Survey Paper on Different Techniques for Reducing Mutual Coupling between MIMO Antennas

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Abstract : In recent years, MIMO antennas, capable of radiating waves in multiple types and polarizations, have gained significant importance in contemporary communication systems. This study paper provides a theoretical overview of several solutions for reducing reciprocal connectivity in MIMO systems. The increased mutual coupling can adversely affect antenna properties, diminishing the overall performance of MIMO systems. Digital domain calibration of mutual coupling can enhance performance, but employing techniques like faulty parasitic and grooved elements, complementary splitting ring resonators, and decoupling networks provides a simple and effective means to mitigate mutual coupling effects. Comprehensive explanations, examples, and comparative studies of diverse mutual coupling reduction approaches are still uncommon in the literature. Consequently, this article aims to address this gap by presenting numerous MIMO antenna design strategies along with their respective mutual coupling reduction techniques, utilizing various structures and processes

Keywords: Decoupling Network, MIMO Antenna, Metamaterials, Neutralization Line, Parasitic Elements, ECC, UWB, WLAN, EBG Structure, DGS, MC.

1. INTRODUCTION

The MIMO technique is now widely integrated into numerous wireless protocols, and it stands out as a prospective approach for future implementations. This is attributed to its manifold advantages, including enhanced system performance distinguish to single antenna or channel communications, more data rates, a higher channel capacity, and heightened reliability. These essential features are anticipated to be crucial in modern wireless communication systems. In the current densely populated and overcrowded wireless environment, where multipath situations prevail, MIMO antenna systems emerge as a viable solution to provide the required high data rates, particularly in areas with high structural density, such as tall buildings.

Various strategies, such as the incorporation of faulty soil structures, electromagnetic band separation structures, parasitic elements, neutralization lines, metamaterials, and others, need to be integrated into the MIMO antenna element. This integration aims to reduce for mutual interference involving antenna components and enhance element isolation. To significantly minimize mutual coupling, careful optimization of the size, form, location, and dimensions of these insulating structures is imperative. The ensuing section provides a comparative analysis of diverse mutual coupling approaches

TECHNIQUES OF MUTUAL COUPLING REDUCTION:

1.1 EBG structure:

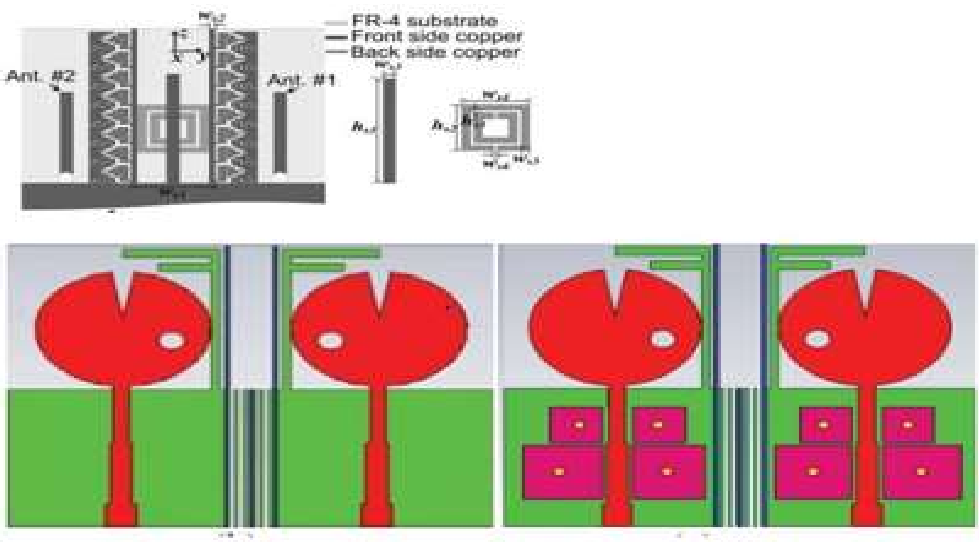

Fig 1: Mimo Structure EBG [3] and [8]

In contemporary applications, the EBG method is actively employed to minimize MC among various antenna structure within MIMO systems, demonstrating superior isolation when compared to alternative methods. The EBG structure functions as a stop band, effectively blocking electromagnetic waves within specific frequency bands through the creation of a refined and periodic pattern of small metallic structures on dielectric substrates.

The utilization of EBG approaches has yielded significant advancements, particularly highlighted in recent progress, notably in the year 2019. A pivotal study within this timeframe investigated an electromagnetic structure featuring a two-element CP-DRA matrix, incorporating an EBG structure engraved on the ground floor of the MSTL. This innovative Construction design achieved insulation exceeding 26 dB within the intended band of frequencies, showcasing a remarkable improvement in performance without compromising the compact dimensions of the array [7].

Furthermore, a meticulously designed EBG-based high-isolation MIMO antenna was developed to meet specific characteristics. Tailored for the FR-4 substrate and measuring 55 × 49 × 1.6 mm^3, this antenna featured circular patches with triangular and extruded circular shapes, contributing to enhanced radiation efficiency (> 0.45) within the X band (8.0 to 12 GHz). The incorporation of a mushroom-shaped EBG structure near the micro-strip power line resulted in substantial isolation (-22dB) achieved across the entire bandwidth [8].The global research landscape has shown a significant focus on this subject, indicating extensive efforts to explore and enhance the applications of EBG structures in reducing mutual coupling within MIMO antenna systems. For a better understanding, some of the more studies are noted and underlined in the table below

Table No-1: MIMO antenna Using EBG structure :

Ref. No.	**Substrate Material**	**Antenna Design**	**Shape of EBG structure**	**Efficiency**	**ECC**	**Isolation**
1	Rogers RO4350 B	Microstrip patch antenna	mushroom-type EBG structure design	56.57%	-	25dB
2	FR-4	Microstrip patch antenna	Dual-layer mushroom EBG structure	66.94%	0.01	28dB
3	FR-4	Planar Antenna	1-D EBG and split ring resonator combination	82%	0.002	53.7dB
4	FR-4	Microstrip patch antenna array	Planar electromagnetic bandgap (EBG) structure	60%	-	25dB
5	FR-4	PIFA	Fractal based Electromagnetic Band Gap (FEBG) structure	70%	-	40dB
6	FR-4	Microstrip patch antenna	electromagnetic bandgap (EMBG) structure based on metamaterial	80%	-	31dB

1.2 Neutralization line :

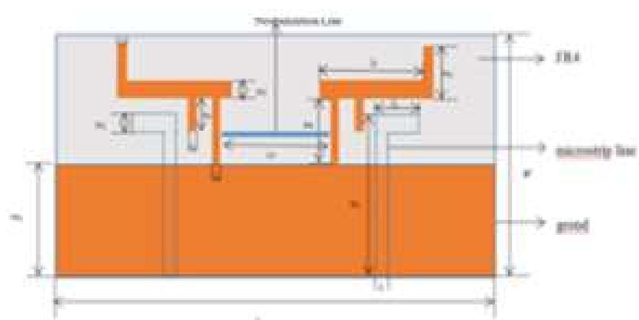

Fig 2: Structure using NL [9] and [10]

MIMO technology poses distinct challenges due to the presence of multiple antenna elements, necessitating careful consideration of mutual coupling effects. To address this, the

Neutralization Line (NL) method has emerged as a viable solution in modern MIMO antenna systems.This technique has proven effective in achieving significant isolation improvements when compared to alternative methods designed for the same purpose.

Extensive global research efforts have been dedicated to mitigating isolation levels involving MIMO antenna using the NL method. Notably, a recent study in 2019 introduced a dual-frequency MIMO system featuring a micro strip monopole antenna. Initial measurements revealed isolations of approximately 16.8 dB and 19.5 dB for the low and high ranges, correspondingly . Subsequent incorporation of a connecting neutralization line into the design resulted in noticeable improvements in isolation. Additionally, the resonant frequencies of the designed antenna underwent a shift, aligning with the requirements of WLAN applications. The isolation improvements were measured at 2.5 dB in the smaller region and 5.1 dB in the bigger region [9].This observation underscores the global emphasis on advancing NL-based solutions to tackle MC challenges in MIMO systems

There is a great deal of research around the world focused on this area. Some of the Primary research are indicated and highlighted below in the table for greater understanding.

Table No-2: Structure using NL

Ref.	Substrate Material	Antenna Design	Additional Technique combined	Efficiency	Isolation	ECC
10	FR-4/ 30×65×1	Printed Monopole antenna	A normal connecting line of 0.3 mm width	81%	0.006	15dB
11	135×80×0.8 FR-4	Dual symmetric microstrip antenna system	Two Crossed neutralization lines.	61%	0.18-0.081	23dB
12	50×40×1.6/ FR-4	Two elements symmetrical microstrip Antennas	Line of neutralisation using an inductor and a capacitor	85%	0.002-0.006	20dB
13	4*×4*×1.6/ FR-4 *=cm	double-sided 4-element symmetric circular monopole antenna	Stepped Neutralization line	-	0.004	21dB
14	FR-4	Two symmetric printed antenna element	three connecting neutralization lines	80%	-	15dB
15	FR-4 35 mm × 16 mm	Ultra-wideband MIMO antenna.	Wideband Neutralization Line	-	-	22dB

2.3 Parasitic element method:

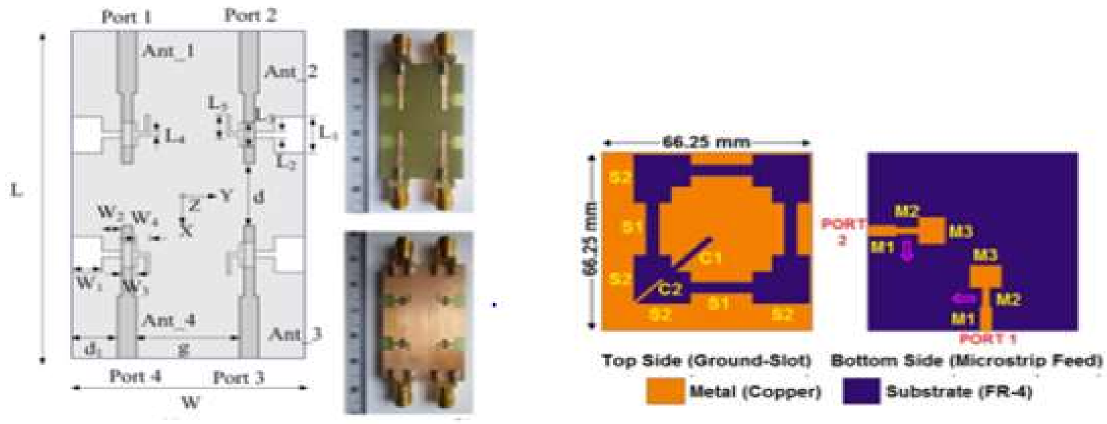

Fig 3: Parasitic element Structure [16] and [19]

The Parasitic Element technique minimizes mutual coupling between antennas by introducing an additional docking path. In this method, one of the two coupling pathways is in opposition to the incoming signal. thereby reducing mutual coupling. The key advantages of employing this technique include the simple of use design, small size, and ease of production using various technologies such as PCB (Printed Circuit Board) or waveguide. The introduction of an antenna or stray slot is instrumental in achieving these benefits. This approach is notable for its straightforward design, small physical footprint, and versatility in manufacturing using different technologies like PCB or waveguide.

Table No-3: Antenna using parasitic element method

Ref.	Substrate Material/ size	Antenna Design	Shape of structure	Efficiency	ECC	Isolation
16	FR-4/ 66.25×66.25 ×1.6	Dual polarized slot antenna	Square Ring Slot Antenna	60%	0.005	20dB
17	95 mm× 60mm/FR-4	mimo antenna	Dual slot antenna	77%	-	20dB
18	48×48×1.6 mm^3/FR-4	(2×1) Antenna System for Parasitic Structure	rectangular shape with (10) square slots	89%	0.1	25dB
19	42×25×1.6 mm^3/FR-4	Compact	Open ended	80%	0.5	22dB

		MIMO	ground slot			
20	22×24.3×1.52 mm^3/FR-4	UWB MIMO antenna	meandered feeding lines and Stub to ground connection	82%	0.4	15dB

1.4 Metamaterial method :

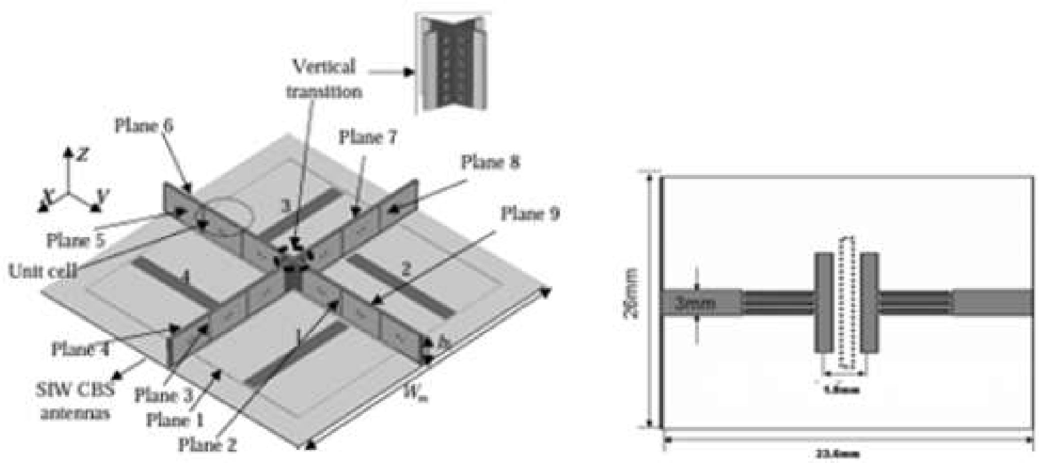

Fig 4: Metamaterial method Structure [22] and [24]

The Metamaterial method emerges as a promising solution for reducing MC between different antenna elements in MIMO structure systems. This technique has demonstrated high isolation levels compared to alternative methods employed for the same purpose. Metamaterials, which are artificially engineered composites, derive their electrical properties from their structure rather than the constituent materials. This approach is relatively new and has gained significant attention.

Recent developments in the field include the proposal of a dual-frequency MIMO system with an Array of Patch Antennas Through using a CLL Metamaterial in the year 2019. Initially, the achieved isolation reached a maximum of 55 dB, accompanied by a gain 8.2dB and efficiency 97%,. Subsequent implementation of the metamaterial method [21] resulted in a noteworthy improvement, with a 55 dB enhancement in isolation. The CLL-MTM superstrate demonstrated comparable gain and efficiency to unloaded array antennas, with minimal changes of 0.1 dB and 2%, respectively [21]. Additionally, a method for reducing MC between closely spaced radiating elements was proposed, involving the insertion of a fractal isolator—a metamaterial-based electromagnetic bandgap structure. Through this approach, the distance between radiators was reduced to 0.65, leading to significant reductions in reciprocal coupling at up to 21, 20, and 31 dB. This proposed technique holds applicability in two-element antennas across various domains, including MIMO, RFID technology, and Radar [27].

There is a great deal of research around the world focused on this area. The table highlights and key denotes studies to enhance comprehension.

Table No-4: MIMO using metamaterial method

Ref.	Substrate Material/ Size (mm3)	Antenna Design	Shape of Metamaterial structure	Efficiency	ECC	Isolation
22	Rogers RO4003 RO4450B/ 119 × 119× 22.5 mm	substrate integrated cavi-ty-SICBS antenna	dual-layering mushroom structure	-	0.02	42dB
23	FR-4/ 26 × 29.3× 1.6 mm	CRLH configuration antenna	Cascade transmission line	66.9%	0.01	28dB
24	FR-4/ 26× 23.6 mm^2	CRLH configuration antenna	defected gro undstructure	-	-	45dB
25	Rogers RT5880	dielectric resonator antennas	metamaterial polarization-rotator(MPR) wall	-	0.02	16dB
26	FR-4	two antipodal Fermi-based tapered slot antenna	metamaterial-based corrugations,	77%	-	15dB

3. CONCLUSIONS

This article conducts a thorough investigation and comparative analysis of various techniques proposed by different authors to alleviate mutual coupling in MIMO antennas. Diverse methods, such as mushroom EBG, cutting plane, rectangular DGS, U-shaped parasitic element, and protruding pieces, have been scrutinized for their potential effectiveness. Each technique exhibits its own set of advantages and drawbacks, taking into account factors such as complexity, cost, manufacturing techniques, and operating modes.

The primary objective of the researcher is to enhance the MIMO antenna system, focusing on improving capacity, reducing BER, raising the gain, and enhancing diversity. Additionally, the

MIMO antenna under consideration is designed to be versatile, suitable for deployment in single, double, and multiband applications. This versatility opens up opportunities for further exploration into compact and multiband printed MIMO antennas across a wide range of applications.

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