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Mutual Coupling Reduction Techniques between MIMO Antennas for UWB Applications

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Abstract— The recent research has proved that the Multiple-input-multiple-output (MIMO) systems can substantially increase the channel capacity by employing multiple antennas at both the transmitter and receiver, without increasing either transmitter power or bandwidth. Hence it is very much essential to know all the aspects of MIMO system. Usually, in any MIMO system the antenna design plays a major role in improving the system performance and channel capacity. The antenna bandwidth must support the wireless system for transmitting larger data rates. Also, the mutual coupling effect between the antennas must be taken into consideration, while designing an efficient MIMO system. The objective of this paper is to discuss various techniques to reduce mutual coupling of MIMO antennas for UWB application.

Keywords: *MIMO, UWB.*

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I. INTRODUCTION

In the present scenario of wireless communication, people demand high data rate and reliable communication. UWB has become the solution for future short-range high-data wireless communication applications. Federal Communication Commission (FCC) has allocated the unlicensed frequency band of 3.1 GHz to 10.6 GHz with an EIRP of−41.3 dBm/MHz to avoid interference with narrowband communication systems. After the announcement of unlicensed 7.5 GHz of spectrum, there has been a wide variety of applications developed for indoor/outdoor communications, high accuracy radars and imaging systems, etc. In UWB Communication systems, an antenna is one of the most critical components to be realized to have a good system performance.

Antenna design for portable devices with compact size is the one of the main challenge especially for UWB wireless communication.

The challenges of feasible UWB antenna design also include wide impedance matching, radiation stability, low profile and low cost. Moreover, UWB systems also suffer from multipath fading like other wireless systems. The Multiple-input-multiple-output (MIMO) technology usually provides multiplexing gain and diversity gain and further improves the channel capacity and link quality. So to solve the problem faced by UWB systems, the MIMO technology is introduced. The major challenges in the design process of MIMO antennas for UWB systems are minimize the size of antenna elements for the MIMO and reduce the mutual coupling between the antenna elements.

The various methods employed to reduce mutual coupling in MIMO have little effect on the wideband impedance matching for the UWB applications. The half wave dipole antenna, monopole antenna and Microstrip patch antennas are the most widely used antenna for MIMO systems.

II. MIMO ANTEENA DESIGN

A conventional RF communication system has one antenna in the transmitter and another antenna in the receiver, commonly designated as a single-input–single-output (SISO) system. In the last decade, significant advances in the multiple-input–multiple-output (MIMO) technology have been achieved by wireless communication engineers. This is due to the development of spatial multiplexing and diversity coding techniques to increase the channel capacity of MIMO systems. Advanced diversity antennas are required to support this exciting new development.

A schematic representation of MIMO system with N number of transmitting and receiving antennas is shown in Fig. 2.1. The idea behind the system is to transmit various data streams using different antennas at the same carrier frequency and without additional power. When a data stream is transmitted from pth antenna, it is received at the qth antenna after travelling in different paths as shown in the Fig. 2.1. The reflection of signal from different objects in the path produces the multipath propagation. The signal received at the receiver is represented as

$$\mathbf{Xq(t)} = \sum_{p=1}^{N} hqp(t)Sp(t) \qquad \mathbf{(1)}$$

ISSN: 2321-8169
18 – 22

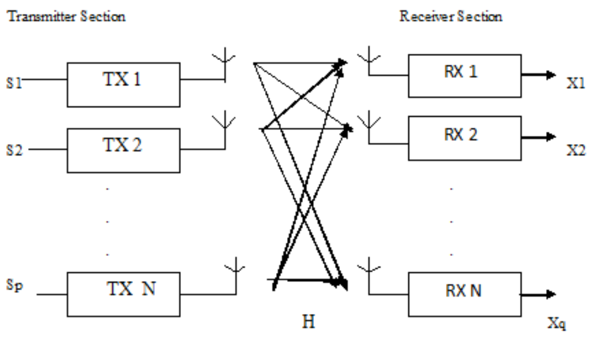

Fig.2.1 A schematic representation of MIMO antenna

Where, xq(t) represents the q^{th} received data, sp(t) represents the p^{th} transmitted data and hqp(t) represents the path gain between p^{th} transmitter and q^{th} receiver. The important technique for modern wireless communication system is antenna diversity. Section 2.1 gives an overview of several diversity techniques and their influence on MIMO performance. .By employing multiple-antennas in MIMO, the effects such as multi-path, co-channel interference and small-scale fading can be reduced. The mutual coupling between antenna elements may become severe for compact devices due to their small distance. In order to decrease the mutual coupling between antenna elements, several techniques have been proposed and they are explained in section 2.2.

2.1 Diversity Techniques for MIMO Systems

1.1.1 Spatial Diversity

Spatial diversity is achieved by using more than one antenna element at transmitter and/or receiver to increase the number of channel paths between TX-RX. With sufficient element spacing, correct number of elements, and appropriate array geometry or topology, signal quality over the wireless channel can be improved. Adopting this scheme for MIMO, channel capacity can also be optimized. As a rule, antenna element spacing should be a multiple of its frequency wavelength, to ensure independent fading on each element. Insufficient spacing between antenna elements will cause mutual coupling between the elements, which will cause input impedance modification and pattern distortion to occur.

2.1.2 Polarization Diversity

Mutual coupling can be mitigated with the use of polarization diversity, which can be viewed as an extension of the space diversity scheme. In a typical case of linear polarization diversity, signals are transmitted and received via horizontally polarized as well as vertically polarized antennas of two distinct polarizations constructs independent and Pairing vertically polarized TX and RX antennas is usually desirable for optimum performance since vertically polarized signals normally propagate slightly better than horizontally polarized signals. Nevertheless, a MIMO system for indoor applications will suffer from cross-polarization induced by the highly reflective interior structures. This cross-polarization factor is a phenomenon where a signal is received with polarization that is orthogonal to the transmitted polarization.

2.1.3 Pattern Diversity

Designing antennas with distinct radiation pattern, for the case of array with two elements, constitutes the scheme of pattern diversity. High correlation effect in a MIMO channel is minimized by taking advantage of the angle spacing of the TX and RX signals. With angle diversity, angle of departures of the TX signals or angle of arrivals of the RX signals are discriminated with the use of directional antennas pointing specifically to each angle direction. This ensures isolation between each TX or RX signals, and thus produces low correlation effect on the signals. Angle diversity is highly dominant when each of the antennas is able to receive the multipath signals from many different directions. This causes the angle spacing to be narrowly spaced and thus generates high directivity due to the non-overlapping patterns. The highly orthogonal antenna patterns produce the desirable low correlated or uncorrelated MIMO signals. Small antennas, in comparison, tend to have overlapping omnidirectional patterns due to larger angle spacing causing high correlation impact on the MIMO channel. Other method to guarantee high capacity performance in a MIMO system is to employ the exceptional technique of multimode diversity. This method exploits the characteristic of multimode antennas that exhibits orthogonal radiation patterns for different excitation modes. Moreover, a single multimode antenna which is excited with fundamental TEM modes, can offer the advantage of having multiple orthogonal patterns for low correlation effect while eliminating the need for multiple antenna elements as opposed to other diversity schemes.

2.2. Technologies to reduce mutual coupling between antennas in MIMO system

One of the main challenges to employ MIMO technology in portable devices is the design of small MIMO antennas with low mutual coupling. The mutual coupling or correlation between antenna elements in MIMO through surface wave propagation, because the antennas share the common surface currents should be minimized either by antenna design or by the introduction of features on the ground plane to inhibit the current flow. Various methods have been introduced to improve the isolation characteristics of MIMO antenna for UWB application are

(i) Decoupling structures
(ii) Antenna elements of different types
(iii) Meta material structures

(iv) Electromagnetic Band Gap (EBG) or neutralization structures

2.2.1 Decoupling structures

Normally the antenna elements were set orthogonally with respect to each other to enhance the isolation and pattern diversity. Various decoupling structures have been inserted between the antenna elements to enhance the wide band isolation. Few of them are,

In [1] to enhance isolation and increase impedance bandwidth, two long protruding ground stubs are added to the ground plane and a short ground strip is used to connect the ground planes of the two planer-monopole (PM) together to form a common ground. To further enhance isolation and increase impedance bandwidth, two long ground stubs, Stub 1 is placed in parallel with PM 1 and is bent to reduce the overall antenna area, while stub 2 is a simple straight stub placed in parallel with PM 2.

Two open L-shaped slot (LS) antenna elements and a narrow slot on the ground plane. The antenna should be placed normal to each other to obtain high isolation, and the narrow slot is added to reduce the mutual coupling of antenna elements in the (3-4.5 GHz) low frequency band.[2]

In [8] two square monopole-antenna elements, a T-shaped ground stub, a vertical slot cut on the T-shaped ground stub to reduce mutual coupling, and two strips on the ground plane to create a notched frequency band.

The MIMO antenna in [13] employed two-folded monopole elements, each coupled with a parasitic inverted-L element, to achieve UWB operation. Two meander lines, a connection line and a short parasitic line, were used to enhance isolation between the two input ports.

In [10] two antennas share a single radiator, which reduce the overall size of the MIMO system. T-shaped slot in the radiator and a stub on the ground achieves high isolation and the pentagonal radiator with perpendicular feeding structure produce dual polarization. Decoupling is achieved by extending a branch in the symmetry axis of two antenna elements and etching a T-shaped slot in the radiator.

2.2.2 Antenna elements of different types

The technique of orthogonal placement of antenna feeds/elements provides good isolation among the antenna elements. However, it will result in a dual-polarized system or polarization diversity. However, the true challenge will be the placement of the antenna elements in the same polarization and to obtain high isolation without any decoupling structures while maintaining compact dimensions.

In [3] high isolation between slot antennas can be easily achieved with the help of the directional radiation properties of a slot antenna. The microstrip-fed stepped-slot antenna achieves high isolation without any decoupling network is due to inherent directional radiation properties of slot antennas (SAs) and their asymmetrical placements.

Two symmetrical half-slot antenna elements with coplanar waveguide-fed structures and a Y-shaped slot that is cut at the bottom center of the common ground plane. Y-shaped slot is employed to improve the isolation performance at low UWB frequency band. [4]

Antennas in [14] enhanced isolation by notching rectangular or T-shaped slot on the ground, which suppressed the surface currents flowing between adjacent ports.

In [7] a printed circular disc compact planar antenna reducing the mutual coupling and the correlation between the elements.

An array of 4 monopole radiators and a u-shaped slot was inserted in radiator 2 to rectify the mismatch and improve the wideband matching characteristics. A separate partial ground plane was chosen for each radiator because it plays an important role in matching and also provides better isolation.[9]

In [11] A radiation patch connected through a via with the strip placed beneath the patch. The strip not only provides another coupling path, but also serves as the impedance transformer, resulting in good isolation (dB) and dual band rejection at WiMAX (3.4–3.7 GHz) and WLAN (5.15–5.35 and 5.725–5.825 GHz) overthe UWB system operation (3.1–10.6 GHz).

2.2.3. Metamaterial structures

To concentrate electromagnetic fields and current near the antenna structure instead of spreading them along the antenna ground metamaterial structures are used. Because spreading of fields and currents results high mutual coupling between the antenna elements. The circuit size is reduced by using metamaterial technology also this structure produces better performance in both antenna and passive circuit applications.

In [19] A microstrip antenna array with a novel Ring Resonator structure that is included between the antenna elements for mutual coupling reduction. The effects of the inclusion of this structure increase the antenna performance.

The split ring resonators (SRR) and their variants are used as a metamaterial structure in[18].

Two single metamaterial antennas which are constructed based on the modified composite right/left-handed

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18 – 22

(CRLH) model. In order to reduce the mutual coupling of the antenna, a defected ground structure (DGS) is inserted to suppress the effect of surface current between elements of the proposed antenna.

A unit cell structure which has a inductive spiral loop embedded in a dielectric substrate. A magnetic field normal to the plane of the spiral induces a current in the loop, a phenomenon that effectively creates an inductance within the substrate and creates magnetic energy storage in the unit cell. This storage enhances the magnetic permeability of the otherwise non-magnetic substrate material. This"induced" inductance along with the capacitance in the structure forms a resonance structure.

In [12] WLAN and Wimax bands are achieved by using slotted ground structure and metamaterial rectangular split ring resonator.

2.2.2 Electromagnetic Band Gap (EBG) or neutralization structures

Electromagnetic Band Gap (EBG) structure was used to improve the isolation by blocking surface wave propagation. The EBG structure with no metallic vias or vertical components was formed by etching two slots and adding two connecting bridges to a convenient unipolar EBG unit cell.

Two identical monopole antenna elements with a comb line structure on the ground plane used to improve the impedance matching and enhance the isolation [6].

2.3 Performance comparison of various MIMO antennas

Ref	Size	Bandwidth (Ghz)	Isolation(db)	ECC(ρe)	Gain(dbi)
1	40X26mm^2	2.9-10.6	<-15	<0.2	6.5
2	32X32mm^2	3.1-10.6	<-15	<0.02	1.7-4.2
3	42X25mm^2	3.1-12	<-22	<0.01	4
4	23X18mm^2	3-12.4	<-15	<0.015	4
5	3X19X0.4mm^3	2.3-2.4	<-15	<0.16	2
6	26X31mm^2	3.1-10.6	<-25	<0.001	<5
7	59X27mm^2	3.1-10.6	<-24	<0.06	4.7
8	22X36mm^2	3.1-11 Notched at 5.15-5.85	<-15	<0.06	Decreased due to notched fr
9	50X39.8mm^2	2.9-10.6	<-17	<0.03	4.2
10	40X40X0.8mm^3	3-11	-	<0.02	10.2
11	30X40X0.8mm^3	3.1-10.6 Notched at WiMax and WLAN	<-15	<0.05	Decreased due to notched fr
15	35× 40× 0.8 mm^3	3–11.6	−16	0.01	< 6.5
16	26 × 40 × 0.8 mm^3	2.9–10.6	−15	0.2	< 6.5
17	27 × 30 × 0.8	3–11	−20	0.012	< 5.25

2.4 Envelope Correlation Coefficient

The behavior of the MIMO antenna can be analyzed in terms of two important parameters: ECC and CCL. The acceptable limits of these parameters are ECC<0.5 and CCL <0.4 bits/HZ/s. The envelope correlation coefficient (ECC) is an important parameter to evaluate diversity performance, which depicts the extent of isolation or correlation of different communication channels. The ECC can be obtained from the S parameters and radiation efficiency of UWB MIMO antenna

$$\rho_e = |\rho ij|^2 = \frac{|Sii^* Sij + Sji^* Sjj|^2}{(1-|Sii|^2 - |Sji|^2)(1-|Sjj|^2 - |Sij|^2)\eta rad,_i \eta rad,_j} \quad (2)$$

Where ηrad,I is the radiation efficiency of the ith antenna element.

III. CONCLUSION

This paper focuses the basic and important concepts of MIMO antenna. Moreover this paper gives the various technologies used to improve the isolation between antennas in MIMO. Also a comparative study of performance of the above said techniques were discussed.

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