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Analysing the Characteristics of MIMO Antennas: Enhancing Isolation and Employing Soft Computing Techniques via a Systematic Review

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Abstract: MIMO systems play a crucial role in communication systems due to their reliance on antenna design for the air interface. As network evaluations continue, there have been advancements in network capacity and technology to meet user requirements. Recent literature focusing on the MIMO system has revealed that metamaterials and soft computing approaches offer improved performance for mobile communication. This review encompasses the literature on the MIMO system, employing various design models and covering standard journals from 2016 to 2023. All research studies discussed in this review utilized tools such as HFSS, CST, and MATLAB. Additionally, a concise examination is conducted on isolation enhancement and soft computing approaches. Furthermore, a comparative analysis is provided for diversity measures including isolation, gain, axial ratio bandwidth, ECC, and CCL. The challenges and future directions highlighted in this review serve as inspiration for antenna researchers to develop MIMO antennas tailored for mobile communication.

Keywords: *Input Multiple Output, Mobile Communication, Metamaterials, Soft Computing Approaches, Diversity Measures, Isolation methods and Mutual coupling.*

1. INTRODUCTION

Multiple-input multiple-output (MIMO) are broadly employed in advanced telecommunications systems including long-term evolution (LTE) and wireless local area network (WLAN). The primary characteristics of 5th-generation mobile communication system are higher data rates, higher reliability, and lower latency [1]. Nowadays, MIMO technology has been used in numerous applications for achieving high data rates by increasing the channel capacity [2]. Modern communication systems should support many communication standards using a single compacted antenna without degrading the data rate. A high-speed multiband communication is supported by reconfigurable MIMO systems [3].

The ability to change the characteristics of radiator with regard to resonant frequency, radiation pattern or polarization is referred to as an antenna's reconfigurability [4]. The reconfigurable MIMO antenna uses electronic switching constituents like radio-frequency micro-electro-mechanical systems (RF MEMS) [5], positive-intrinsic negative (PIN) diodes [6], and varactors [7] to vary the antenna properties.

But the total volume of the antenna is increased due to the integration of these switching devices into a MIMO antenna.

As a result, it is challenging to incorporate reconfigurable MIMO antennas onto a smaller and compacted wireless device while retaining high isolation between the components. Therefore, reconfigurable compact MIMO antennas must tackle the issues of isolation and reconfiguration without increasing the antenna dimension.

In recent days, several MIMO antenna array types have been described to suit the needs of WLAN/5G standards. High port isolation, single- or dual-band operation, and a small dimension are all desirable characteristics of these arrays. Because it significantly affects the system's overall performance, including its spectrum efficiency, spatial correlation, and channel capacity performance, mutual coupling (MC) between the antenna components is an important design aspect for MIMO systems [8]. Numerous external and internal decoupling mechanisms have been created in order to promote isolation or to reduce MC between antenna parts [9]. The internal decoupling can also be called as self-isolation method. In MIMO systems, the external decoupling techniques are subject to design and size constraints. Alternatively, the internal decoupling or self-isolated technique provides the best isolation with a simplified circuit, increased efficiency, and small size.

The isolation in the operating frequency band can also been improved with the use of electromagnetic band gap (EBG) [10], appropriate structure planning [11], proper placing of split ring resonator (SRR) [12], U-shaped neutral lines [13], and loading grounded branches [14].

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The polarisation orthogonality can also enhance the isolation of MIMO antennas. Furthermore, the available MIMO antennas often offer two or three frequency bands but their size of substrate is very high. Also, the isolation of these antennas may not be strong enough. Therefore, there is still a strong need for further development of dense multiband MIMO antenna. The contribution of the review methodology is defined below:

- In this paper, the designs of MIMO antennas and their characteristics are discussed. This study mainly concentrates on well-ordered statistics regarding MIMO antenna designing procedures for analysing the necessary antenna performance.
- Also, the impacts of MC on MIMO systems and the standard MC reduction strategies are also thoroughly reviewed in this work. Decoupling networks, parasitic elements, infected ground structures, neutralization lines, and metamaterial absorbers are just a few of the MC reduction approaches that are presented along with their design structures.
- Several grouping of MIMO antennas with soft computing approaches are also discussed namely, ultra wide band (UWB) MIMO antenna, Dual band MIMO antenna and circularly polarised (CP) MIMO antenna with its design and fabricated structural designs.
- Additionally, the assessment tables included in the text will assist researches to put the defined ideas into practise and adapt them for improving MIMO antenna performance. This work can offer more clarity on challenges and potential future research directions with the help of THz technology for emerging 6G communication systems.

The organization of the review paper is as follows: The systematic review methodology with research questions is discussed in section 2. The diversity parameters of the MIMO antenna are discussed in section 3. The isolation enhancement techniques are described in section 4. Section 5 describes the several categorizations of MIMO antenna. Section 6 describes the soft computing approaches to optimize the design parameters of the antenna. Section 7 and 8 describes the MIMOP characteristics for 5G and challenges. Finally, the review ends with section 9 conclusion.

2. REVIEW METHODOLOGY

The review methodology to explain a systematic review undergoes three main stages namely, planning, conducting and reporting phase. In the planning stage, the research questions are raised for the purpose of review. In the conducting phase, the searching process is employed and in the reporting phase, the evaluation of work report is employed.

2.1 Research questions

The main goal of the systematic review is to address the following research questions which are listed below:

- ❖ What are the isolation enhancement techniques are employed to prevent MC reduction?
- ❖ What optimisation methods are employed to improve MIMO antenna?
- ❖ What are the defective ground structures are placed to enhance the efficiency of the MIMO antennas?
- ❖ What are the categorization of MIMO antenna are being studied?
- ❖ What MIMO antenna parameters are being studied?
- ❖ What are the major challenges to design the MIMO antenna?

2.2 Search strategy

Based on the research questions and other goals the searching strategy is conducted. In the searching phase, the word searching, inclusion/exclusion-based searching process and the resource referred are carried out. The word searching process is adapted by the combination of some hint words namely, “MIMO”, “Isolation”, “mutual reduction”, “optimization” and “circularly polarised”. The resource referred are IEEE, Springer, Elsevier, research gate, science direct and Web of Science (WoS).

2.3 Study selection

In order to assess the articles' true significance, there is a need to scan the titles and journals of the paper and it had been done. In the exclusion stage, the research which were irrelevant are eliminated. Additionally, to screen each manuscript the particular criteria is utilised by excluding the subsequent kinds of papers:

- ➢ Exclude papers that served just as posters.
- ➢ Exclude surveys without proposed design.
- ➢ Exclude surveys with unclear information about the publication.
- ➢ Papers whose first language was not English should be excluded.
- ➢ Exclude the technical reports and the papers which were published in workshops.

3. PARAMETERS OF MIMO ANTENNA

A number of crucial characteristics, including Channel Capacity Loss, Envelope Correlation Coefficient (ECC), Mean Effective Gain, Diversity Gain, and Total Active Reflection Coefficient, must be examined in order to assess the diversity performance of the MIMO antenna.

3.1 Envelope Correlation Coefficient (ECC)

The ECC of MIMO antennas is a crucial metric for determining the level of channel isolation in a multi-channel communication system. If the value of ECC is low then the mode diversity of the antenna will be very high. The radiation pattern of MIMO is used to express the ECC mathematically as given below [15]:

$$ECC_{u,v} = \frac{\left| \iint_{4\pi} \left[\vec{E}_u(\theta,\varphi) \cdot \vec{E}_v(\theta,\varphi) d\Omega \right] \right|^2}{\iint_{4\pi} \left| \vec{E}_u(\theta,\varphi) \right|^2 d\Omega \iint_{4\pi} \left| \vec{E}_v(\theta,\varphi) \right|^2 d\Omega} \quad (1)$$

$$ECC_{u,v} = \frac{\left| S_{uu}^* S_{uv} + S_{vu}^* S_{vv} \right|^2}{\left(1 - |S_{uu}|^2 - |S_{vu}|^2\right)\left(1 - |S_{vv}|^2 - |S_{uv}|^2\right)} \quad (2)$$

It is evident that the majority of planar antennas experience loss and hence the method that uses S-parameters to calculate ECC should be avoided

3.2 Diversity Gain ($DGain$)

$DGain$ of a MIMO antenna in wireless systems represents its superiority and dependability. $DGain$ should be higher than 10 dB within the permitted frequency range for the MIMO antenna. The $DGain$ can be computed based on ECC value as given below:

$$DGain_{u,v} = 10 \times \sqrt{1 - \left| ECC_{u,v} \right|^2} \quad (3)$$

3.3 Channel Capacity Loss ($CCLoss$)

The maximum amount of information that may be transferred across a communication link with nearly zero loss is known as the $CCLoss$. $CCLoss$ of any MIMO system should be less than 0.4 bits/s/Hz. The following is the formula for $CCLoss$ with respect to S-parameters:

$$CCLoss = -log_2\, det\left(\chi^R\right) \quad (4)$$

Where χ^R denotes the correlation matrix of the receiving antenna

$$\chi^R = \begin{bmatrix} \xi_{11} & \xi_{12} & \xi_{13} & \xi_{14} \\ \xi_{21} & \xi_{22} & \xi_{23} & \xi_{24} \\ \xi_{31} & \xi_{32} & \xi_{33} & \xi_{34} \\ \xi_{41} & \xi_{42} & \xi_{43} & \xi_{44} \end{bmatrix} \quad (5)$$

Where ξ_{uu} and ξ_{uv} for $i, j = 1,2,3,4$ are described as given below:

$$\xi_{uu} = 1 - \left(\sum_{v=1}^{4} |S_{uv}|^2 \right) \quad (6)$$

$$\xi_{uv} = -\left(S_{uu}^* S_{uv} + S_{vu}^* S_{vv} \right) \quad (7)$$

3.4 Mean Effective Gain (MEGain)

MEGain is the proportion of average received power to average incident power and this parameter is important to examine the performance of MIMO antennas. The MEGain can be estimated using the following formula [16]:

$$MEGain = \frac{1}{2}\left(1 - \sum_{v=1}^{4} S_{uv} \right) \quad (8)$$

For optimal diversity performance, the typical value of $MEGain$ should be $-3dB \le MEGain \le -12dB$.

3.5 Total Active Reflection Coefficient (TARefC)

The proportion of the total power that is reflected from the radiating components to the total power that is incident on the patch is known as the TARefC of a MIMO system. The following expression provides the equation for the generalised TARefC for an N-port MIMO antenna [17]:

$$TARe\,fC = \frac{\sqrt{\sum_{u=1}^{4} |q_u|^2}}{\sqrt{\sum_{u=1}^{4} |p_u|^2}} \quad (9)$$

Here $q_u = [s] \cdot p_u$. Also, $[s]$, $[q]$ and $[p]$ denote the scattering matrix, scattering vector and the excitation vector correspondingly. The TARefC for two-port MIMO antennas is expressed as follows:

$$TARe\,fC = \frac{\sqrt{\left(\left| \left(S_{11} + S_{12} e^{j\theta} \right) \right|^2 + \left| S_{21} + S_{22} e^{j\theta} \right|^2 \right)}}{\sqrt{2}} \quad (10)$$

The TARefC measures how much power is reflected and how much is incident, and it is anticipated that the antenna will take all the power. As a result, the TARefC value for the MIMO antenna should ideally equal 0.

4. ISOLATION ENHANCEMENT IN MIMO ANTENNA

MC occurs in MIMO antenna, when antenna elements are placed in the orthogonal manner. This coupling can be reduced by utilizing the antennas with certain separating distance from the terminal of mobile. The antenna can be kept at the upper and lower segments of top two edges. Antenna positioning causes the phases in the coupling currents and polarization [18]. The field and group coupling models are reduced when the adjacent antennas are placed in the perpendicular position. When linear polarization antennas are placed in the orthogonal manner, it may enhance the isolation and ensure diversity in polarization. But, these kinds of antennas need huge spacing and ground [19]. There were five isolation enhancement approaches are proposed in the existing literature works.

4.1 Decoupling networks (DN)

The term MC is the electromagnetic field interaction among the elements of antenna. This coupling affects the matching behaviour, radiation pattern and voltages of the receiving elements. The DNs are utilized for minimization of coupling; these networks decouple the adjacent element's input ports by utilizing the negative coupling. Hence, it eliminates the coupling occurred by the adjacent ports. Lumped and distributed components are utilized to reduce coupling and enhance the isolation. One of the major advantages of DNs is the spatial efficiency. Some of the literature works based on the DNs are reviewed here.

Roy, S. and Chakraborty [20] designed multiple band MIMO antenna with SRR based DN model. The antenna was fabricated by the jean substrate having the dimension of $100mm \times 60mm \times 1mm$. The antenna resonated at two frequencies and achieved better gains of 3dB at 2.4GHz and 5dB at 5.8 GHz. Islam et al. [21] developed reconfigurable MIMO antenna and filtering based DN for cognitive communication. The antenna operated at 4.7 GHz (mode 1) and 4.7 GHz (mode 2) and obtained radiation efficiency of 92.04% (mode 1) and 89.64 (mode 2). There are two types of the decoupling models; they are external and internal decoupling. External decoupling models are based on the inclusion of additional elements for minimization of coupling. Some of the techniques utilized in 1G to 6G for external decoupling are NL (neutralization lines), defective ground structure (DGS), and metamaterial-based designs. Internal decoupling models are based on the diversity in polarization and some of the techniques utilized for internal decoupling are multiple polarization and orthogonal polarization. The design of MIMO antenna with DN is illustrated in Figure (1).

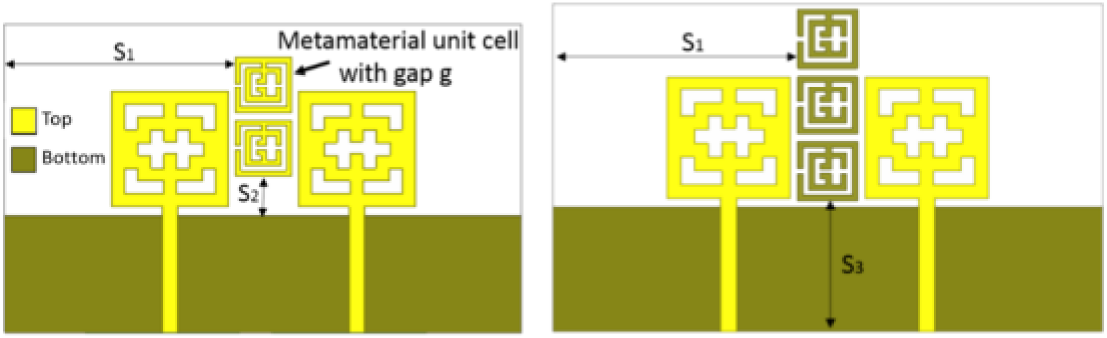

Figure (1) Design of MIMO antenna with decoupling network [20]

4.2 Parasitic elements (PEs)

PEs are not linked with the elements of antenna and these elements eliminate the coupling by generating the opposite coupling. Further, these elements are developed for enhancing the bandwidth and isolation. Bamy et al. [22] developed miniaturized dual band antenna with PE for 5G application. For attaining better electromagnetic performances of antenna, two F shaped PEs were utilized. Kim-Thi et al. [23] presented CP based MIMO antenna with PE for enhancement of isolation. Authors were utilized four PEs and it was placed on one part of the radiation patch for the enhancement of isolation and gain. Tran et al. [24] presented 4-square patches as PEs for the isolation enhancement in two port MIMO antenna. Inclusion of PE ensured high resonance in the large frequency range. The experimental analysis proved that with PE achieved better impedance of 14.8%. The design of MIMO antenna with PEs is illustrated in Figure (2).

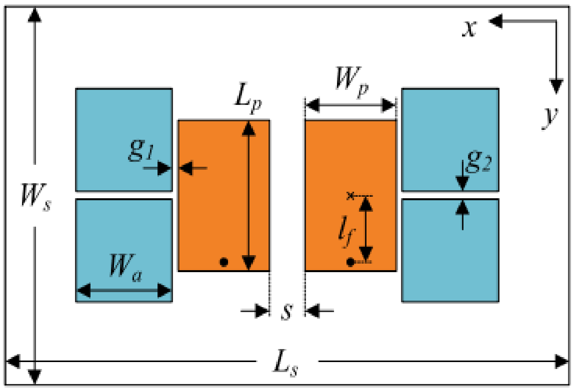

Figure (2) Design of MIMO antenna with parasitic elements [24]

4.3 Defected ground structures (DGS)

Slots and defects fixed on the ground plane of antenna is called as DGS. Because of the simple design structure, DGS attained more popularity. The efficiency and isolation are enhanced by DGS. The surface current developed on the ground is coupled with the nearby components and it causes large coupling. This can be overcome by introduction of the DGS at the ground plane. Some of the shapes of the DGS are E-shape, I-shape, spherical, circular and rectangular. It is the simple format of the EBG (electromagnetic band gap). The DGS have benefits in the field of power amplifiers, couplers, microstrip antennas and MIMO antennas. One of the major challenges of using DGS is that the disturbances were occurred on the ground. This minimizes the combining capacity of the model on the multiple layered architecture.

Khalid et al. [25] developed 2x2 MIMO antenna with DGS for mmWave-5G applications. Dimension of the antenna was $30mm \times 28mm \times 0.508mm$ and the design was operated at 26.41 GHz. Hakim et al. [26] designed a single and 4-port MIMO antenna for 5G application. Here, the DGS based stub slotted antenna configuration was utilized and for attaining the wide bandwidth, the DGS was utilized. Dey et al. [27] developed EBG with hair pin shaped DGS for the isolation enhancement in MIMO antenna for 5G application. Due to the introduction of hair pin shaped DGS, the isolation was improved by 47.7dB. The design of MIMO antenna with DGS is illustrated in Figure (3).

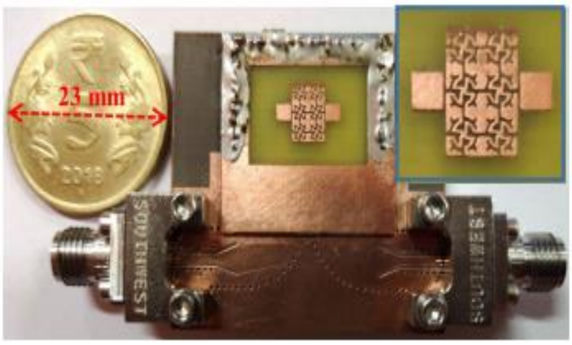

Figure (3) Fabricated design of MIMO antenna with DGS [27]

4.4 Neutralization line (NL)

Isolation in MIMO antenna are improved using the NL and the current on the inputs are considered in the specific location. Here, the current is high and the impedance is less and the phase of antenna is reversed by considering the proper length for NL. The NL architectures permits the signals to obtain from one antenna to another. This reversible current is given to the neighbouring element for minimizing the coupling. Wang et al. [28] developed MIMO antenna with simple NL model for 5G mobile application. Here, the design has the compact size of $40mm \times 40mm \times 6mm$ and the NL was placed on the outer region of the board. Du et al. [29] designed coplanar waveguide with three band MIMO antenna and NL for three applications like 5G, WiMAx and WLAN. Here, the meandering NL was placed between the elements of antenna. The design of MIMO antenna with NL is illustrated in Figure (4).

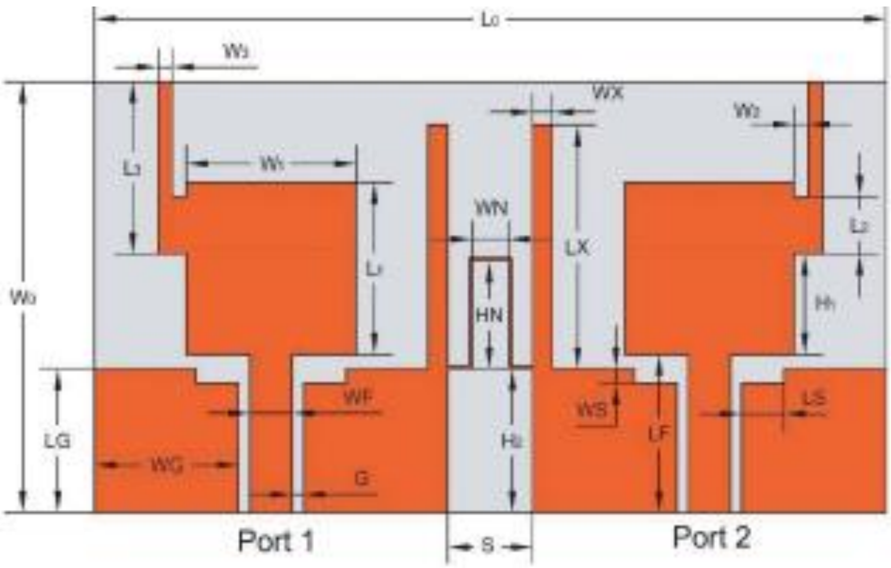

Figure (4) Design of MIMO antenna with neutralization line [29]

4.5 Metamaterial absorber (MTMA)

MTMA are the materials which has either negative permeability or permittivity. There are two types of MTMA and they are MTMA based MIMO antenna and MTMA unit cell. The first model utilizes NZI (non-zero index), DNG (double negative), ENG (epsilon negative) and MNG ($\mu-$ negative). Then, the second model utilizes SRR and CSRR based antennas. MTMA are utilized to enhance isolation and it act as the band notch filtering. Most of the 5G and 6G antennas literatures utilized SRR and CSRR due to its simple nature and cost effectiveness. Zhou et al. [30] presented single layered MTM for attaining high gain in MIMO model. The MTMA was made by enhanced SRR and square metal meshing at various surfaces. The impedance bandwidth attained was -10 dB and the coupling was reduced by -45 dB. Krishnamoorthy et al. [31] designed 4-port MIMO antenna which operated at 38 GHz for 5G applications. Here, the three element SRR was fixed to the patch radiator and it allowed to operate at the desired frequency.

Shabbir et al. [32] developed 16 port MIMO antenna with NZI-ENG for 5G communication. The antenna was designed on the FR-4 substrate and has the dimension of $22mm \times 20mm$ and covered the frequency of about 3.35 to 3.65 GHz. Due to the inclusion of NZI-ENG, the isolation attained was higher than 30 dB. The design of MIMO antenna with MTMA is illustrated in Figure (5).

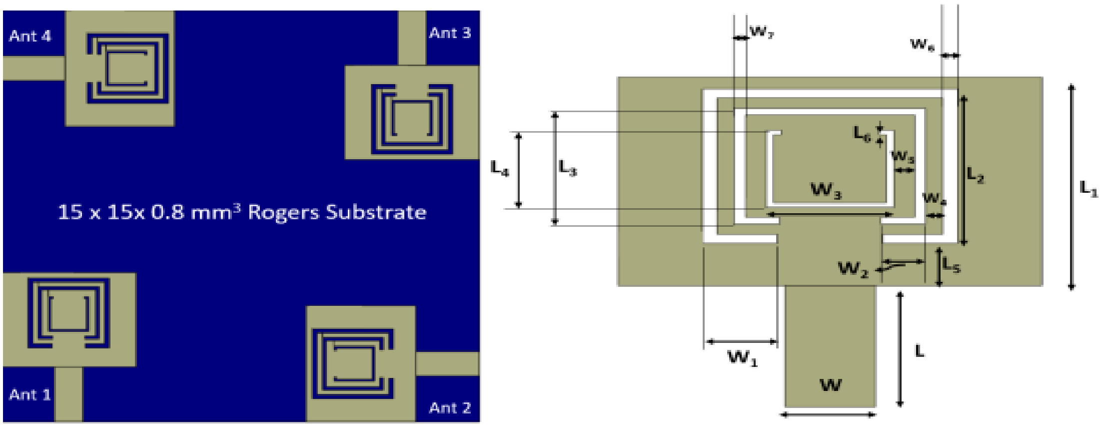

Figure (5) Design of MIMO antenna with metamaterial absorber [29]

5. Classification of MIMO antenna

The MIMO antenna are divided in to three main stages namely, ultra wide band (UWB) MIMO antenna, Dual band MIMO antenna and circularly polarised (CP) MIMO antenna. The following sections provide further details on each type of MIMO design. The design approaches of UWB MIMO antenna, double band antenna, CP antennas with its radiating component and ground planes are illustrated in Figure (6).

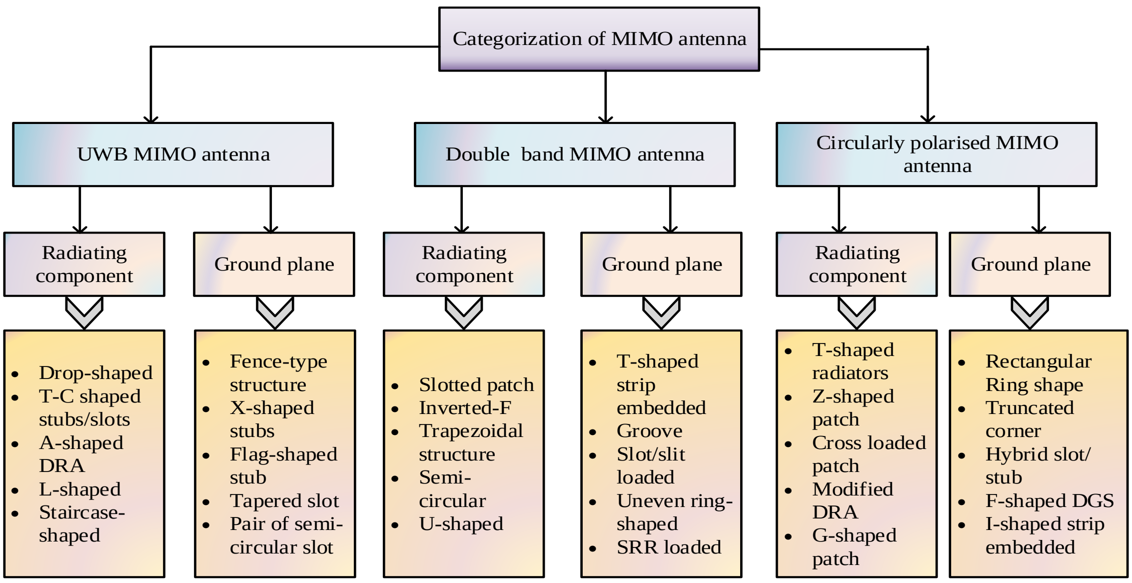

Figure (6) Categorization of MIMO antenna

5.1 UWB MIMO antenna

The frequency range of 3.1 to 10.6 GHz is offered by UWB technology and it has a channel bandwidth of more than 500 MHz. This section describes several UWB MIMO antennas, including changes to ground plane (GP), isolation strategies, and radiating patches

The 4 port MIMO antenna is designed for WLAN application and the groove is etched in the ground plane to avoid MC and it attains an isolation of more than 15dB [33]. The fabrication design is illustrated in Figure (7). In [34], the 4 port high isolation antenna for UWB communication by employing neutralization technique was designed. Tang et al. [35] had designed MIMO antenna for UBW communication with DGS to boost up the bandwidth efficiency of the antenna. For 5G application, Tiwari et al. [36] had designed rhombus shaped UWB MIMO antenna with truncated corners. To upsurge the impedance bandwidth, the symmetric slot antenna had been designed by Wang et al. [37] with quasi shaped slots.

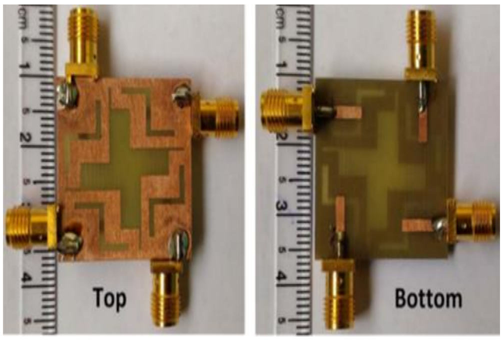

Figure (7) Fabricated four port UWBMIMO design [33]

As stated in [38], a unique antenna array with a decoupling structure is created by placing a tapered slot on the array. In [39], the author had designed MIMO antenna with coplanar waveguide (CPW) feed line and the centrally linked circular slots allows for wideband operation. The CPW feed four port MIMO antenna had designed [40] for wireless application by using a monopole asymmetrical structure.

Tri directional pattern diversity characteristics was considered to reduce MC [41] of the MIMO antenna. Compact size isolation enhanced UWB antenna was designed in [42] with high impedance structures. The fence type decoupling structure was introduced in the ground plane and the rectangular slot on the radiation patch improves the resonance properties [43].

A MIMO antenna described in [44] consist of two identical antenna components and it is placed symmetrically in opposition to one another on a single dielectric substrate. Circular shaped MIMO antenna with X shaped stubs is introduced for good impedance matching [45]. The simulated design of UBW MIMO antenna is illustrated in Figure (8). Table (1) lists the reviewed antennas with their diversity characteristics.

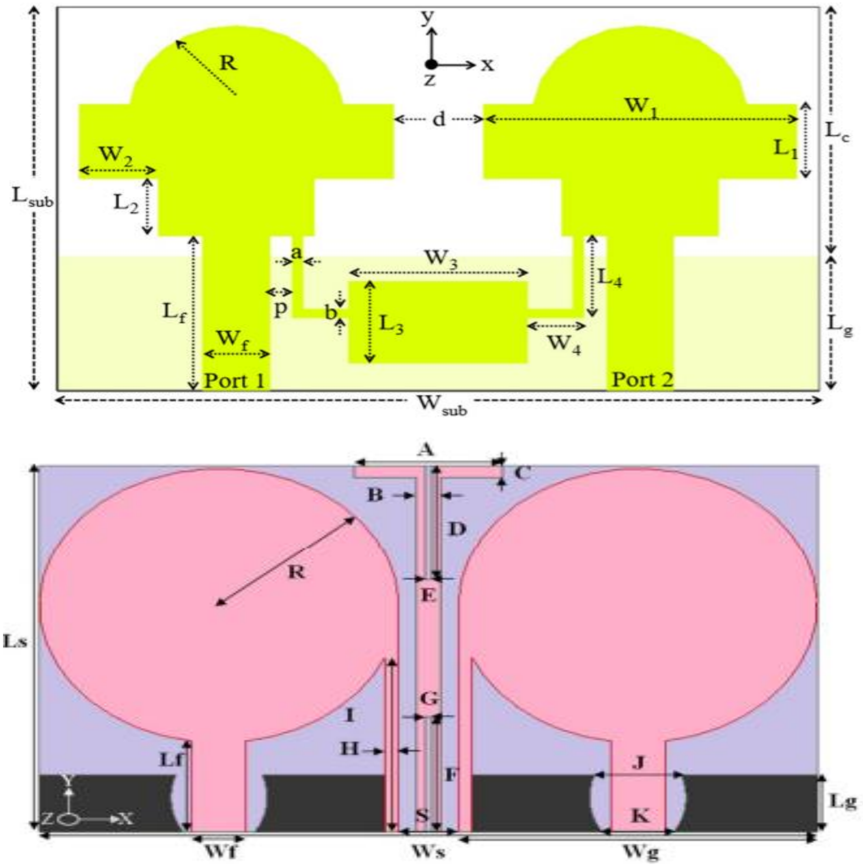

Figure (8) Geometry of the simulated antenna design of UWB MIMO antenna [34, 45]

Table (1) Comparative analysis of UWB MIMO antenna

Ref	Port analysis	Antenna Size (mm^3)	Frequency (GHz)	Isolation (dB)	Gain (dBi)	Efficiency (%)	ECC	CCL
[34]	4 × 4	48 × 34 × 1.6	3.53-10.07	≤−23	2.91	79.80	≤0.039	≤0.29
[36]	2 × 2	25 × 36 × 1.6	2.77-17.44	≤−19	N/A	N/A	<0.008	<0.31
[37]	2 × 2	30 × 50 × 1	3–10.7	≤−20	38	N/A	<0.06	N/A
[38]	4 × 4	42 × 42 × 1	3.4-4.3	≤−10	N/A	64	<0.06	N/A
[40]	4 × 4	45 × 45 × 1.6	4.3-6.46	≤−20	5	90	<0.2	<0.018
[41]	4 × 4	110 × 110 × 1.45	1.8-7.3	≤−20	5.2	90	0.0025	N/A
[42]	2 × 2	29.5 × 60 × 1.6	3-20	≤−20	4.9	83	<0.00012	0.325
[43]	2 × 2	50 × 35 × 1	3-11	≤−25	>3	>80	<0.004	N/A
[44]	2 × 2	18 × 28 × 1.6	1.9-14	≤−15.5	4.8	N/A	<0.09	<0.4
[45]	2 × 2	16 × 26 × 1.6	2.82-14.46	≤−22	6.8	>91	<0.08	N/A

5.2 Dual band MIMO antenna

Two distinct frequencies are used by a dual-band antenna to broadcast and receive radio signals. According to their configuration and intended purpose, these dual band antennas may employ either one of the two frequencies independently or both simultaneously. Due to the elimination of connection issues, the dual-band offers increased dependability, flexibility, and stability.

Several authors had defined dual band MIMO antenna designs with decoupling structures and enhanced high impedance structures to attain a dual band. To attain a dual lower and higher frequency band antenna, the authors had defined comb shaped slots in the ground structure [46], Swastika shaped slot in the patch [47], U shaped slot by adapting arrow shaped strip, and rectangular strip [48]. In [46-48], to enhance the isolation and also to prevent MC, several decoupling structures are placed in the ground planes namely, comb shaped T stubs, defected ground structures geometrical slots and meander line resonance branch respectively [49]. The fabricated four port dual band antenna is illustrated in Figure (9).

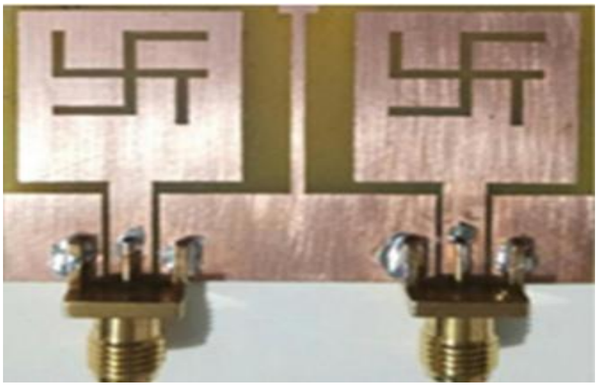

Figure (9) Fabricated four port dual band MIMO design [46]

To achieve good impedance matching in the antenna, two asymmetric U-shaped slots in [50], dummy elements with lower and higher bands are used in [51] a rectangle SRR slot and zigzag conductive strip incorporated into a semi-annular patch also, the fork shaped feed line for isolation enhancement [52].The EBG structures is introduced in [53] and orthogonal plus shaped partial ground in [54], which offers excellent isolation and lowers MC. Table (2) lists the several reported double band MIMO antennas with its parametric analysis. The simulated design of four port dual band antenna is illustrated in Figure (10).

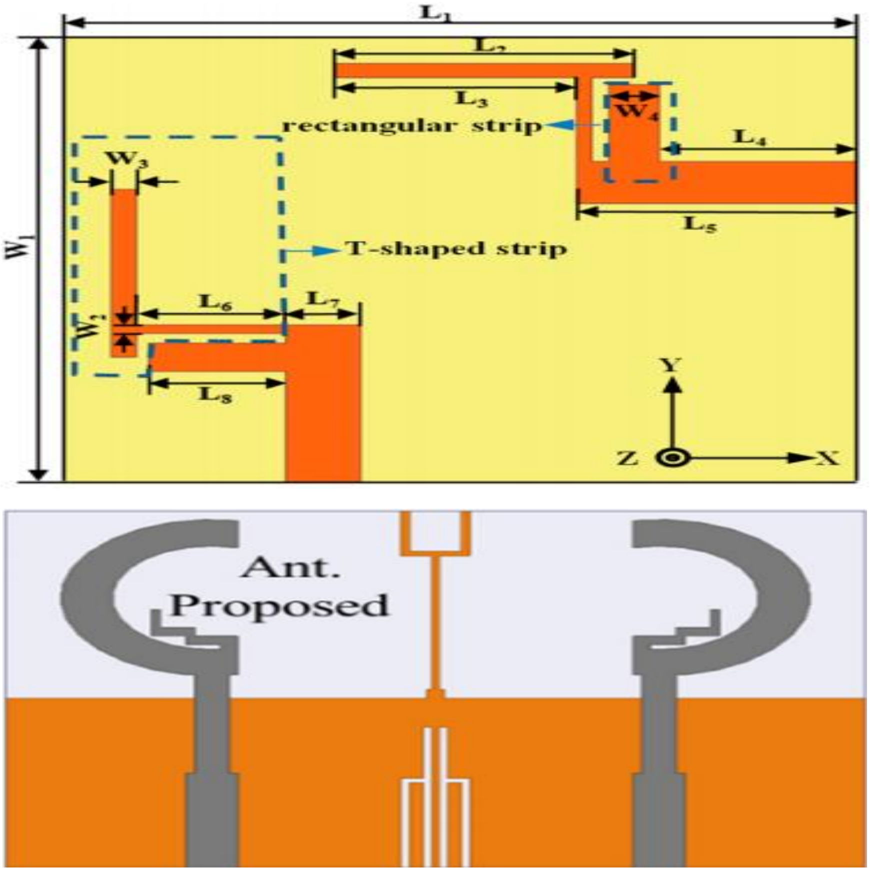

Figure (10) Geometry of the simulated antenna design of dual band MIMO antenna [48, 52]

Table (2) Comparative analysis of dual band MIMO antenna

Ref	**Port analysis**	**Antenna Size (mm^3)**	**Frequency (GHz)**	**Isolation (dB)**	**Peak Gain (dBi)**	**Efficiency (%)**	**ECC**	**CCL**
[46]	2 × 2	20 × 34 × 16	2.1-4.1 /4.9-6.8	<−21	4.19	>70	<0.004	<0.32
[47]	2 × 2	46 × 30 × 1.6	1.8-3.6 /5-7.9	<−17.21	4.1/4.7	92.69/ 90.99	<0.003	<0.35
[48]	2 × 2	32 × 32 × 1.59	2.36–2.59 /3.17–3.77	<−15	5.8	76	<0.02	N/A
[49]	4 × 4	30 × 30 × 0.8	4.5-6.1	<−15.4	4.02	67–82	<0.15	N/A
[50]	4 × 4	38 × 38 × 1.6	2.38–2.45 /2.9-4	≤−18	N/A	N/A	<0.008	<0.35
[51]	2 × 2	70 × 70 × 0.8	2.4~2.5 /5.6~5.8	<−25	N/A	N/A	N/A	N/A
[53]	1 × 2	51 × 29.6 × 1.6	2.4/5.2	<−25	2.2/3.8	N/A	0.07	N/A
[54]	4 × 4	58 × 60 × 1.6	1.5-2.6 /3.3-3.6	<−10	2.2/3.8	N/A	<0.08	<0.4

5.3 Circularly polarised MIMO antenna

CP printed antenna with novel GP is introduced in [55] to produce a CP radiated field and the impedance bandwidth of the antenna. The fabricated CP antenna is illustrated in Figure (11). The shape of the designed antenna is L shape and the diagonal placement of DR are studied in [56]. A CP MIMO antenna is reported in [57], where two of the components exhibit LHCP and the other two exhibit RHCP. A mirrored F-shaped DGS and three grounded stubs are used in [58] for high isolation, and CP is attained using simple offset feeding. The ring shaped design is emphasised in [59,60] to enhance the bandwidth and to attain CP, the rectangular slits are converted in to Z shaped slots. In order to increase bandwidth, two diagonally slotted square patches are created in [61]. Four parasitic elements are also employed to get rid of MC. The simulated design of CP MIMO antenna is shown in Figure (12). Table (3) lists the several reported CP MIMO antennas with its diversity characteristics.

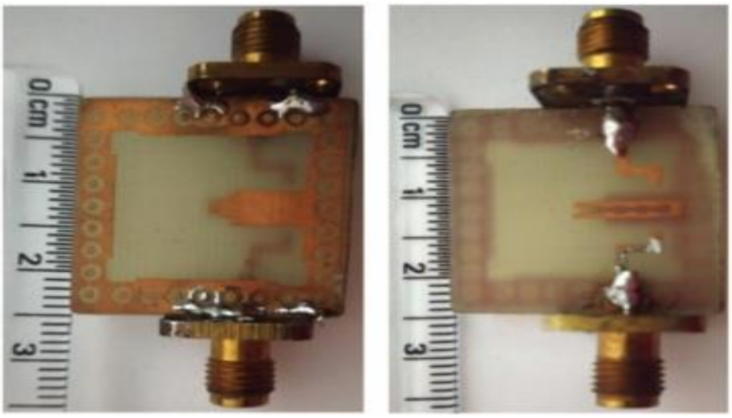

Figure (11) Fabricated CP MIMO design [55]

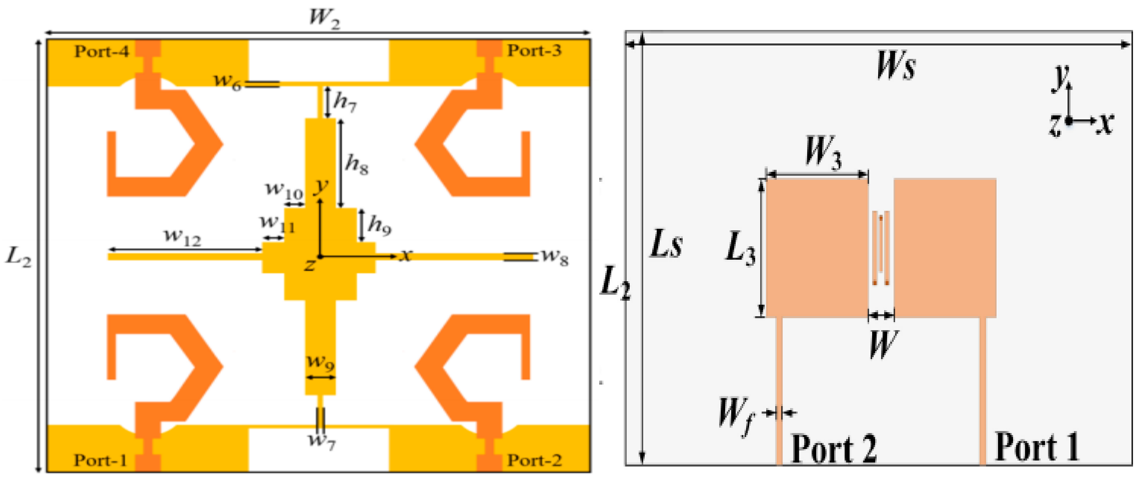

Figure (12) Geometry of the simulated antenna design of CP MIMO antenna [57, 58]

Table (3) Comparative analysis of CP MIMO antenna

Ref	**Port analysis**	**Antenna Size (mm^3)**	**Frequency (GHz)**	**Isolation (dB)**	**Gain (dBi)**	**AR bandwidth**	**ECC**	**CCL**
[55]	2 × 2	24 × 24 × 1.6	3-8.10	<−16	2.7	4.42–6.11	<0.004	<0.32
[56]	2 × 2	350 × 350 × 26.1	3.50-4.9	<−28	6.2	3.5-4.4	<0.04	N/A
[57]	4 × 4	70 × 68 × 1.6	4-13	≤−18	6.4	4.2-8.5	<0.25	N/A
[58]	2 × 2	150 × 100 × 0.8	2.47-2.55	≤−20	6.1	2.5-2.6	0.003	N/A
[59]	4 × 4	80 × 80 × 11.6	3.35–3.82/ 5.09–5.41	<−18	6.8	3.53.7 /5-5.1	<0.04	N/A
[60]	2 × 2	80 × 40 × 1.6	2.9–3.2/ 3.44–3.64/ 4.75–5.5	≤−15	2	3.3-3.5 /5-5.3	<0.2	N/A
[61]	2 × 2	N/A	4.75–5.9	≤−22	8.2	5-5.8	N/A	N/A

6. SOFT COMPUTING APPROACHES FOR MIMO ANTENNA

The optimization in engineering design system is based on the trial and error model. It is not accurate and doesn't perform well on the complex models because of huge design parameters. Hence, the researchers are developing models by programming codes for optimizing sensitive and complex models correctly. Optimizing the parameters of antenna are essential for attaining better performance.

Soft computing approaches (optimization) are utilized in MIMO system for achieving better and efficient solution to the performance. Generally, the length and width of the antenna dimensions are optimized by the metaheurisctic optimization approaches. Soft computing approaches utilized for various applications in wireless communications are J-GWA (jaya-grey wolf algorithm), QNA (Quasi newton algorithm), ACO (Ant colony algorithm), GA (Genetic algorithm), SLA (Sea lion algorithm), SSA (Social spider algorithm), and SSA (Slap swarm algorithm). Some of the MIMO models based on the optimization approaches are described in this section.

Boursianis et al. [62] developed MIMO antenna for 5G application using SSA. Here, the antenna has bow-tie shape and it was operated at 28 GHz. The substrate utilized was Taconic and achieved better isolation of -20dB for the entire resonating frequency.

The simulated design of soft computing based MIMO antenna is illustrated in Figure (13).

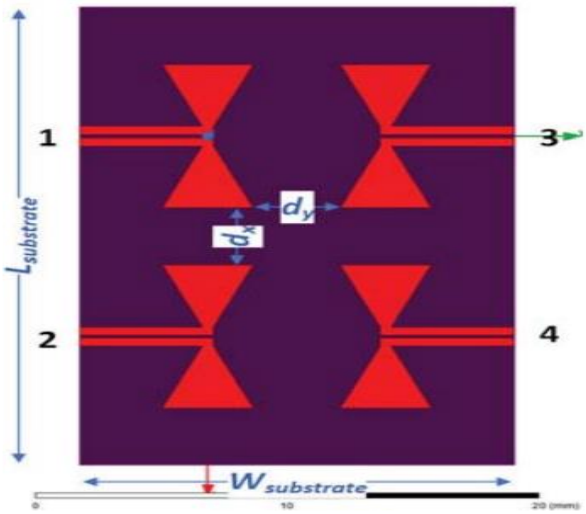

Figure (13) Geometry of the simulated antenna design soft computing based MIMO antenna [62]

7. MIMO CHARACTERISTICS FOR 6G

Investigations are underway for future 6G communication networks even if the 5G networks developing phase of adoption. The sixth-generation of cellular technology (6G) is intended to support expanding data hungry models and boosted connections. This improves the network capacities for overcoming the operating challenges faced by 5G mobile communication. Due to the functionality of 6G networks, the latency and bandwidth may be larger than the 5G networks. With a focus on web enables devices, 6G will provide extremely high reliability by including the artificial intelligence and advancement of cellular broadband. Also, it results in high hardware prices, power consumption, and challenging designs. The higher frequency bands, such as the terahertz (THz) and millimetre-wave bands are being embraced by upcoming communication systems (6G) in order to meet the aforementioned demands. Some of the important applications of THz band wireless communication include the Internet of Nano-Things, military, entertainment services, health monitoring systems, and ultra-high-speed on-chip communications. This has motivated experts to keep improving current wireless networks in preparation for the transition to 6G cellular services.

8. CHALLENGES AND FUTURE DIREC- TIONS

Massive MIMO is obviously better than traditional multiple antenna systems. However, a number of issues still prohibit the practical deployment of MIMO. Hardware components may encounter a number of challenges related to material selection, size, cost, and characteristic properties (bandwidth, gain, efficiency, MC, etc). It is difficult to understand the consequences of MC of the MIMO antenna elements due to their tight spacing. However, the issue has been somewhat handled by the small size and decoupling techniques for improving isolation between the antennas, and the effect on the characteristics' results was favourable. Decoupling techniques are still one of the fundamental characteristics of MIMO antennas. By utilising decoupling methods, it is feasible to upsurge the spacing of the array elements and significantly boost the spectral efficiency. Future work will focus on using a metamaterial technique with special properties as isolation to deal with hardware challenges, component characteristics, and their modification and enhancement This technique will effectively employ improvements in terms of size, gain, efficiency, bandwidth, and other areas. Another issue that has an impact on the pricing of the products on the market is the high cost of massive MIMO in smart phones. As a consequence, perfect outcomes may be achieved at a reasonable cost with modern technology.

9. CONCLUSION

There are several devices that use wireless communication technologies, including WLAN, tablets, and mobile systems of all have compact size and operate in various frequency ranges. As a result, to obtain high gain, antenna design should focus more on optimising size for integration with other electronics devices. Single antenna elements in wireless systems are unable to meet the necessary specifications. This systematic review is a detailed reference for the researchers who were working in the field of MIMO antenna. This research focused on analysing the several diversity parameters of the MIMO antenna, isolation enhancement techniques, UBW, dual band and CP MIMO antennas and the soft computing algorithms to optimize the design parameters of the antenna. Several isolation enhancement methods such as DN, PEs, DGS, NL and MTMA absorbers are discussed. Also, to attain UWB characteristics, dual band and CP, the fence shape, drop shape, L shape, ring shape, flag shape, U-shape, rectangular and ring-shaped stubs are loaded and also, the high impedance decoupling structures are placed in to ground plane to prevent MC. Then, the several optimization techniques such as PSO, GA are analysed for the optimal design parameters of the antenna. Finally, the review is concluded with the MIMO characteristics under 6G technology and challenges. Thus, it can be said that this review study will contribute significantly to improve the quality and performance of the design with high data transmission rates.

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