



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 12, Issue 9, September 2023

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.423

9940 572 462

6381 907 438

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Immunity Building in MIMO System Using MAAD in Elliptical Shape

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ABSTRACT: In high frequency Tele-communication and radar systems, synthetic A-Radar and Multiple Input-Output antenna systems are used. These antennas connected radiate in different pattern and in different polarization. Since the antennas are connected in arrays, it provides good gain and beam forming capability; such characteristics are preferred in latest communication technology. The size of antenna array should be in miniaturized size for the growing communication technologies requirement. This compact size antenna array creates crosstalk effects between the elements which are radiating actively and also induces inductive mutual coupling between the elements in the array. As a result, the performance of MIMO antenna systems is degraded in terms of impedance matching, gain, efficiency. In order to maintain the integrity and performance of MIMO systems, it is instructive that mutual coupling should be kept to the minimum. To achieve this immunity against electromagnetic interference, it is proposed to design an antenna array configuration consists of two radiating elements that are constructed from elliptically-shaped curves and meta-surface decoupling mechanism. This meta-surface material is aligned with the finite ground structure to mitigate surface wave's effect between the radiating elements. This decoupling structure with analytic curves of elliptical shape provides more flexibility and high isolation between the radiating elements. The wave propagation in decoupling structure is further avoided by using negative permeability meta-surface material. This project of designing antenna array with good isolation and producing high gain is proposed to applicable for wideband highly decoupled MIMO antenna system for communication systems application such as Air Traffic Controller, Remote sensing of environment, Military etc.

KEYWORDS: MIMO Wireless System, Metasurface antenna array decoupling (MAAD), Elliptical shape decoupler.

I. INTRODUCTION

Currently, the field of mobile communication technology is in the transition phase from 4G to 5G technology. The explosive growth of mobile data is driving the users' demands for higher wireless communication services. Communication systems need to achieve timely and fast access to information, higher transmission efficiency, and better system security.

As a result, 4G is starting to gradually fail to meet the new communication needs and the shortcomings are coming to the fore. From 2020, 5G took the stage of commercialization, which marked it was gradually becoming the mainstream technology in modern mobile communication. Its frequency band covers sub-6 GHz (450 MHz–6 GHz) and mm-Wave band (24.25–54.6 GHz). The salient features of 5G are high-speed data transfer, and reliable connectivity with zero percent latency. Additionally, the good user's Quality of Experience (QoE) in the 5G era requires excellent antenna diversity and larger channel capacity support.

To overcome the signal fading due to multipath effects, diversity systems with two receivers were developed, which was the beginning of the evolution of MIMO Existing studies have shown that, compared to simple input simple output (SISO) systems with a simple structure, MIMO systems have multiple additional paths, and the multipath effect, delay, and packet loss can be reduced to enhance the communication modes. Moreover, according to Shannon's theorem, the channel capacity depends on the channel bandwidth and signal-noise ratio (SNR). Additionally, MIMO systems have



demonstrated the potential for increasing the data throughput multiple times with a fixed bandwidth and transmission power by virtue of the multi-port design. Therefore, the study of MIMO systems is an important part of developing 5G communication systems.

In this paper, our investigation focuses on decoupling techniques for MIMO systems. We review some excellent MIMO decoupling schemes of the last five years and discuss the potential works it faces. These decoupling techniques are divided into two types, including external decoupling techniques and internal decoupling techniques. External decoupling techniques rely on adding additional structures to counteract the mutual coupling, which are further classified into neutralization lines (NL), grounding branch structures, parasitic decoupling elements (PDE), defective ground structures (DGS), metamaterial techniques, etc. Internal decoupling techniques are related to polarization diversity, where orthogonal polarization and multi-polarization are commonly used.

The rest of this paper is as follows. The second part emphasizes the causes of mutual coupling and its negative effects on MIMO systems. The third part briefly describes how to evaluate the degree of mutual coupling by performance parameters. Part four discusses some decoupling schemes for MIMO wireless systems applicable in 5G devices. The fifth part is a detailed analysis of the advantages and disadvantages of each decoupling technique. Finally, it is conclusion and envisages the future development direction of decoupling techniques.

II. EVALUATION PARAMETERS OF MUTUAL COUPLING

There are many parameters to judge the behavior of MIMO systems, including performance parameters, such as operating band, matched impedance, channel capacity, etc., and diversity performance parameters, like envelop correlation coefficient (ECC), diversity gain (DG), total active reflection coefficient and mean effective gain (MEG). The evaluation of the degree of mutual coupling between antenna elements is usually characterized by the S-parameter and ECC. These two parameters are briefly introduced in the following section to set the stage for the analysis of MIMO decoupling techniques later.

S-Parameters: Viewing an array of n antenna elements as a network with n-port. Assuming that the incident waves of the n-port network are a_1, a_2, \dots, a_n , and the outgoing waves are b_1, b_2, \dots, b_n , the relationship between the outgoing and incoming waves can be expressed by Equation (1):

$$b_1 = S_{11} a_1 + S_{12} a_2 + \dots + S_{1n} a_n \quad b_2 = S_{21} a_1 + S_{22} a_2 + \dots + S_{2n} a_n \quad \dots \quad b_n = S_{n1} a_1 + S_{n2} a_2 + \dots + S_{nn} a_n, \quad (1)$$

Expressed in matrix form, Equation (1) is as follows:

$$b = S a, \quad (2)$$

Of which:

$$a = [a_1, a_2, \dots, a_n]^T, \quad (3)$$

$$b = [b_1, b_2, \dots, b_n]^T, \quad (4)$$

$$S = \begin{bmatrix} S_{11} & S_{12} & \dots & S_{1n} \\ S_{21} & S_{22} & \dots & S_{2n} \\ \dots & \dots & \dots & \dots \\ S_{n1} & S_{n2} & \dots & S_{nn} \end{bmatrix}, \quad (5)$$

Among them, S_{ii} is called “reflection coefficient”. It indicates the voltage reflection of the port i when other ports are connected to the matching load. As we all know, the operation bandwidth of a MIMO system is decided by its impedance matching situation. Adding any decoupled structures will change the radiation impedance of the proposed antenna arrays. Thus, S_{ii} needs to be referenced when we consider decoupling design because it represents impedance match indirectly. By adjusting S_{ii} , desired operation bandwidth can be attained. S_{ij} is called “transmission coefficient”. It represents the voltage transmission from port j to port i when the i element is connected to the matching load. The mutual coupling degree of two ports is measured by S_{ij} . Additionally, the preferred isolation is achieved by modifying S_{ij} . The unit of these parameters is usually expressed in “dB”. To ensure that the RF element is in a normal working state, it is generally required S_{ii} be less than -6 dB and S_{ij} be less than -10 dB.



Taking the two-port network as an example, assume that 1 is the feed port and 2 is the coupling port. The S-parameters of the two-port network are given in Equation (6):

$$S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}, (6)$$

where S_{11} is the input reflection coefficient, or input return loss; S_{22} is the output reflection coefficient, or output return loss; S_{12} is the reverse transmission coefficient or isolation; and S_{21} is the forward transmission coefficient, or gain.

Assuming that the power of port 1 is P_1 and the power of port 2 is P_2 , the isolation of the ports can be given by Equation (7):

$$S_{12} \text{ dB} = 20 \lg S_{12} = 10 \lg \frac{P_2}{P_1}, (7)$$

The degree of mutual coupling of the antenna element is inversely related to the absolute value of the transmission coefficient. Therefore, the larger the absolute value of the transmission coefficient, the smaller the degree of mutual coupling of the antenna.

Envelope Correlation Coefficient (ECC): A good diversity effect is a key to ensuring the communication quality of MIMO systems. The effect of diversity depends on the correlation of antenna signals. The envelope correlation coefficient, as a measurement parameter, is used to measure the degree of similarity between different signals and can also be used as a basis for judging the mutual coupling of different ports.

The most accurate ECC calculation method is based on the far-field pattern function. it can be given by Equation (8):

$$ECC_{i,j} = \frac{\iint_{\Omega} F_1(\theta, \varphi) \cdot F_2^*(\theta, \varphi) d\Omega}{\sqrt{\iint_{\Omega} |F_1(\theta, \varphi)|^2 d\Omega \iint_{\Omega} |F_2(\theta, \varphi)|^2 d\Omega}} (8)$$

$F_i(\theta, \varphi)$ is a function of the radiation pattern of the field when port i is excited, and the other ports are matched under the condition of $Z_0 = 50 \Omega$, “ \cdot ” represents the Hermite product. However, due to the complex measurement process and the limitation of available pattern characterization tools, this method is time-consuming.

Boris et al. showed how to compute the ECC from the S-parameter description of the two-antenna system. The equation has been derived using the law of energy conservation, which has the advantage that it does not require the computation or the measurement of the radiation pattern of the antenna system. It is given by Equation (9):

$$ECC_{1,2} = S_{11}^* S_{12} + S_{21}^* S_{22} - S_{11} S_{12}^* - S_{21} S_{22}^* (9)$$

Further, Thaysen and Jakobsen deduced that in a MIMO system consisting of $N \times N$ antenna elements, the ECC between antenna elements and antenna elements can be expressed by Equation (10):

$$ECC_{i,j,N} = \frac{\sum_{n=1}^N S_{in}^* S_{jn}}{\sqrt{\sum_{k=1}^N |S_{ik}|^2 \sum_{k=1}^N |S_{jk}|^2}} (10)$$

However, Equation (10) is only applicable to the ideal case where the antenna is loss-free. In practical applications, the realistic power losses of the antenna structures should be taken into account. Dama et al. proposed a modification of the S-parameter method which included the antenna losses. It is expressed in the two-antenna system as Equation (11):

$$ECC_{1,2} = -S_{11}^* S_{12} + S_{21}^* S_{22} - L_{12}' + L_{12}'' - S_{11} S_{12}^* - S_{21} S_{22}^* - L_{11}' + L_{11}'' - S_{22} S_{21}^* - S_{12} S_{21}^* - L_{22}' + L_{22}'' (11)$$

The elements L_{ij}' and L_{ij}'' are obtained from the power loss calculation.



In addition, a modification of the S-parameter method that took into account the effects of the radiation efficiency was proposed. However, instead of giving the exact value, it gave an upper bound for ECC. It is expressed by Equation (12):

$$ECC_{i,j,N} = -\sum_{n=1}^N S_{ni} * S_{nj} (1 - \sum_{n=1}^N S_{ni}^2) (1 - \sum_{n=1}^N S_{nj}^2) \eta_{rad,i} \eta_{rad,j} + 1 \eta_{rad,i-1} \eta_{rad,j-1} \quad (12)$$

where $\eta_{rad,i}$ and $\eta_{rad,j}$ are the radiation efficiency of antenna elements i and j , respectively. Additionally, once the efficiency goes below 60%, the errors start increasing dramatically. The smaller the value of ECC, the lower the mutual coupling effect. When $ECC = 0$, it means that the relationship between the two ports is completely independent. It is usually considered that MIMO systems with ECC below 0.5 can run normally. When calculating ECC, the above equations can be flexibly selected.

Characteristic Modes Analysis

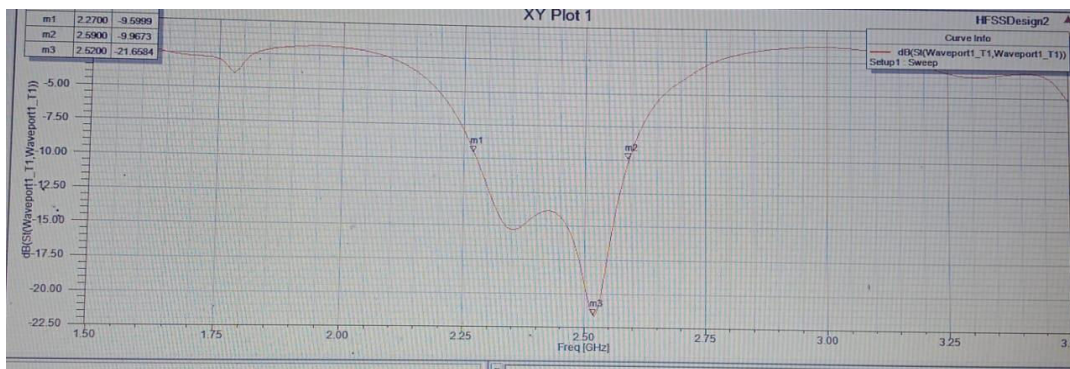
The characteristic modes analysis (CMA) was first proposed by Garbacz in 1965. Then, its field of use expanded from PEC to dielectric or magnetic material objects. Now, CMA can be carried out in most commercial EM simulation software as a tool to guide antenna decoupling design. With the help of CMA, the characteristic modes of arbitrary conductive structures are revealed, and the best location with good isolation of radiators can be found easily.

The research excited two different characteristic modes to realize pattern diversity based on CMA. A monopole element acted as an electric source, which was placed on the maximum point of one mode E-field maximum points to excite it. Similarly, a loop element acted as a magnetic source placed on the other mode H-field maximum point, and it was generated successfully. It can be observed from radiation pattern that the modes on the two antennas were orthogonal. Therefore, an orthogonal polarized MIMO was established with isolation better than 20 dB.

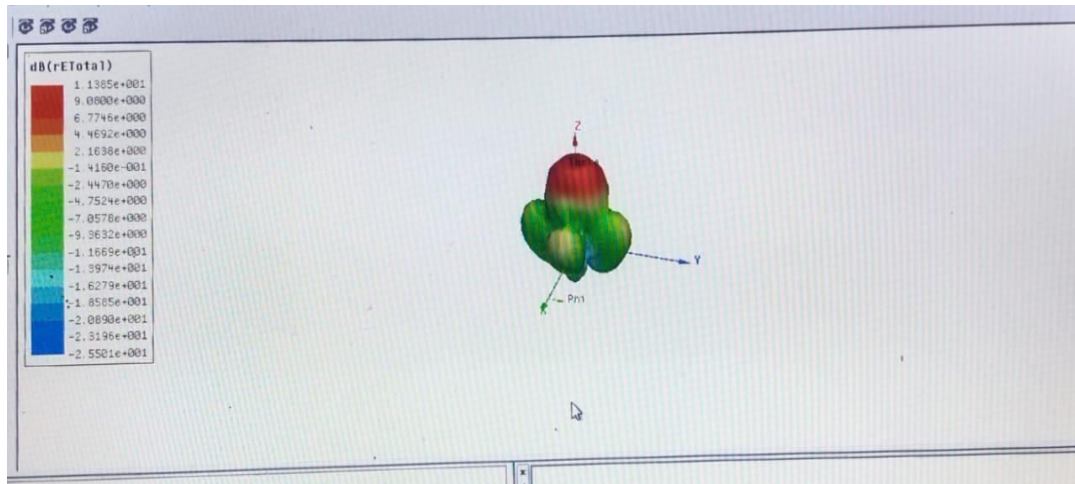
The CMA also can be used to find feed points to obtain desired resonant frequency. Moreover, on the optimization of structures, a parametric analysis can be performed based on CMA. In a twelve-port MIMO system with dual-band depicted was proposed. The characteristic current distributions of each radiation branch were shown by CMA. Thus, the isolation enhancement was achieved by adjusting the length of the relevant branches, and it was better than 12.5 dB. The eight-port MIMO was placed on the bezel in .Its wide band was generated by coupled feeding and CMA optimization, which was applied for 5G mobile devices. According to characteristic current distributions, a patch branch with a weak current was chosen to modify. After optimization, the number of characteristic modes became more, which bandwidth was expended and isolation realized better than 15 dB between eight elements.

III. RESULT AND DISCUSSION

Thus the simulated result shows gain of the antenna and the s-parameter of the designed antenna using HFSS software.



The Figure shows the Normalized radiation patterns



The figure shows the gain of the antenna

In this project a MIMO antenna was designed along with the elliptical shape decoupler in order to reduce the interference. The above output shows the improvement in gain and reduced in s-parameters. By means of using the elliptical shape decoupler the radiation from the antenna and to the reflected back radiation will not be present on to the corner due to the presence of elliptical shape the decoupler is meant to increase gain and to decrease the interference to meet current requirement of speed of obtaining the information.

IV. FUTURE WORKS

For future research one can look at, the limit of metasurface walls and metasurface substrate one can fit before they stop reducing mutual coupling. This will obviously depend on the available surface area between the radiating antenna elements and the available height above the antenna. These designs utilized an SRR metasurface for mutual coupling reduction because it is a 2D structure, hence it is less complicated to fabricate and it costs less. If costs and fabrication complexities are not a limiting factor, one can look at combining other mutual coupling reduction methods with this type of design. Mutual coupling methods that do not change the original structure of the antenna would be recommended. This is because the radiation pattern of the antenna is not affected, and the design can be implemented on already existing antennas without changing the whole antenna design i.e. 1D EBG structure, MTM-EBG decoupling slabs.

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