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COMPACT BROADBAND MIMO ANTENNA WITH REDUCED MUTUAL COUPLING AND IMPROVED DIVERSITY GAIN FOR 5G APPLICATIONS

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Abstract
A broadband printed directive antenna with parasitic strip and compact size is presented, which is designed as an antenna element for Multiple-input Multiple-output (MIMO) system. The antenna is composed of a meander dipole, a concave parabolic reflector, a circular patch, a director and a parasitic strip which is utilized to obtain good impedance matching. The parabolic reflector is utilized to minimize antenna dimensions as well as to enhance the directivity in lower band whereas, circular patch is used for circular polarization. Moreover, a rectangular metal strip worked as a director is used to broaden the impedance bandwidth and improve the gain at upper band. Four antenna elements are placed orthogonal to each other for miniaturized size and good isolation. Experimental results indicate the proposed MIMO array achieves a return loss of -21.28 dB and gain of 4.11 db. Due to the compact size, low profile and broad bandwidth, the proposed MIMO array is suitable for various MIMO communication systems.

Keywords:
Multiple Input Multiple Output (MIMO), Directive antenna, Envelop Correlation Coefficient (ECC), Isolation.

Introduction
MIMO (Multiple Input Multiple Output) antennas are antenna systems that employ multiple antennas for both transmission and reception in wireless communication systems. They leverage spatial diversity to improve communication reliability, throughput, and spectral efficiency. At the transmitter, multiple antennas simultaneously transmit independent data streams. These streams are combined to create spatial diversity, which helps mitigate fading and interference effects. At the receiver, multiple antennas capture the transmitted signals, enabling spatial multiplexing to increase data throughput.For secure communication systems and the cases where the targets are required to be resolved accurately, instead of particular antenna element antenna arrays are employed. This is because the antenna arrays result higher Gain and higher Directivity compared to that of a single antenna element. Directivity and Resolution bear the same meaning. Both the terms are used to specify the capability of an antenna (or antenna array) to select the appropriate target in the crowd of similar objects as that of the actual target. [1] A compact broadband MIMO (Multiple-input Multiple-output) antenna element, tailored for modern communication systems. By leveraging the parabolic reflector, the antenna's dimensions are minimized while directivity is optimized, particularly in the lower band.[2] Four-port MIMO antenna tailored for 5G mid-band applications, specifically targeting the n79 band, crucial for 5G smartphone connectivity. The MIMO antenna demonstrates exceptional diversity performance, boasting low mutual coupling (less than -20 dB) among antenna elements, a diversity gain of 10 dB, and an envelope correlation coefficient (ECC) below 0.01, aligning closely with ideal values. With compact dimensions of 56 × 56 mm^2 and a slim profile of 1.6 mm, the antenna is well-suited for integration into 5G-enabled smartphones and high efficiency of 87% further solidify its suitability for 5G applications. [3-4] The edge-to-edge separation between the two antennas is $\lambda 0/31$ and still maintains low mutual coupling levels between the two antennas, a hybrid method of mutual coupling reduction applied in designing a textile MIMO antenna for on body applications. [5-7] In wireless communication technology, a number of new developments have led to improved wideband characteristics, improvement in

isolation, good polarization diversity, orthogonality performance, and design of simple structures. The UWB MIMO antenna consists of two identical monopole antenna elements with a comb-line structure on the ground plane to improve impedance matching and enhance isolation. Low power and high data rate interference immunity are the fundamental advantages of UWB communication system. However, the low transmitted power limits UWB systems to short-range communication. In order to increase data rate and/or overcome multipath fading, the multiple-input multiple-output (MIMO)/diversity technology has been considered for UWB systems.[8] Long Term Evolution (LTE) adopt multi-antenna mechanisms to increase coverage and physical layer capacity. Therefore, Multiple Input Multiple Output (MIMO) antenna systems are required on LTE systems. Other than the specific antenna system figure of merit (FoM), i.e. total antenna efficiency, gain imbalance, correlation coefficient also the MIMO system performance is defined by radiated data throughput, based on measurement of radiated MIMO data throughput on available LTE MIMO 2x2 reference devices have shown to be ineffective as a correlation instrument since they have been based on different test devices and different test methodologies.[9] Implementation and parametric analysis of 3 X 3 MIMO antenna. To achieve high isolation and to join the ground planes of all the radiating elements two metallic strips are used in the ground plane. The reflection coefficient of the antenna is less than -10 dB with each port excited.[10] The estimation accuracy of a MIMO channel capacity formula that considers only S-parameter of the antennas, the significance of the capacity formula is providing simple evaluation method of MIMO antenna. This estimation approach is quite convenient since it does not require either complex 3D radiation patterns or the channel matrix. An evaluation is performed by using dipole arrays. [11-12] The MIMO 2x2 reference antenna concept has been created specifically to emulate these three performances ranges. A MIMO antenna design is presented for sub-6 GHz 5G mobile applications, the resonant frequency of the radiators placed at the edge is 2.5 GHz, which also follows the design configuration of pattern diversity, while the center placed radiators resonating at 3.5 GHz.[13] A very compact Super wide band multiple-input–multiple-output antenna with dual notched band characteristics is presented. Super wide band characteristics is obtained by means of radiating patch and high isolation between two input ports are obtained by using T-shaped stub in ground plane.[14] A compact 2 × 2 MIMO antenna with a shared ground plane was proposed in this study for futuristic 5G communication. Despite the simple geometry, a large reduction in antenna size was achieved by introducing slits in the radiators to increase the current path. High isolation between the resonators was obtained by introducing slots in the patches and rotating them by 45° in the clockwise direction.[15] The MIMO antennas are used to solve the problem of SISO antennas. On the other hand, their performance factors like gain, efficiency, MEG, and DG all are affected, due to the close proximity of MIMO antenna elements. The degradation in these parameters is due to the radiation and emission properties of radiators and ground, which is commonly encountered as a mutual coupling. Antennas with high directivity are essential for long distance communication. Solution of this problem is antenna array. When a bunch of radiating elements are placed and grouped either electrically or geometrically, antenna array is formed. Single antenna element suffers from wide radiation pattern as well as lower directivity. Without changing elemental dimensions antenna arrays are capable of enhancing directivity. Antenna array is capable of transmitting high power, consuming low power and enhancing spectral efficiency.

We design a broadband MIMO antenna with a small compact size, which is smaller than reported designs. The original antenna element includes a meander dipole, a modified reflector and a parasitic strip which is used to improve impedance matching. To enhance the gain and widen the operating bandwidth at upper band, a metal director and a circular patch is also introduced. The proposed antenna element is utilized to form a four-element MIMO array, which obtains a wide bandwidth, low correlation as well as compact size. Therefore, the proposed MIMO array is a good candidate for 2.40 GHz WLAN band (2.40-2.48 GHz), WiMAX bands (2.50-2.90 GHz) and LTE 2600 (2.5-2.69 GHz), Routers (2.4-5 GHz) applications due to the obtained results.

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Antenna Design:

The single antenna element is shown in Fig. 1. It is printed on a FR4_epoxy substrate with permittivity (εr = 4.4). The size of the antenna is 36×27×0.5 mm^3. The antenna is composed of a meander dipole, a reflector, circular patch and a straight metal strip acting as director. Besides, a parasitic strip is placed between the dipole and the reflector to improve impedance matching. The driven dipole, which works at half-wavelength mode, is folded to reduce the antenna size. The reflector, which is employed to obtain unidirectional radiation at the lower band, is also designed to be concave parabolic to reduce the antenna size while maintaining the same directivity as that of using a traditional straight reflector. Circular patch is used to improve diversity gain. For the upper band, a metal strip is introduced to improve impedance matching and directivity. The antenna is fed by a 50-Ω coaxial cable. The inner and outer conductor of the coaxial cable is connected to the two arms of the meander dipole.

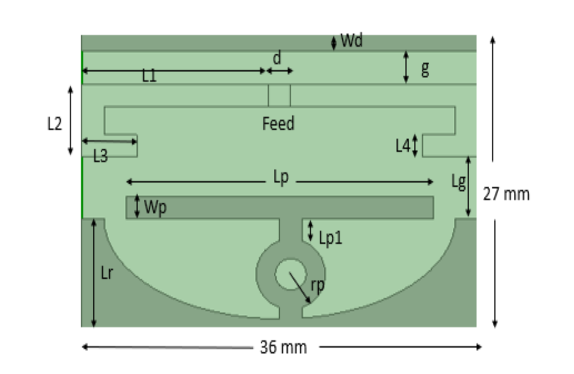

Fig 1. Geometry of Single Antenna

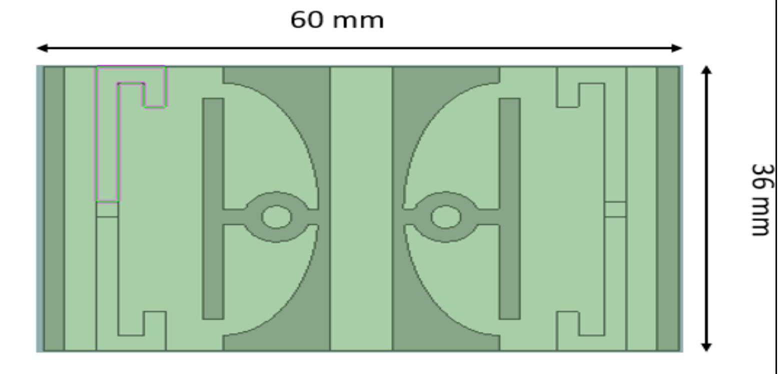

Fig 2. Geometry of 2 X 2 MIMO antenna

The meander dipole which is placed above the director at a distance of length of 3mm where the feed is given between the terminals of the meander diploe. Antenna resonates at 2.45 GHz and it just has a narrow impedance bandwidth of 200 MHz In order to minimize the antenna size. It is observed that antenna is resonating at 2.42 GHz with a deteriorated impedance matching when the distance is reduced. This could be explained by the input impedance of the antenna. It indicates that reducing the distance increases the input resistance and inductive reactance of the antenna. Consequently, the impedance matching between 2.4-2.6 GHz turns poor due to the change of the coupling between the dipole and the reflector. For the purpose of improving the impedance bandwidth while keeping the compact size, a parasitic strip and a circular patch is introduced to place between the dipole and reflector. Adding the parasitic strip brings a capacitive coupling between the dipole and reflector thus shifts the original resonant mode down to 2.4 GHz in addition to the generation of a new resonance and due to circular patch, the gain is improved. To further widen the impedance bandwidth and improve the directivity at upper band, a metal strip is placed at the upper side of the antenna. The single antenna is converter into two-by-two MIMO antenna by placing two single antennas in a size of 36x60x0.5 mm^2 which is shown in Fig 2. Again, this 2x2 antenna is converted into 4x4 MIMO antenna by placing two more antennas in a size of 72x80x0.5 mm^2 which is shown in Fig 3. The impedance matching could be adjusted by altering length of patch. In fact, the wide operating bandwidth is obtained by properly combining the dipole, reflector, director and parasitic strip together. Moreover, the impedance matching in lower band is improved dramatically by adding the parasitic strip as the |S11| comparison (with/without parasitic strip). By assuming the dipole antenna as the source of coupling, the equivalent circuit model to explain the principle of operation. more power could be coupled from the driven dipole to the reflector. By adjusting the distances, the coupling could be controlled to obtain wide impedance bandwidth. The radiation of antenna is unidirectional at the lower band. For the upper band, a metal strip is introduced to improve impedance matching and directivity. The antenna is fed by a 50-Ω coaxial cable.

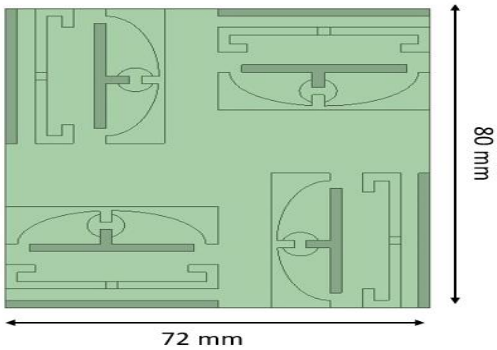

Fig 3. Geometry of 4X4 MIMO antenna

RESULTS AND DISCUSSION

Comparing, with single antenna design the operating frequency of antenna is at 2.8 GHz whereas the operating frequency of 2x2 antenna is at 2.56 GHz. The placement of one more antenna could obtain a low mutual coupling with a compact geometry. Antenna 1 and antenna 2 are placed opposite to each other to obtain low mutual coupling. The overall size of antenna is 36×60×0.5 mm^2.The simulation results prove that more gain is obtained compared to the single antenna . The gain obtained is 2.41 db.

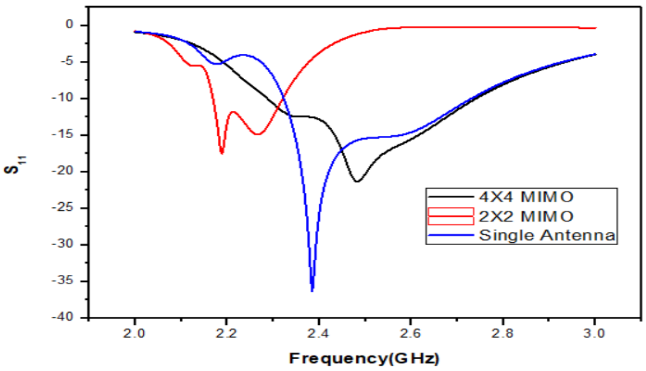

Fig 4. S-Perameters of MIMO antenna.

The 4x4 MIMO antenna operates at 2.58GHz. the S-Parameters of single ,2x2 and 4x4 MIMO antennas are shown in Fig 4. The simulation results showcase promising performance of the two (2×2) MIMO antenna design implemented with FR4 material in HFSS software. The obtained gain is 2.41 db. The gain has improved compared to Single Antenna. Further the gain of 4x4 MIMO antenna is improved compared with 2x2 MIMO which is shown in Fig 5. The implementation of a 2x2 array MIMO antenna using FR4 material in HFSS software has yielded significant insights into its performance characteristics. Through careful analysis of the radiation pattern, we observed it exhibits directional characteristics. Overall, the study demonstrates the feasibility and effectiveness of the proposed MIMO antenna design, showcasing its potential for various wireless communication applications.

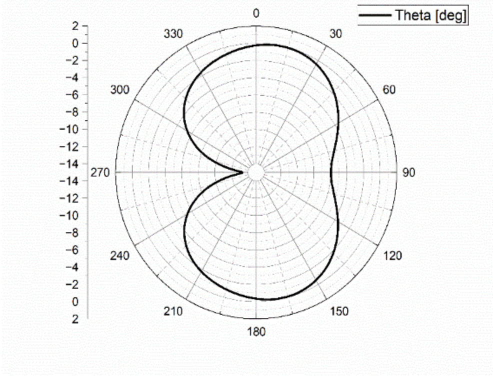

Fig 5. Gain of a 4x4 MIMO Antenna

The proposed compact antenna with wide bandwidth and good directivity is suitable to build MIMO array. A good MIMO array should have a low signal correlation between antenna elements. In this design four single antenna arrays are used to obtain MIMO array. The placement of Array could obtain a low mutual coupling with a compact geometry. Due to the square loop configuration of Array, the mutual coupling between opposite elements is much reduced. Besides, the overall size of Antenna is 80×72×-0.8 mm^2.Comparing with single antenna array and two array antenna the operating frequency of single array is 2.8 GHz and for two array the operating frequency is 2.6 GHz and the operating frequency of MIMO array is 2.52GHz. The gain obtained at single array is 1.27 dB, at two antenna array is 2.51 dB and at four array MIMO antenna is 4.11 dB.

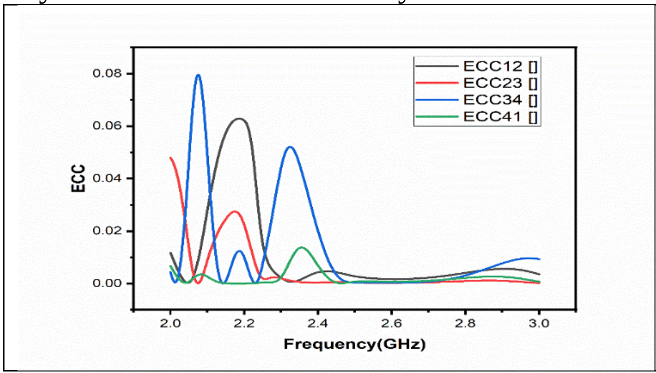

Fig 6. ECC of MIMO antenna

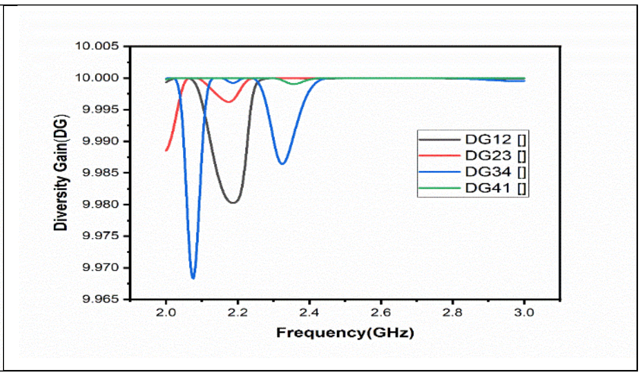

Fig 7. Diversity Gain (DG) of MIMO antenna

Envelop Correlation Coefficient (ECC) is the important in designing the MIMO antenna. The ECC of single ,2x2 and 4x4 MIMO antenna is shown in Fig 6. The gain plot showcases consistent and satisfactory performance across the desired frequency range, validating the effectiveness of the design. The achieved gain levels of4.11 dB affirm the antenna array's suitability for MIMO applications.The ECC and Diversity gain(DG) is related with the equation DG= $\sqrt{1 - ECC^2}$.The Diversity Gain of single ,2x2 and 4x4 MIMO antenna is shown in Fig 7.and Table 1 shows the dimensions of single ,2x2 and 4x4 MIMO antenna with operating frequency and improved gain. Through rigorous simulation, it has been observed that the antenna array exhibits excellent gain performance across the desired frequency range of 2.48 GHz. The gain plot illustrates consistent and substantial radiation patterns, indicating efficient energy transfer and reception capabilities and has a return loss of -21.28 dB. Through careful analysis of the radiation pattern, we observed it exhibits directional characteristics. Overall, the study demonstrates the feasibility and effectiveness of the proposed MIMO antenna design, showcasing its potential for various wireless communication applications such as Internet of Things (IOT), WLAN Band etc.

Table 1. Antenna Measurements Table.

Parameter	Single Antenna	2x2 MIMO Antenna	4x4 MIMO Antenna
Length of Antenna	36 mm	36 mm	80 mm
Width of Antenna	27 mm	60 mm	72 mm
Operating frequency	2.8 GHz	2.56 GHz	2.52 GHz
Gain in dB	1.7	2.41	4.1

CONCLUSION

The emergence of Multiple Input Multiple Output (MIMO) technology has significantly enhanced data rates, spectral efficiency, and signal reliability in wireless communication systems. However, the compactness required for modern wireless devices often leads to challenges such as mutual coupling and ground disturbance. These phenomena degrade antenna performance by causing integration-related distortion effects. we have explored various strategies to mitigate these challenges. We have investigated different types of separation techniques, including spatial separation and polarization, to control the effects of interconnection. By optimizing the design parameters and configurations of MIMO antennas, we aimed to achieve reduced mutual coupling and enhanced diversity gain.

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