INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

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OPEN ACCESS

Received: 27.12.2020

Accepted: 28.02.2021

Published: 28.04.2021

Citation: Nayak RS, Bajidvali SK, Gupta A, Venkatarao V (2021) High Isolation Eight-Element Mimo Antenna Array Tightly Arranged Based on Embedded Meta-Material Cells. Indian Journal of Science and Technology 14(15): 1168-1176. https://doi.org/10.17485/IJST/v14i15.2319

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Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

High Isolation Eight-Element Mimo Antenna Array Tightly Arranged Based on Embedded Meta-Material Cells

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Abstract

Objectives: To design A high isolation eight-element multiple and input multiple output (MIMO) antenna array tightly arranged based on embedded meta-material cells for the applications of 5G mobile terminals. **Methods:** In this, antenna array with a four block structure in which every block is formed by a method of tightly arranging two Inverted-F Antennas (IFAs) is used. These IFAs antennas are designed by the novel MIMO meta-material Cells which composed of two layers that are mutually connected through shorted pins are embedded with the high isolation using the High frequency structured simulator (HFSS) in the FR-4 (glass-reinforced epoxy laminate material) substrate. **Findings:** Simulation results reveal that the proposed IFAs antennas can provide isolation with a mutual coupling reduction of 18 dB with respect to the transmission coefficients and can also obtain sufficient bandwidth by the proposed antenna array for the 5G mobile terminals applications. **Novelty:** Isolation of Ports in every block can be improved by using the inductor.

Keywords: Multiple Input Multiple Outputs (MIMO); Meta-material cells; tightly-arranged pair and Inverted-F Antennas (IFAs)

1 Introduction

In the present scenario, the potential solutions for the high speed of communications, high communication capacity, short delay times and massive connection density have been offered by the fifth generation (5G) mobile communications technology in a growing demand point of view for high-quality mobile communications. The MIMO (Multiple Input Multiple Output) technology was introduced in the communication system of high distribution environments to effectively increase the channel communication capacity for achieving the goals of 5G mobile communication [1]. In the frequency spectrum of 5G mobile terminals, one of the most frequency spectrums which became most popular is the 3.5 GHz (3.4-3.6 GHz) band [2,3]. Within this, the 5G frequency band, a number of studies have been proposed earlier for mobile phones on MIMO antennas [4].

Integrating the large number of antennas with the low envelope correlation coefficient (ECC) and high isolation within the mobile phone is however became a difficult task for the cell phones in a given limited region [5].

The Multiple Input Multiple Output (MIMO) technologies can significantly improve the efficiency of communication frequency spectrum. There should be a requirement of reduction in mutual coupling of multiple antennas for providing the isolated channels in these MIMO systems [6]. In the space limited mobile terminal however, this was a demanding task. A number of methods are there for the mutual coupling reduction between the tightly arranged two antennas [7–9]. Adding of a new path usually through the typical form of either a decoupling element or neutralization strip is the first method of cancelling out the primary coupling between two antennas. The reduction in mutual coupling between tightly arranged elements is difficult as of the above method has no intuitive design rule. Blocking the coupling path with the help of ground slits or defected ground structure (DGS) is the second method of mitigating the mutual coupling [10]. In third method, however there is a narrow bandwidth in the matching network, this was considered as an efficient method to reduce mutual coupling. Then, general decoupling technology of orthogonal mode with no additional structure is the fourth method of mitigating the mutual coupling. Within a compactness point of view for the fifth generation MIMO antenna systems, several studies have been focused and a dual antenna pair is introduced with the main goal of compactness by tightly integrating the two antennas with a high isolation [11].

In order to improve the isolation between the antenna elements, several methods have been introduced to reduce mutual coupling. Some of those methods are electro-magnetic band gap, neutralization line technology, mushroom-shaped decoupling structure and meta-material decoupling. In contrast to the MIMO antenna with and without implementing of these decoupling structures, an improved isolation can be achieved in the MIMO antenna with the above decoupling structures [1]. Design of some of those decoupling structures is complex and some of other structures have a large size. The meta-material structures are attaining a great attraction in the present scenario and are also most extensively considered for a variety of applications. Antenna arrays have been applied with the meta-material structures as a possible application for the decoupling of antenna arrays [2].

In this work, a compact MIMO antenna with eight elements for 5G mobile devices using a highly isolated external decoupling method is proposed. Structure of the proposed eight-element antenna is composed of four blocks and in an every block two tightly arranged elements designed. High isolation at the ports can be achieved by using the lumped component of inductor. Moreover, the use of five double-layer meta-material cells embedded in the FR-4 substrate can implement a high isolation by installing those cells in the center of each block element.

2 Configurations of dual-element MIMO antenna

There are three types of arrangement used widely for the two elements in the designing of dual-element MIMO antenna. The configurations of face-to-face, back-to-back and face-to-back are such arrangements. These three different types of arrangements designed based on the IFA element with dual element antenna are shown in the Figure 1. All of the three configured designs have the same dimensioned elements. 35 mm, from the corner of the platform is predetermined as an offset distance (p). The three configured arrangements are discussed with the mutual coupling concept separately in the following contents.

2.1 Face-to-face configuration

This discussed the face-to-face configuration of dual element design. The spacing between the two elements is different in port isolation of those two elements [3]. Maintaining the 5 mm of edge-to-edge distance attains the strong mutual coupling which is about to 5 dB. The space of elements is required to be increased in order to improve the isolation [12]. If even reaching of 20 mm distance also the insulation is still 10.5 dB only. Hence, increasing element space is not a good option. Then the mutual coupling is reduced by using the Lumped inductor. This Lumped inductor is employed in the IFAs in-between two open stubs [13]. Just 1mm of edge-to-edge distance (d1) is set which corresponds to the wavelength in free space ($\lambda 0$) of 0.01 at a 3.5 GHz.

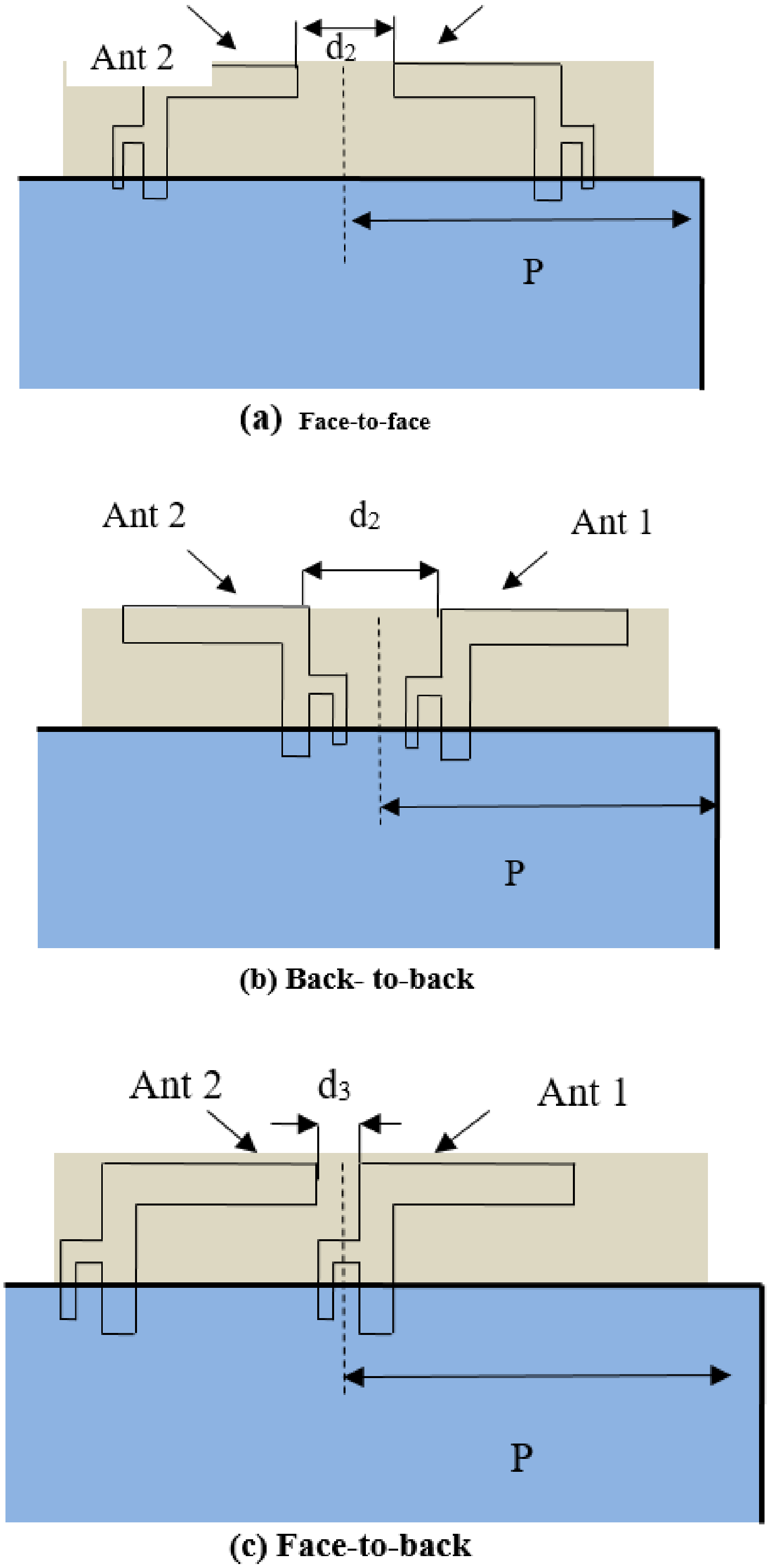

Fig 1. Three Dual-Element Antenna Configurations

Then the principle of decoupling operation is explicated. In a λ / 4 mode of operation, these IFAs are operated. Current became maximum at the supply port and gets minimum at the open stub end. In this arrangement of face-to-face configuration, the minimal positions of current in the two elements are approached each other. The operating mode of elements is being kept uninfluenced by feasibly employing a lumped inductor. Thus, an additional current path which cancels out the existed coupling is provided by introducing of the inductor. The inductor's L value controls the intensity of that current path.

2.2 Back-to-back configuration

This discussed about the dual element design in back-to-back configuration which means approaching of two feed ports one and each other. The isolation of the port consists of spaces with different elements[14]. Maintaining the 5 mm of edge-to-edge distance in this configuration attains the strong mutual coupling of a peak value about to 5 dB. Port isolation increases with increasing distance however with a low tendency[15]. If even reaching of 20 mm distance only also attains a high peak value of -9.3 dB. It should be noted that an effective way of reducing the mutual coupling is employing of an inductor on a minimal position of current of the two elements in the face-to-face arrangement configuration of design[16]. Whereas, employing of a capacitor in accordance with the complementary theory on the maximal position of current of the two elements can be a promising method of decoupling for this back-to-back configuration[17]. At this maximal position of currents, a 0.2 pF value of Lumped capacitor is employed in-between two open stubs of IFAs. 2.5 mm of edge-to-edge distance is set. Effect of introducing the capacitive feed is analyzed by modifying this back-to-back model. The operating mode of λ/4 is maintained for each element by replacing the feed port as inductor with a shorted pin. This shorted pin and shunt stub are fused as a single pin. A short stub serves as a capacitive feed. The energy is coupled from the short stub by folding the open end stub. The distance is 0.2 mm from the short stub to folded stub. 1mm is the edge-to-edge distance between the two elements and 0.5 pF is the capacitor value of C. Apart from the s4 = 8.4 mm and s5 = 2.6 mm all the other parameters remain unchanged.

2.3 Face-to-back configuration

In this the face-to-back arrangement of configuration is described in which open stub of one IFA is tightly arranged to the feed port of the other IFA. The spacing between the two elements is different in port isolation[18]. Mutual coupling weakens when there is an increase in edge-to-edge distance but if even the distance is increased up to 20 mm also, the maximum port isolation is about to 10dB only. Finding out of an inductor or capacitor is a difficulty in order to provide an additional coupling path since considering of fact that maximal current position of two elements in a IFA are closer to each other[19]. Since those components are not arranged as symmetrical form, a different effect is there on the two elements[20].

It was concluded from the analysis of above three configuration arrangements is that high port isolation can be achieved for all the three configurations by introducing of either inductor or capacitor[21].

3 High isolation eight-element MIMO antenna design

This paper proposes a high isolation eight-element MIMO antenna array tightly arranged based on embedded meta-material cells. Firs the eight-element antenna design is divided in to four dual element blocks then each block is designed with a embedded meta-material cells with the tightly arrangement for the high port isolation and lastly four blocks are designed as a one antenna structure. Meta-material cells with five dual layers are installed in between the two antenna elements to implement high insulation by embedding it on a FR-4 substrate. The HFSS is used to investigate the proposed eight-element MIMO antenna.

3.1 Design element

In a design of MIMO antenna, one of the more significant elements is the Monopole. This operated under the λ/4 mode. The antenna design size can be reduced by bending the strcture into "L" shape. Often a shunt stub is connected to act as a suitable inductor if the monopole approaches to ground. Similar to the inverted F antenna (IFA), this modified structure also a familiar. IFA element design is placed on a mobile platform which operates under the 3.5GHz band along a lengthy side. 35mm distance is maintained from the short length side of platform to open stub of IFA. The FR4 substrate with a thickness of 0.8mm, $\acute{\varepsilon}_r$ of 4.4 and tanδ of 0.02 is used on which the IFA and ground plane are printed. 3mm is the antenna element size where as ground plane comprises 140*70mm^2 of a size. IFA has a much better impedance matching. IFA bandwidth for a -6dB is approximately420MHz.

3.2 Mimo antenna array configuration

Figure 2 shows the configuration of the proposed MIMO antenna array. Two identical patch antennas of rectangular shape with a five meta-material cells are there in the MIMO antenna. The FR4 substrate ($\acute{\varepsilon}_r$ =4.4, tanδ=0.02) with a thickness of 1.6 mm is used on which the MIMO antenna array is printed. Coaxial feed lines are used to feed the two patch antennas which were separated with a distance of 0.13mm. The structure of decoupling designed is a two-layer meta-material. The top layer is embedded at a distance of 0.1mm to upper surface in the FR-4 substrate is a T-shaped stub structure where as bottom layer also embedded at a distance of 0.8mm to the lower surface in the FR-4 substrate which consists of two inverted U-shaped patches. The top layer is connected to the bottom layer with the help of two short pins.

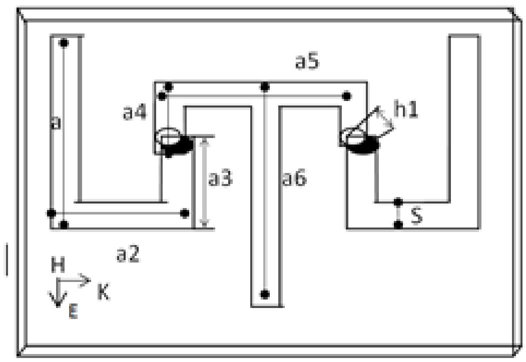

Fig 2. Configuration of the Two-Layer Meta-Material Cell

The proposed two-layer meta-material structure is shown in Figure 2. Dimensions for the proposed two-layer MIMO antenna with the designed two-layer meta-material are W = 60mm, L = 60mm, W1 = 15mm, L1 = 30mm , d1 = 7mm, d2 = 15mm, m = 11mm, n = 7.5mm, s = 0.8mm, a1 = 6.3mm, a2 = 3mm, a3 = 2.5mm, a4 = 2.5mm, a5 = 5.2mm, a6 = 6.3mm, h = 1.6mm, h1 = 0.8mm, h2 = 0.1mm.

3.3 Block design with two elements

The MIMO antenna consists of eight IFA elements that form four blocks. Along the two lengthy side edges, these four blocks are arranged on a ground plane. The 35mm is the distance from the corner of ground plane to the center of each block. 150mm × 75mm is the dimensions for this ground plane. The block dimensions can be shown from Figure 3 in detail. This block has two IFAs. The FR4 substrate that has a thickness of 0.8mm, $\acute{\varepsilon}_r$ of 4.4 and tanδ of 0.02 is used to print those two elements arranged in a face-to-face configuration. Edge-to-edge distance between the two elements is only 1mm. The two open stubs of IFA elements are added with one inductor of an 18nH value. The block folds 90 degrees along the edge of the mobile platform. Ground clearance becomes zero between the antenna and the ground plane.

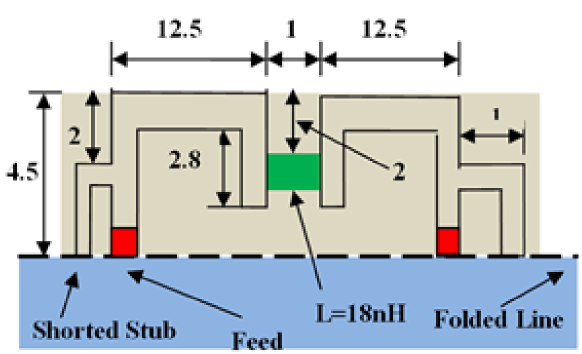

Fig 3. Dimensions of the Two Tightly-Arranged Elements Block (Unit: mm)

3.4 Eight element MIMO antenna design

Based on the proposed dual element structure, a MIMO antenna design with eight elements is proposed. The antenna consists of four blocks. Each block is offset 40mm from the center of the long edge of the frame floor. All two adjacent blocks are mirrored about the symmetrical axis. Eight SMA (Sub Miniature version A) connectors are used to connect the power line from below. Changing the position of the blocks has little effect on performance as the elements are the main radiators.

The structure of the proposed antenna set is has an antenna array consists of six L-shaped slot antenna elements positioned along the two long edges of a 68mm × 136mm ground plane (typically on a 5.3-inch Smartphone) Two antenna elements Inverted Fs attached inside the FR4 -Substrates are positioned perpendicular to the ground plane. L-shaped slit antenna elements and inverted F antenna elements have orthogonal polarization to improve isolation. Furthermore, the space between the two inverted antenna elements F can be increased due to the central symmetrical structure of the antenna array. Therefore, good isolation between the two inverted antenna elements F can be further improved. Also there is enough space for 2G / 3G / 4G antennas.

4 Results

4.1 Diversity Performance

The envelope correlation coefficient (ECC) is measured in an anechoic chamber and calculated with complex radiation far field in order to evaluate the performance of the diversity quantitatively for the proposed MIMO system. Figure 4 shows the ECCs of the proposed MIMO antenna which were measured. A promising performance of the diversity is shown by the ECCs observed as less than 0.06 / 0.07 in a desired band for the proposed antenna. Because of the higher port isolations and orthogonal radiation pattern, a better performance of diversity is achieved.

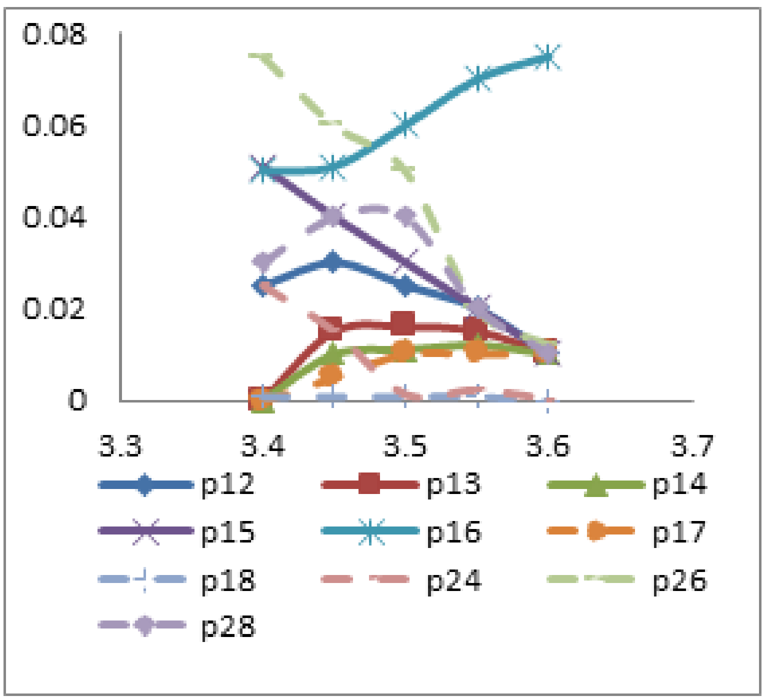

Fig 4. Measured Correlation Coefficients of the 8x8 MIMO System

4.2 Antenna efficiency

The measured efficiencies of the proposed 8 × 8 MIMO system, which is powered through port 1 and port 2, are shown in Figure 5. The antenna efficiency is observed for the proposed antenna when powered at port 1 and ports 2 are as 49%-56.4% and 61.6%-72.9% respectively.

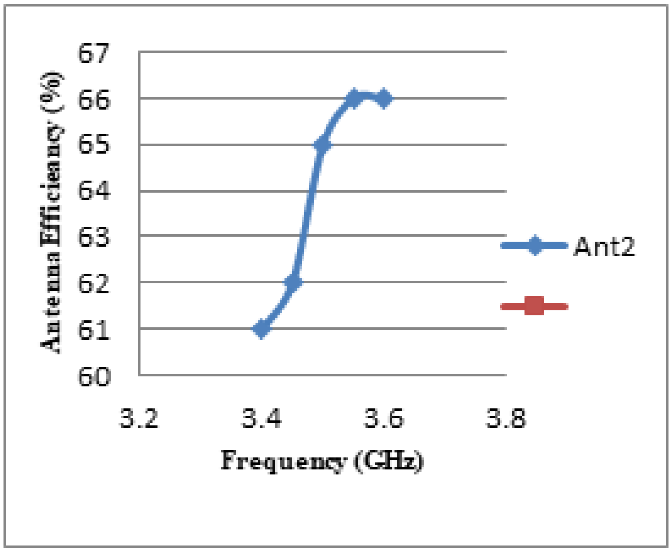

Fig 5. Measured Total Efficiency of 4x4 & 8x8 MIMO Antennas

4.3 Antenna Isolation

The proposed MIMO antenna design is simulated and then measured the S-parameters of the first block. Simulation and S-parameters measures are shown in the Figure 6.

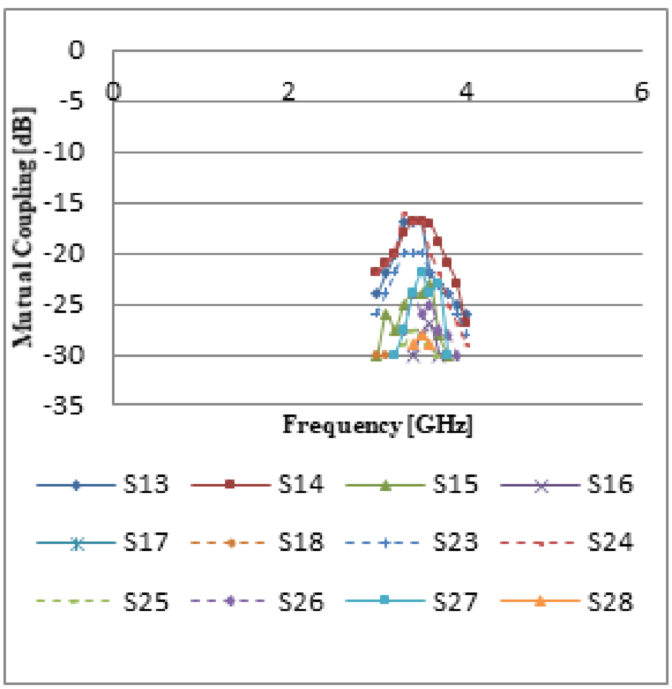

Fig 6. Measured Port Isolation among Different Blocks

As shown from the Figure 6, the port 1 bandwidth is observed as 750 MHz (3.06-3.81 GHz) and port 1 bandwidth is observed as340 MHz (3.33-3.67 GHz) at a mutual coupling rate of -6dB. The required bandwidth to cover the frequency band of 3400-3600 MHz is observed as 340 MHz. Then the port isolation at this overlapped bandwidth observed as greater than 14 dB. Figure 6 shows the mutual coupling measured between different blocks. It can be seen that the isolation between any two ports is greater than 17 dB. The mutual coupling measuring for the different blocks is shown in the Figure 6 which can be concluded that the port isolation is higher than 17 dB between any of two ports.

D. Comparison

The analysis of comparison between the existed antenna designs and proposed antenna design is tabulate in the Table 1 which can explicitly shows the advantages of the proposed MIMO system. It can be concluding from the Table 1 is that, performance of proposed MIMO antenna has a better ECC, efficiency and high isolation than the existed designs even though they are highly compact with two-quarter wavelength units. Furthermore, the decoupling mechanism of proposed design is also different from existed antennas.

Table 1. Comparative analysis

Antenna array	ECC	Efficiency	Isolation
Orthogonally Dual polarized antennas	<0.14	>46%	>9dB
mirrored gap-coupled loop antennas	<0.12	>42%	>9dB
Quad-antenna linear array	<0.23	>41%	>13dB
Proposed tightly arranged IFAs	<0.06	>61%	>17dB

5 Conclusion

A high isolation eight-element MIMO antenna array tightly arranged based on embedded meta-material cells is proposed in this paper for the 5G mobile terminal applications. The meta-material cells composed of two layers at different levels are embedded within a design of MIMO antenna is proposed and the HFSS is used to investigate the performance of proposed antenna. It has a four blocks in the structure in which every block has an area occupied with the 27.4 mm $\times$ 4.5 mm. Face to face configuration is implemented in each cell that tightly arrange the two IFA elements. Just a 1mm dimension has been given between the edge to edge distances of two IFA elements. Coupling of an inductor had canceled the mutual coupling. As illustrated from the results the proposed MIMO antenna provides a high efficiency and a high isolation with the mutual coupling reduction of 18 dB compared to the other existed antenna structures. Then the proposed antenna is most suitable for the 5G mobile terminal applications by these advantages of compact antenna size and high isolation properties.

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