Hybrid Techniques of EBG, CSRR and DGS for the Suppression of EMI in MIMO Antenna

Bhagya Shree.K[1], C.Rekha[2], N.Subhananthan[3]
[1] 1PG Scholar, [2]Associate Professor, [3]Assistant Professor
[1, 2, 3] Department of ECE, PET Engineering College,Vallioor, TamilNadu

Abstract- *The purpose of this paper is to design a rectangular patch MIMO antenna with decoupling structures like Electromagnetic Band Gap Structure(EBG), Complementary Split Ring Resonators(CSRRs), and Defected Ground Structure(DGS) to operate over a 5G frequency band with a frequency range of 3.25GHz.An EBG structure consists of periodic metal patches that create a bandgap when the negative effective permeability is attained. So that the surface wave will be immensely suppressed which leads to the reduction of unwanted radiation in undesired direction. Thus, by creating a shielded environment , EBG structures also minimize the impact of Electro Magnetic Interference(EMI) on the antenna array. By incorporating CSRR structures, the resonance properties of the CSRRs can be utilized to attenuate or eliminate specific harmonic frequencies, resulting in reduced interference and improved antenna performance. The DGS structure works by introducing impedance variations in the ground plane and it is added to reinforce the decoupling effect between the antenna elements. These three structures work all together to achieve the desired transmission and reflection coefficient, and efficiency. Finally, the results are simulated and analyzed.*

Keywords- Electromagnetic Band Gap Structure(EBG), Complementary Split Ring Resonators(CSRRs), Defected Ground Structure (DGS), Electro Magnetic Interference(EMI)

I. INTRODUCTION

In recent years, isolation enhancement in antenna array applications poses a strong challenge in the antenna community. The mutual coupling or isolation between closely placed antenna elements is important in a number of applications. Surface waves cause many disadvantages for microstrip antennas such as a mutual coupling effect between elements on an antenna array, which exists whenever the substrate has a dielectric permittivity greater than one ($\varepsilon r > 1$). In an antenna array, the mutual coupling effect will deteriorate the radiation properties of the array. To achieve low mutual coupling between closely spaced antenna elements and to suppress surface waves, several studies have been conducted including Electromagnetic Band Gap Structure(EBG), Complementary Split Ring Resonators(CSRRs), and Defected Ground Structure(DGS) . An eminent increase of wireless devices, inadequate bandwidth, and limited channel capacity have substantially promoted efforts to develop advanced standards for communication networks. Subsequently, this has promoted the development of next- generation (5G) new radio communication systems. However, the available spectrum is limited and hence requires alternative ways of effective utilization of the available spectrum. MIMO (Multiple Input Multiple Output) serves as one of the promising solutions for effective utilization of spectrum. Antenna Array Also called an array antenna, antenna arrays are several antennas connected & arranged in a regular structure to form a single antenna. In general, MIMO comprises a set of two or more antennas that work together to achieve increased system capacity the use of MIMO increases link reliability and spectral throughput of the system. The major Advantages of Antenna Arrays are Increase in the overall gain, Provides diversity reception. Cancel out interference from a particular set of directions, Determines the direction of arrival of the incoming signals, Maximize the Signal to Interference Plus Noise Ratio (SINR). Though there are significant advantages in the use of MIMO antennas, they suffer from a mutual coupling effect. One method of reducing mutual coupling between antenna elements is by introducing decoupling elements including Electromagnetic Band Gap (EBG) structures, Complementary Split Ring Resonators(CSRRs) and Defected Ground Structures (DGS).

The proposed antenna is printed on an FR-4 substrate with a noticeable cost reduction. The antennas overall dimensions for all methods are the same as they approach 70 mm × 40 mm with increased isolation. Sourav Roy et al. [1] proposed a meta-inspired decoupling method to reduce the isolation with a bandwidth of 1.34 to 3.92 GHz and 4.34 to6.34 GHz. The gain ranges from 3 to 5 dBi with dimensions of 100 mm × 60 mm × 1 mm and isolation of−10 dB. It is designed and fabricated on a jean's substrate, which has a dielectric permittivity of 1.6 and loss tangent of 0.02Luo et al. [2] presented an H-shaped antenna placed in a square loop with FR-4 substrate while covering the band from 5.2 to 5.8 GHz with isolation of 14 dB between ports. The gain of the proposed antenna is approximately 5 dBi, and the efficiency approaches 80%. The antenna dimensions are 42 mm × 42 mm

× 0.8 mm with a noticeable size reduction Wu et al. [3] Sub-6 GHz Highly Isolated Wideband MIMO Antenna Arrays a four-port MIMO antenna array with a band notch that uses electromagnetic bandgap(EBG) to reduce mutual coupling. The band notch is centered at 4.6 GHz covering the band from 4 to 5.2 GHz with isolation of 17.5 dB between ports with dimensions of 60 mm × 60 mm × 1.6 mm using FR4 substrate. The relative permittivity, efficiency, and gain are 4.4, 90%, and 8 dBi, respectively. Several attempts have been made to improve the bandwidth by cutting the resonant slot inside the patch [4]. The main problem in designing a MIMO antenna array is mutual coupling. Numerous studies used various methods to decrease the effects of this problem. In [5], a two-port MIMO antenna array using defected ground structure (DGS) to obtain high isolation between ports with dimensions of 45 mm × 45 mm × 1.6 mm has been presented. The isolation is less than 14 dB. The gain and peak efficiency of the array are 4 dBi and 91%, respectively. The bandwidth ranges from 2.2 to 6.28 GHz. The antenna is designed on an FR-4 substrate. In [6], a four-port MIMO antenna array with a size of 40 mm × 30 mm × 1.6 mm with a noticeable size reduction. The bandwidth ranges from 3.2 to 5.7 GHz, and it is fabricated on FR-4 substrate. The isolation of the antenna array using DGS is less than −10 dB, especially S31, and this result is not sufficiently good. The gain of the proposed antenna is about 3.5 dBi, and the efficiency approaches 82%. Meanwhile, Yang and Zhou [7] presented circular patch and L-shaped as an isolating element decoupling structure with a compact size of 30 mm × 30 mm × 0.8 mm with a noticeable size reduction.

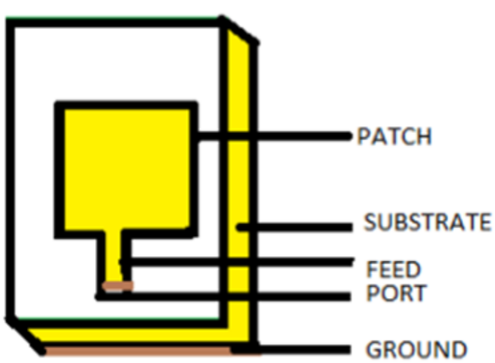

Fig: Basic Structure of Microstrip Patch Antenna

ANTENNA DESIGN AND ANALYSIS

The proposed design is printed on the rectangular FR4 substrate material (εr = 4.4, tanδ = 0.02.) with the thickness of 3 mm and the dimension of 70*40 mm2. The two port array consists of two rectangular patch antenna elements which are identical and symmetrically placed on the top layer of FR4 substrate with the distance of edge to edge 10mm. The EBG structure is inserted between the gap of antenna elements non radiation edges, which is constituted by periodic interdigital slit embedded mushroom patches grounded by metal vias with the diameter of 1mm. Antenna elements share a common ground which is located in the bottom layer of substrate. Moreover, CSRRs are etched in the ground two sides adjacent to the non radiation edges of antenna elements. In addition, HDGSs are at the position which adjacent to the radiation edge of antenna elements. The antenna elements are fed from 50Ω input ports behind the ground plane. In this design, a full wave electromagnetic simulation software high-frequency structure simulator (HFSS) is used to analyze and optimize the proposed antenna.The following table shows the design dimensions.

WA	70mm	LA	40mm	PW	24mm	PL	20mm
CL	4.5mm	DL	2mm	H	3mm	D	10mm

Fig: Dimensions of antenna array

ELECTROMAGNETIC BAND GAP STRUCTURE

A periodic arrangement of materials or structures designed to control the propagation of electromagnetic waves in a specific frequency range. It acts as a frequency-selective filter for electromagnetic radiation, preventing certain frequencies from propagating through the structure while allowing others to pass.

Fig: Electromagnetic Band Gap Structure

The EBG unit cell can be represented as equivalent parallel resonant LC circuit based on the simplification of 1- D equivalent circuit model. When the surface wave between antenna elements propagates through the EBG structure, it will exhibit a resonant behavior with a resonance frequency $\omega 0=1/\sqrt{LC}$, where the L and C are the equivalent inductance and capacitance associated with the 1- D equivalent circuit model of EBG structure.

Conspicuously, the negative effective permeability can be attained when ω is below ω0. Combining the above mentioned analysis and discussion, ω0 is immediately linked to the physical model of EBG structure and can be tunable. Hence, we can appropriately adjust the shape and the size of EBG structure for achieving negative effective permeability. As mentioned previously, the surface wave will be immensely suppressed when travelling in negative effective permeability media. Consequently, the coupling effect between antenna elements will be tremendously alleviated with the insertion of EBG structure. In order to validate the feasibility of the decoupling concept analyzed in above, the simulated S parameter (reflection coefficient S11 and transmission coefficient S21) of MIMO antenna with and without EBG structure has been depicted.

COMPLEMENTARY SPLIT RING RESONATORS

Complementary Split Ring Resonators (CSRRs) are a type of metamaterial structure that consists of two split ring resonators (SRRs) positioned in a complementary arrangement. SRRs are subwavelength structures that exhibit resonant behavior at specific frequencies. They are usually made from conductive materials and are characterized by a split in the ring, which introduces inductive and capacitive coupling effects, giving rise to resonant behavior. The CSRR structure involves two identical SRRs positioned in close proximity to each other in such a way that their split gaps are aligned but facing opposite directions. This complementary arrangement leads to interesting electromagnetic properties due to the interaction between the SRRs. CSRRs can exhibit resonant behavior and can also exhibit an electromagnetic band gap effect, similar to the behavior of photonic crystals.

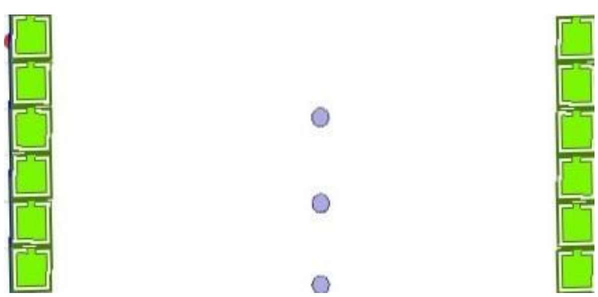

Fig: Complementary Split Ring Resonators

To further improve the isolation of antenna elements, the complementary split-ring resonators (CSRRs) have been introduced to reduce surface which are placed in two sides of the ground adjacent to the non radiation edge of the antenna element. CSRR is a pervasive metastructure which is extensively applied in MIMO decoupling. In previous research works, CSRRs are usually placed between antenna elements which play a role similar to EBG structure in hindering the propagation of surface wave. The distinction between this work and previous research work is that CSRR is employed to steer the EM wave instead of blocking. The CSRR is the evolution of split-ring resonators according to the duality principle. The CSRR also can be regarded as LC resonator like EBG structure, it resonance behavior is due to the induced electromotive force that generates a current that flows within the split ring gap and metallic connector, producing a balanced inductive-capacitive effect. Resonant frequency can be expressed as $\omega 0=1/\sqrt{LC}$, where L and C are the equivalent inductance and capacitance of CSRR respectively which are tunable by adjusting the physical shape and size of the CSRR. When ω is larger than ω0, the highly effective permeability of CSRR can be attained. A material with high permeability will guide and compress the magnetic lines in a compact space. Inspired by this, the CSRRs are utilized to steer the EM wave for pursuing the reduction of surface wave coupling. Hence, the total isolation of MIMO antenna elements will be improved.

DEFECTED GROUND STRUCTURE

A Defected Ground Structure (DGS) is a type of electromagnetic structure used to control the propagation of electromagnetic waves, particularly in printed circuit boards (PCBs) and other planar microwave circuits. DGS involves introducing specific patterns or features into the ground plane of a PCB or other planar structure to create electromagnetic band gaps or alter the electromagnetic behavior of the circuit. This allows for various benefits, including improved performance, frequency filtering, and reduced interference.The concept behind DGS is to intentionally introduce defects or modifications in the ground plane, which affect the flow of electromagnetic waves. This can lead to the creation of stopbands (frequency ranges where certain frequencies are attenuated or blocked) or other desired effects.
Then a H shape DGS is etched on the ground plane along the radiating edge of the antenna devoted to reverse part of the common ground current, which counteracts the partial coupling currents to increase isolation. This paper only provides simulated S parameters. The reflection coefficient S11 and transmission coefficient S21 with and without the these three decoupling structures are exhibited.

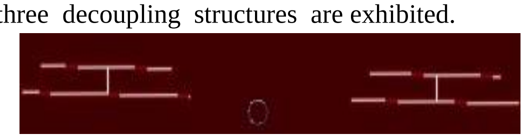

Fig:H Shape Defected Ground Structure (DGS)

SOFTWARE USED

High Frequency Structure Simulator (HFSS 15.0.3): It is used to simulate the proposed antenna. The reason for choosing HFSS is that it uses FEM methods, which deals with very complex structures and it predicts accurate results. It is a high-performance full-wave electromagnetic field simulator for 3D volumetric passive device modeling. It integrates simulation, visualization, solid modeling, and automation in an environment that facilitates learning and where solutions to 3D electromagnetic (EM) problems are quickly and precisely attained. The following figure shows the proposed antenna design with Electromagnetic Band Gap Structure(EBG), Complementary Split Ring Resonators(CSRRs), and Defected Ground Structure(DGS),

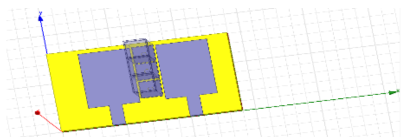

Fig: Proposed design front view

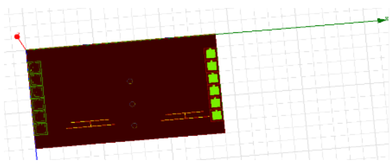

Fig: Proposed design back view

RESULTS AND CONCLUSION

In this paper, a two element MIMO antenna has been developed. The antenna isolation characteristic enhancing procedures and corresponding decoupling concept have been meticulously analyzed. A decoupling mechanism concerning about steering and suppressing surface wave propagation simultaneously was exploited for enhancing antenna isolation characteristic. Furthermore, H shape DGS was introduced to strengthen the total decoupling effect.Then the design is analyzed and simulated.

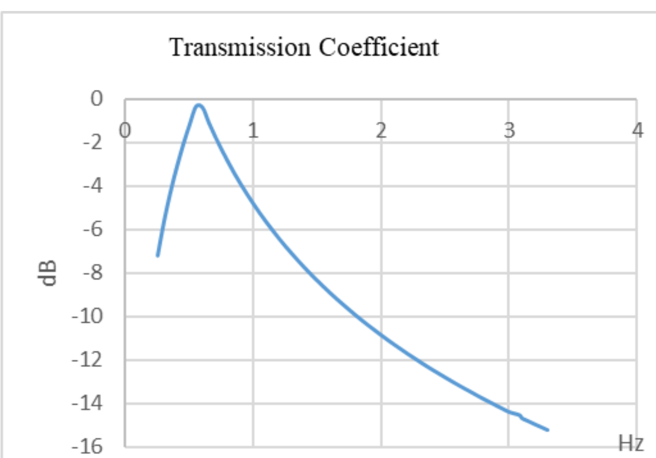

Fig: Transmission coefficient (S11) or Return Loss of proposed antenna

Transmission coefficient S21 is a parameter that describes the forward transmission ratio of the antenna.

It is the ratio of the amplitude of the transmitted wave to that of the incident wave.

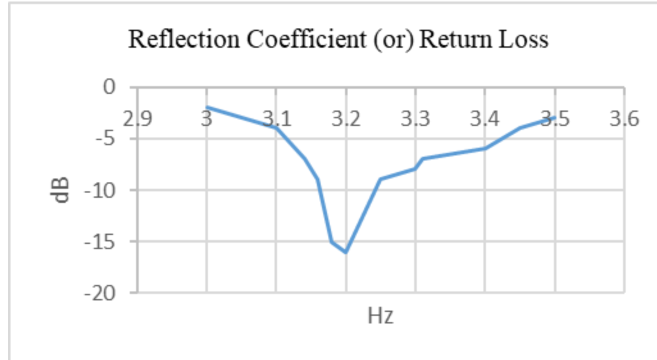

Fig: Reflection coefficient (S11) or Return Loss of proposed antenna

Reflection coefficient S11 is a parameter that describes the backward reflection ratio of the antenna.

The ratio of the amplitude of the reflected wave to that of the incident wave is termed the reflection coefficient.

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