Design Aspects of MIMO Antenna in Gain Enhancement for Wireless Applications- A Review

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Abstract: The number of digital platform users has extensively increased in the recent era. This imposes a high data rate, low latency and highly reliable wireless communication system. To manage the high data rate requirement, the communication front-end RF system should be integrated with multiple antennas for transmission and reception. This multiple-input-multiple-output (MIMO) system improves the data rate. The main challenge in the MIMO system is mutual electromagnetic coupling between the antenna elements. The isolation should be high for efficient transmission of the electromagnetic signal. Along with this, one MIMO antenna should operate in multiple wireless applications without any interference. This is achieved by integrating a reconfigurability function in the MIMO antenna. Additionally, the gain of the MIMO antenna can be enhanced by adding metamaterial structures as a superstrate or substrate. This paper provides a brief review of MIMO antenna design techniques. Also, integration of reconfigurable and metamaterials with MIMO for frequency switching and gain enhancement, respectively.

Keywords: MIMO Antenna; Pin Diodes; Reconfigurable Antenna; Metamaterial; Gain Enhancement.

Introduction

Advancements in mobile communication demand higher data rates, low latency, continuous connectivity, an increase in channel capacity, and multiple wireless connections with smart devices [1]. To have an increase in data rate for a particular application, multiple antennas operating in the same frequency band can be used. Then the large data can be separated and given to multiple antennas for transmission, by which the data rate can be increased. This concept is represented as a Multiple-Input Multiple-Output (MIMO) system. Integrating multiple antennas that operate in the same frequency range into a system will have the effect of mutual coupling between the antenna elements. The isolation between the antenna elements plays a vital role in MIMO antenna design. The isolation between the antenna elements should be less than -15 dB as per the literature [1], [2]. The electromagnetic coupling between the antenna elements is referred to as isolation, and practically, electromagnetic coupling between radiating structures should be very, very small. If electromagnetic coupling is greater, the radiation of the signal into the free space will be less. This, in turn, decreases the gain and radiation efficiency of the antenna. Isolation between the antenna elements can be improved by incorporating various design techniques such as defected ground structure (DGS), defected microstrip structure (DMS), partial ground, electromagnetic bandgap structures, parasitic structures and resonator structures [3], [4]. To have better isolation in MIMO antenna design is one of the major concerns.

Along with the MIMO concept, in recent mobile handsets, the user can operate various wireless connections such as Wireless-Fidelity (Wi-Fi), Bluetooth, mobile communication, GPS location/tracking and smart Internet of Things (IoT) devices. Here, each application works in different frequency bands as allotted by 3GPP/FCC. Hence, a separate communicating antenna is required for each application. To overcome this, a single MIMO antenna operating in multiple bands and switching between the bands based on the requirement can reduce the incorporation of multiple antennas for each application in a single mobile device. This paper discusses the literature carried out in the MIMO antenna design incorporated with reconfigurable and gain enhancement techniques.

MIMO Antenna Design Techniques with Better Isolation- A Review

In the MIMO antenna design, the electromagnetic coupling between the antenna elements has to be reduced. This will improve the isolation between the antenna MIMO antenna elements. To have an improvement in isolation, various antenna radiating and ground design structures are used in the literature. The authors in [5] proposed a defective elliptical radiating patch with partial ground structure for isolation improvement. A circular slot is etched from the elliptical radiator, and the work discusses a quad-element MIMO. The literature [6] discusses a parasitic metamaterial structure embedded between the 2 x 2 defected microstrip radiating elements in the 2 x 2 MIMO design to have better isolation. In [7], decoupling structures are used between the antenna elements in the radiator and ground structure. In this article, the authors proposed a semi-circular shape defective ground structure with a circular shape defected microstrip structure. These modifications are carried out in the design for isolation improvement between radiating elements.

Metamaterial-Based MIMO Antenna Design Techniques- A Review

For gain enhancement in MIMO antenna design, metamaterial structures are used. These structures are placed as superstrates or substrates, considering a gap of 5 mm to 30 mm between the MIMO design and the metamaterial [8]. Also, in a few studies, metamaterial structures are embedded in the MIMO antenna as a parasitic element for gain enhancement. The authors in [9] proposed a 2 x 2 MIMO design in which a sequence of H-shaped metamaterial structures is incorporated in the antenna as a parasitic element for gain enhancement. The literature [10] used a metamaterial as a substrate for 4 x 4 MIMO for gain and isolation improvement. The metamaterial is placed at a distance of 12 mm below the MIMO structure. The article [4] uses a split-ring resonator-based metamaterial structure along with 4 x 4 MIMO. In this, the metamaterial is placed as a superstrate for gain and isolation improvement. The paper [11] presented a metamaterial structure between the antenna elements for isolation improvement and a 3D printed resonator structure for gain enhancement.

MIMO Reconfigurable Antenna Design Techniques- A Review

The antenna operating characteristics, such as polarization, radiation pattern and frequency, can be dynamically altered by using a reconfigurable mechanism. This review focuses primarily on a frequency-reconfigurable antenna. One single antenna operating frequency can be altered by changing the current flow path. This can be achieved by integrating a switch into the antenna. The devices, such as pin diodes, varactor diodes, RF MEMS switches or optical devices, are used for frequency reconfigurability. The authors in [12] used pin diodes in a 2 x 2 PIFA-based MIMO to switch between the various wireless communication bands. In [13], a 4 x 4 MIMO reconfigurable antenna is suggested by the authors to have frequency switching between the 5G mobile communication band, 3.5 GHz and the WLAN frequency band, 5.2 GHz. By the proper biasing provided to the pin diodes, the MIMO antenna works either in the 5G communication band or the Wi-Fi band. The article [14] suggested a light-dependent resistor (LDR) for the reconfigurability function. In [15], the paper discusses the usage of pin diodes to achieve polarization reconfigurability. For gradual variations in operating frequency, radiation pattern or polarization, varactor diodes are used in the MIMO antenna design for achieving reconfigurability[16]. These are a few recent papers suggesting a reconfigurability feature in the MIMO design.

Table 1. Review and Analysis of the existing work

Aspect	**Existing Research**	**Identified Gap**
MIMO	Many studies on Isolation improvement	Adaptability is poor
MIMO + Metamaterial	Gain Enhancement and Reduction in Mutual Coupling	Dynamic Tuning not available
MIMO + Reconfigurable	Frequency Reconfigurability is commonly used	Less concentration in Isolation, mutual coupling and Gain of MIMO Antenna
MIMO + Reconfigurable + Metamaterial *(Proposed)*	Studies are very limited	Integration provides the best solution for 6G wireless Applications

Future Research Directions

To confront the requirement of high data rate, high gain and to have wireless connectivity for multiple applications, the frequency reconfigurable metamaterial-based MIMO antenna will be a better solution. The frequency reconfigurability between the bands is achieved by integrating the pin diode switching concept in the 4 x 4 MIMO configuration. The gain enhancement is achieved by placing a metamaterial design structure as a superstrate/substrate to the reconfigurable MIMO antenna, as shown in Figure 1.

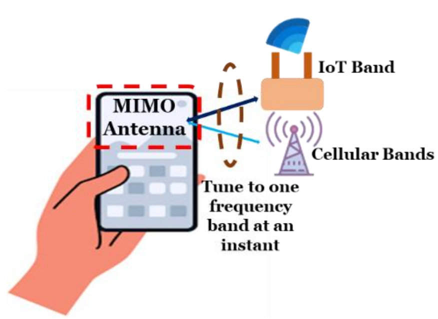

Figure 1. Proposed Metamaterial-Based Reconfigurable MIMO Antenna.

Conclusions

This paper provides a structured review of MIMO antennas for wireless applications. To have an improvement in data rate instead of a single antenna, a MIMO antenna is placed at the frontend of wireless communication systems. For MIMO antenna design, electromagnetic coupling between the antenna elements should be negligible for efficient transmission and reception of data. The design techniques such as DGS, DMS, electromagnetic bandgap and parasitic structures are used to improve isolation in the MIMO antenna.

Further, for gain enhancement, metamaterials or frequency-selective surfaces are used as a superstrate or substrate along with MIMO design. A brief review of the metamaterial structure with MIMO was discussed in the paper. Different frequencies are used by various wireless communication applications (Mobile, WLAN, Bluetooth, GPS and IoT). For each application, separate antennas are incorporated in the wireless system. This can be mitigated by integrating reconfigurability in the MIMO design. The future work is progressing on designing a metamaterial-based reconfigurable MIMO antenna for gain enhancement and operating frequency adaptability.

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