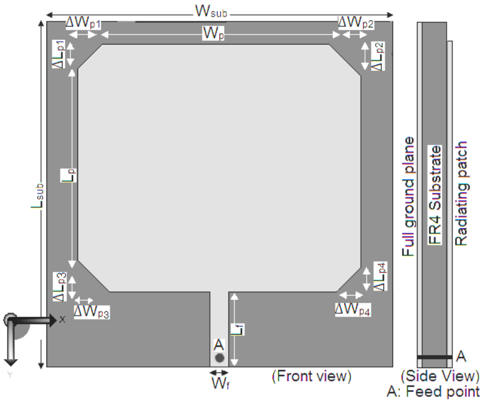


Fig. 1. Geometry of proposed CP-triple band microstrip antenna.

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

(εr) = 4.4, loss factor (tanδ) = 0.02, substrate height (h) = 1.6 mm, effective dielectric constant (ε_{reff}) = 3.33, Ws=Ls = 55 mm^2, Wp = 45 mm, Lp = 39.5 mm, Wf = 3 mm, Lf = 13 mm. To acquire CP with triple band operations, antenna has truncated alongside at radiating corners and optimized as described by Table I.

Proposed triple band MSA has been excited with a small microstrip line having length of $\lambda g/8$ giving 3mm × 13mm of dimensions, offering 50 Ω of matched impedance. Key benefit using such configuration is that, it reduces total geometry of antenna substrate and hence 30% of space saved compact designed has been achieved for MIMO configuration. Performance related parameters are simulated and evaluated in a method of moment based CADFEKO EM-simulation software [30]. Microstrip antenna modeled on a flame retardant (FR)-4 substrate due to its better stability and other properties at microwave frequencies [30]. Simulated triple band single antenna reflection coefficient plot is shown in Fig.2. Designed single element antenna shows that ≤ -10dB impedance bandwidth is obtained at 1.71-1.88 GHz, 3.3-3.7 GHZ and 5.12-5.37 GHz showing tri-band operations at GSM, WiMAX and WLAN of wireless communication.

A total radiation patterns at sampling frequencies of 1.8 GHz, 3.5 GHz and 5.3 GHz is shown in Fig. 3. Proposed antenna offers very low cross polarizations, screening that designed antenna is a good candidate for faded wireless environment.

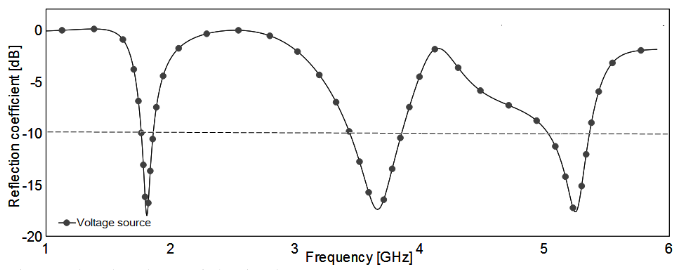


Fig. 2. Simulated S_{11} of single element antenna.

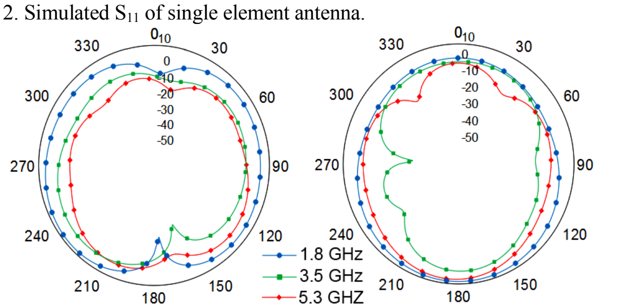


Fig. 3. Simulated radiation patterns of single element antenna at 1.8 GHz, 3.5 GHz and 5.3 GHz.

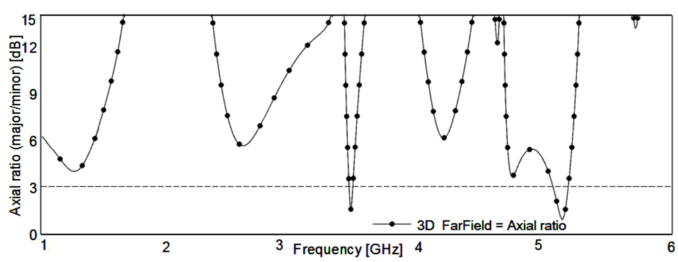


Fig. 4. Simulated single element antenna aixal ratio vs frequency plot.

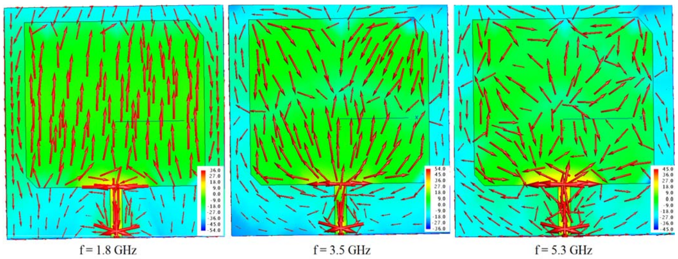


Fig. 5. Current distributions at 1.8 GHz, 3.5 GHz and 5.3 GHz

Fig. 4 shows simulated antenna axial ratio plot with respect to frequency. Pure CP with ≤ 3dB AR is obtained at operating bands of WiMAX from 3.56-3.67 MHz and WLAN from 5.16-5.29 MHz, giving 94 MHz and 203 MHz of ARBW at respective CP bands, while GSM band obeys LP operation as AR is tending to value greater than 3dB, giving dual polarization capabilities at simulation frequencies. Validating dual polarization operation from Fig.5, it is noticed that at 1.8 GHz frequency, current vectors have linear (upward) directions giving LP, while at frequency 3.5 and 5.3 GHz current vectors have closely orthogonal directions, hence CP operations

III. Proposed 4×4 MIMO Antenna Design and Results Discussions

The design of dual polarized 4-port MIMO antenna with precise assessment of MC has been proposed. The proposed MIMO antenna has total dimension of 165×165 mm^2 whose geometrical configuration is illustrated in Fig. 6.

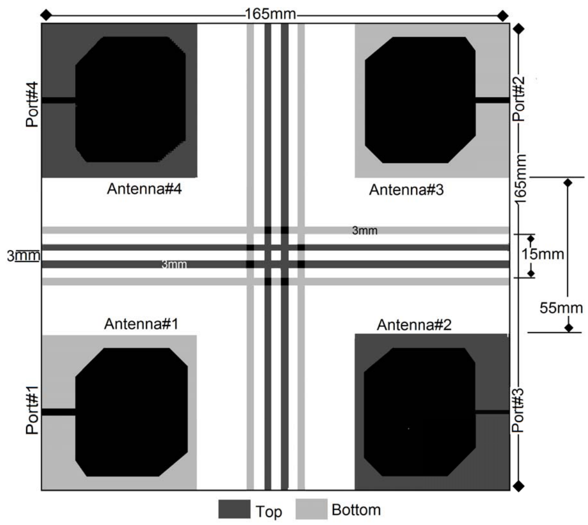


Fig. 6. Geometry of proposed CP-triple band 4-port MIMO antenna with inverted ground planes and parasitic stripping.

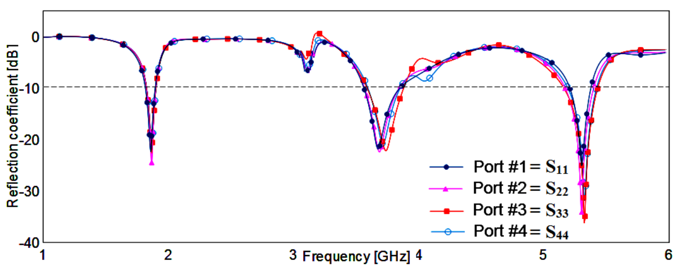


Fig. 7. Reflection coefficient magnitude of proposed 4×4 MIMO antenna.

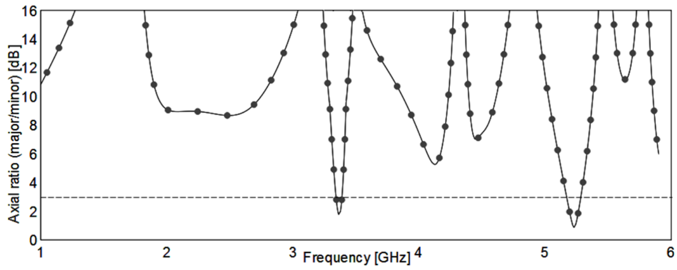


Fig. 8. Axial ratio vs frequency plot of proposed 4×4 MIMO antenna.

The configuration comprising antennas on a common radiating plane is investigated based on least correlation of MC, the most suitable configuration with angular movement of 270^0 between antenna elements for MIMO application has been proposed. Proposed antenna has been simulated over angular a displacements of 270^0, 90^0 and 90^0, -270^0 among the axis of radiating geometry. Proposed antenna have horizontal and vertical dualistic-parasitic strips between the antenna elements having width of 3mm and length of 165mm, spaced at 6mm from each other on top side; similarly they are spaced at 15mm on bottom side of total geometry. The distance between patches on a common substrate has been taken on the basis of confident combinations of operating wavelengths. Here, the distance between patch of 0.33λ have been selected, which yields relatively good port matching. The open ended parasitic strips are positioned in between the antenna elements to suppress effect of mutually induced currents to and from the radiating geometries. Due to inverted antenna elements and their corresponding ground planes the antenna does not exhibits variation in its polarization arrivals from the individual element. The proposed antenna configuration shows best performance in bandwidth and hence increases total capacity of each proposed band. The antenna refection coefficient magnitude in terms of S_{11}, S_{22}, S_{33} and S_{44} at GSM, WiMAX and WLAN band is shown in Fig.7. In relation with single element antenna, proposed MIMO antenna shows better contributions and enrichments in the bandwidth and gain. Proposed antenna achieves improvements in impedance bandwidths of 2.98% at WiMAX and 2.47% at WLAN band. It is also noticed that, proposed 4×4 MIMO antenna compromises almost best increased capacity at WiMAX and WLAN bands in relation with single element antenna. Fig.8. shows axial ratio plot of proposed 4-port MIMO antenna. Axial ratio of ≤ 3dB has been achieved at WiMAX and WLAN bands, offering 96 MHz and 201 MHz ARBW indicating CP operation at same bands, while > 3 dB AR at GSM band possess LP operation hence dual polarized behavior has been confirmed between proposed three bands of MIMO antenna.

IV. Mutual Coupling Reduction Approach For Proposed 4×4 MIMO Antenna

To determine the adequate spacing between the antenna elements in the MIMO system, and to achieve the excessive isolations between the excitation ports while minimizing the phase distortions among them with improved performance specifications, a study of MC analysis is significant in MIMO antenna system [32]. MC cannot be violable effect but it could be controlled by setting some of relative parameters in the mechanism of MIMO antenna system [31]-[33]. Here, inverted ground planes for each radiating antenna along with parasitic strips between them are used to reduce the effect of MC.

A. Significance of Inverted Ground Planes in Proposed MIMO Antenna

To reduce the MC and to gain the isolations within the radiating ports, proposed 4×4 MIMO antenna is designed with inverted ground planes and parasitic strips surroundings to radiating geometries. Due to inverted ground planes and angular displacements within the antennas on same geometry, movement of current from neighboring radiating element has opposite direction hence they make cancellations when they exposed to each other from, offering very less correlations with respect to mutual current. This makes antennas suitable to operate with negligible MC and provides best isolations in radiating ports.

B. Significance of Parasitic Strips

Proposed MIMO antenna is modeled with parasitic strips of 3×165 mm on and above to substrate and also in between the resonating elements. From Fig.9, it has been noticed that surface currents have more density in between and around the antenna elements. This antenna offers great extends in MC and offering less isolation in the excitation ports. Highest isolation of -36 dB has been achieved without using parasitic strips on a common substrate, as elaborated in Fig.10. Parasitic strips acting as an absorber to mutually coupled current in between the radiating elements over the same geometry.

Inter-port mutual coupling performance of individual antenna element with respect to 4×4 MIMO antennas is represented in Fig.12. This result satisfies the required circumstance that, the mutual coupling between the inter-port antennas should be less than -20dB for appropriate operation of the MIMO systems in the estimated range of frequencies. Here up to -37dB isolations between all operating inter-ports has been observed indicating that, each respective port have better value of mutual current immunity when single antenna operation from same geometry is to be considered. The leaky current is allowed to pass through strips from top and bottom of substrate geometry, but these strips are open ended, hence cancel outs the spurious radiations due to capacitance effects mid strips therefore mutual currents from neighboring elements are suppressed with abundant value Fig.11 shows current density of proposed MIMO antenna with insertion of parasitic strips in between the radiating elements. Due to use of strips, antenna currents from the neighboring elements are diverted in to strips itself. Strips are open ended and does not provides other path to current flow hence neutralizes the effect of mutually flowing current from one element to other on a common substrate of MIMO antenna, offering a negligible amount of MC providing very large isolations within the radiating ports. Due to inclusion of strips in proposed MIMO configuration, extraordinary cumulative isolation of -45 dB has been accomplished as shown if Fig.13. Proposed 4×4 MIMO antenna compromises S_{12}= -41dB, S_{21}= -45dB, S_{31}= -43dB, S_{41}= -44dB isolations between four respective excitation ports.

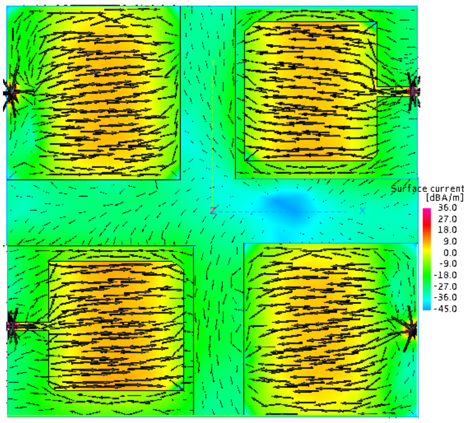


Fig. 9. Simulated 4×4 MIMO antenna instantaneous current distribution without parasitic strips.

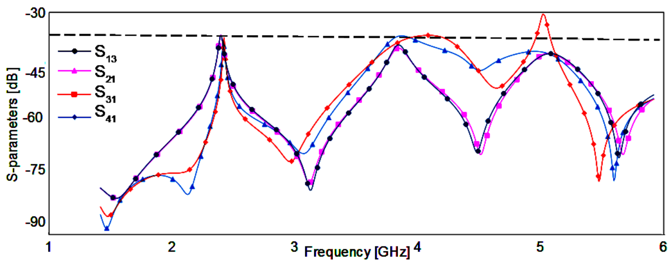


Fig. 10. Proposed 4×4 MIMO antenna isolation without resonating strips.

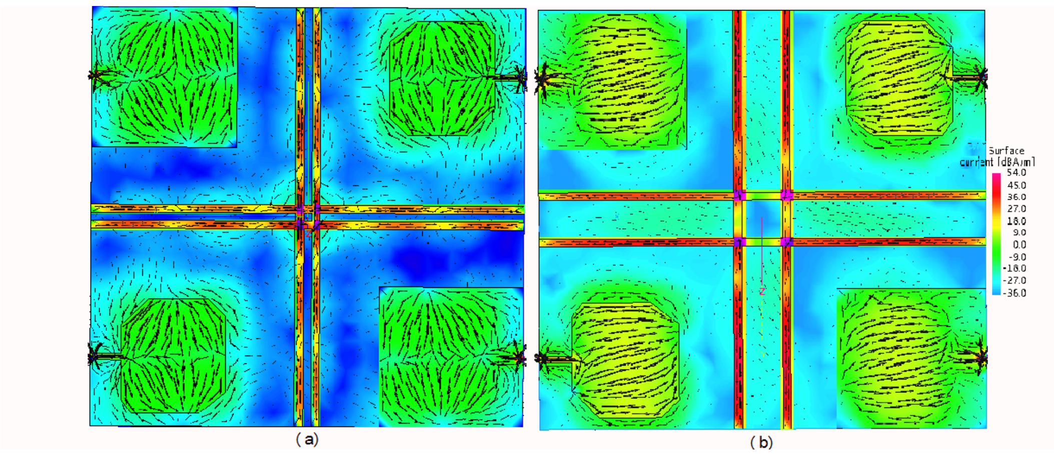


Fig. 11. Simulated MIMO antenna current distribution with resonating strips on: (a) Top side, (b) Bottom side.

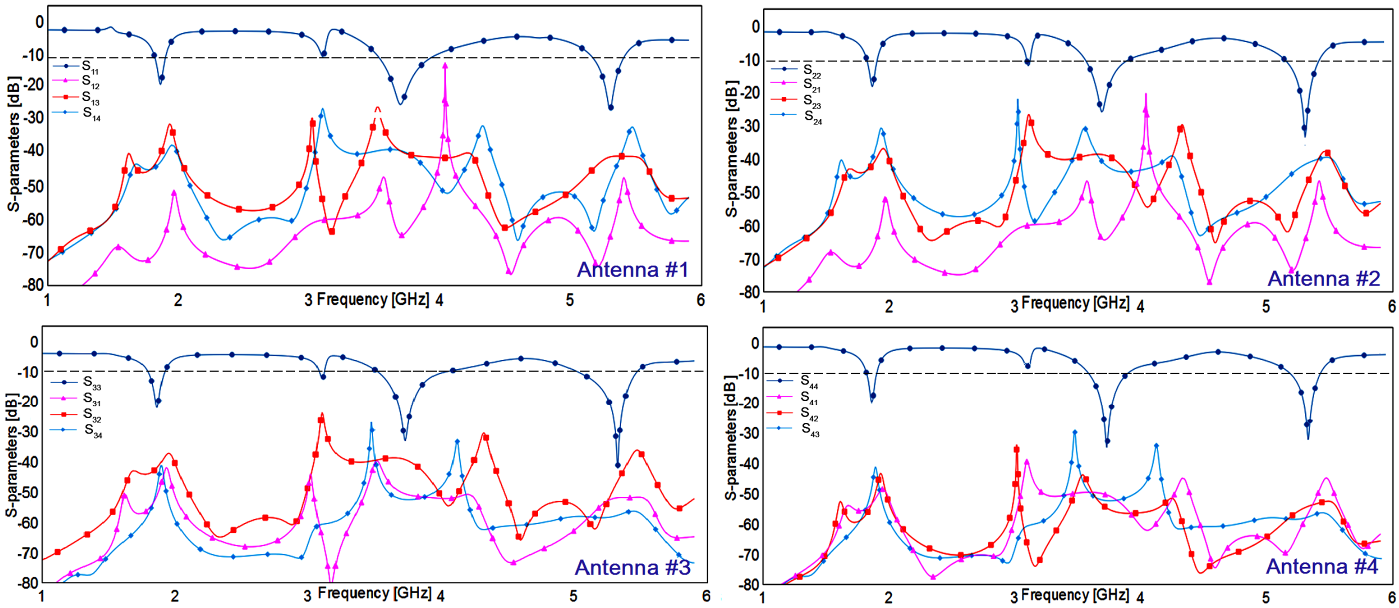


Fig. 12. Inter-port isolation performance of proposed 4×4 MIMO antenna.

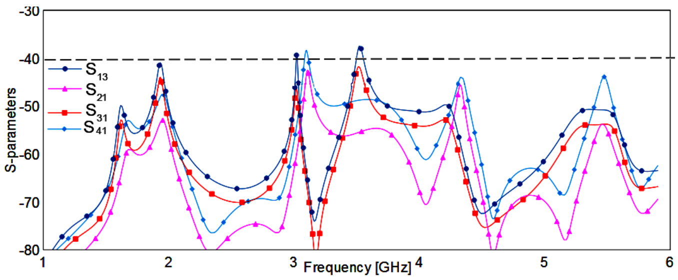
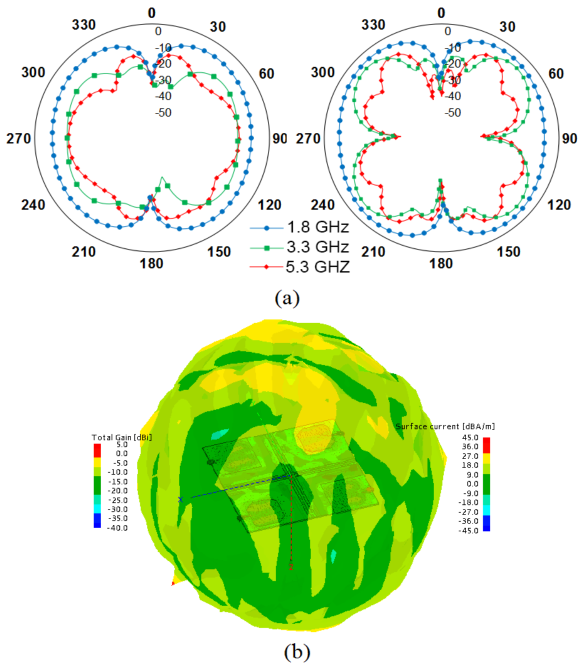


Fig. 13. Proposed 4×4 MIMO antenna MC with resonating strips.



(a)

(b)

Fig. 14. Simulated (a) 2-D radiation patterns of proposed 4-element antenna at 1.8 GHz, 3.5 GHz and 5.3 GHz. (b) 3-D gain.

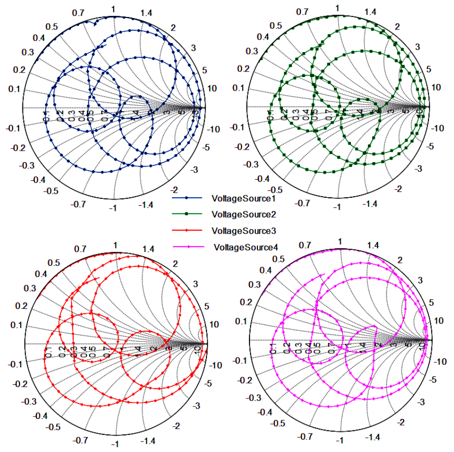


Fig. 15. Simulated dual polarized 4×4 MIMO antenna schmitt chart patterns at 4-respective voltage sources.

Simulated radiation patterns at 1.8 GHz, 3.5 GHz, 5.3 GHz and gain of proposed 4×4 MIMO antenna are shown in Fig.14. It is observed that, designed antenna have lower value of cross polarizations among the operating bands; also improved gain of 5dBi due to MIMO configuration has been validated. Simulated antenna Schmitt chart characteristics at 4-electrifying ports are shown in Fig. 15. As each circle on chart coordinates centered at points at 0 (0.1 to 0.5) which having approximately radius equal to 0.5, hence matched characteristics impedances as waves on ports are having nearly zero reflection coefficients giving VSWR equal to 1. Proposed antenna offers approximately 50 ohms impedances at each input source ports, compromises good impedance marching capabilities.

V. CONCLUSION

A dual polarized triple band microstrip feed 4×4 MIMO antenna with inverted ground plane structure for GSM, WiMAX and WLAN application has been presented. Due to MIMO conformation, impedance bandwidth improvement of 2.98% at WiMAX band and 2.47% at WLAN band has been succeeded. Proposed antenna attains ≤3dB ARBW of 96 MHz for WiMAX and 201 MHz for WLAN band, indicating CP operations at these two bands due to patch truncations, while GSM band operated in LP operation, signifies the accomplishment of dual polarized operation from same geometry. Due to arrangement of inverted ground planes with insertion of parasitic strips on and underneath of substrate also among the radiating elements, effect of MC is controlled in great extends. Parasitic strips acts as an absorber to mutual current flow in between antennas. Designed mutual coupling method compromises S_{12}< -41dB, S_{21}< -45dB, S_{31}< -43dB, S_{41}< -44dB isolations between four respective excitation ports. With the 4×4 MIMO antenna formation, extended peak gain of 5dBi has been succeeded over a single element antenna. Proposed MIMO antenna shows stable radiations at their three respective bands with minimal cross polarizing behavior, henceforth posing itself as an upright candidate for faded wireless multiband network.

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