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REVIEW ON DESIGN OF COMPACT BROADBAND MIMO ANTENNAS

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Abstract **– A compact design of directive antenna element for broadband applications exclusively meant to serve Multiple Input Multiple Output (MIMO) systems is presented. The proposed antenna consists of a parabolic reflector, a dipole and a metallic strip which is rectangular in shape, can be a suitable design for MIMO systems. Also a parasitic is strip inserted between the dipole and the parabolic reflector can improve impedance matching. The concave parabolic reflector can minimize the antenna dimension and can enhance directivity. The metallic strip employed increases gain at the upper band. By suitably arranging the elements ,the array can achieve good isolation and thus makes it ideal for various MIMO applications.**

Keywords**—Multiple-input Multiple-output (MIMO),directive antenna , dipole , parasitic strip.**

I. INTRODUCTION

Multiple-input multiple output (MIMO) systems promises increase in the performance of wireless communication without the needs for additional radio spectrum or transmitting power. They have emerged as an integral part of new wireless standards due to their promising features of providing high data rate, mitigating multi-path fading effects, and providing better transmission quality and coverage resulting in improved reliability. MIMO systems usually contains multiple antennas integrated together to achieve broad bandwidth and low mutual coupling.

For small devices, such as smart phones and tablets, a unique challenge in MIMO antenna design is embedding the antenna inside the device while maintaining sufficiently low mutual coupling between radiators so that the advantages of increased MIMO capacity can be maintained [2].

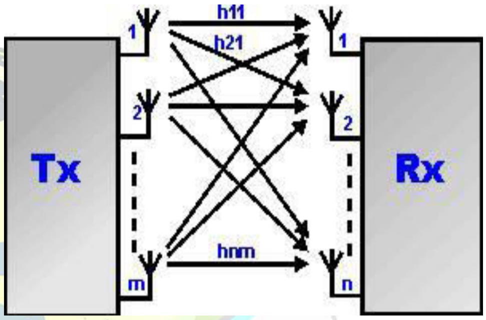

Figure 1: A MIMO system with **m** transmitting antennas and **n** receiving antennas

It is usually required to place multiple antennas in such devices with minimal effect on neighbouring antennas (i.e. highly isolated with low field correlation). Therefore, such antennas need to be carefully designed[3].

Multiple input multiple output (MIMO) technology has played an important role in wireless communication systems, because it can increase the data throughput and link range significantly without additional bandwidth or increasing transmit power. With the rapid development of wireless communication, antennas with low cost, compact size and strong radiation directivity are in great demand for various applications, such as WLAN (IEEE 802.11n standard), WiMAX (IEEE802.16e standard) and LTE etc[4].

MIMO technology has been incorporated into Wireless Local Area Networks (WLAN) through the IEEE802.11n and 802.11ac standards. These MIMO WLAN systems can support up to 4 antenna elements and 4 data streams for each user or mobile station[5]. These systems operate in the frequency bands of 2.4-2.5 GHz (802.11n) and 4.9-5.725 GHz. (802.11n and ac) and as a result there is a need for compact MIMO antennas. World interoperability Microwave Access, WiMAX bands (2.50-2.90GHz)

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are also considered as an upcoming wireless communication technology.

Long Term Evolution (LTE)[6] is the next neration mobile communication standard expected to provide high data rate, which is set to occupy frequency range from 400MHz to 4 GHz. LTE-D 2600 (2570MHz-2640 MHz) bands are the uppermost frequencies, especially used in some Asian countries. MIMO antenna, especially in the LTE base stations and mobile handsets, can be used to advance the speed of data exchanging and realize high data rate transmission without the additional spectrum or power consumption. In these applications, the compact planar and easily fabricated MIMO antenna is obviously a good candidate. Unfortunately, designing a planar MIMO antenna with compact size and broadband is still remaining a challenging problem for both the academic and industrial areas.

Based on the background of the researches conducted, in this letter, a compact planar broadband MIMO antenna design is discussed and analyzed. In the proposed system , an antenna element having a concave parabolic reflector , a meander dipole , a rectangular metallic strip and a parasitic strip is considered ,which may exhibit compact size i.e., comparatively smaller than reported designs. The proposed antenna element can be utilized to form a four-element MIMO array, which could obtain a wide bandwidth, low correlation as well as compact size. Therefore, the proposed MIMO array can be a good candidate for 2.40 GHz WLAN band (2.40-2.48 GHz), WiMAX bands (2.50-2.90GHz) and LTE 2600 (2.5-2.69 GHz) applications due to the obtained results.

II. SINGLE ANTENNA DESIGN

In general, the MIMO antenna element should be directional, which could supply good pattern diversity for a MIMO system. Nevertheless, in order to reach very compact MIMO array configurations, where antennas are close to each other, the pattern distortion can no longer be neglected, and the displacement between antennas will result not only in space diversity but also in an induced pattern diversity.

A. PARABOLIC REFLECTOR

For achieving a good pattern diversity, directive antennas are the best available. Directive antennas radiates or receives greater power in a specific direction allowing for increased performance and reduced interference from unwanted sources. Directive antennas are also known as high gain antennas. The traditional methods to design planar directive antennas is to use Yagi Uda[7] antennas which is simple and easy-to-implement solution to achieve nearly orthogonal patterns. Yagi-Uda antennas are famous for their distinct features like: high Front-to-Back Ratio (FBR), high gain and directive end-fire radiation pattern[8]. Yagi antennas can be easily fabricated, have low cost, are robust and are highly compatible with printed circuitry, therefore, they are extensively used in wireless communication systems and in applications like: radars, local positioning systems (LPS) and wireless sensor networks [9]. As with all end-fire arrays however, doubling the gain (3 dB improvement) requires a 4-fold increase in length which prevents its use in our compact application.

Alternatively, Landstorfer antenna[10] also exhibits high gain and low mutual coupling between elements. Slot antennas[11] provide wide bandwidth compared to Microstrip -based ones. They are rigid in structure and can be easily etched out of a ground plane and therefore, they are suitable for fast moving objects. They own inherent broadband characteristics ,achieves high FBR and directional radiation pattern. However , most of the elements in [10]-[12] are narrowband. Because broadband MIMO antennas could cover wide spectrum to meet the requirement for various wireless communication systems, several antennas were designed to have wide bandwidth [11],[13]. But the antenna’s structures are non-planar, which cannot be conformable to the mounting host.

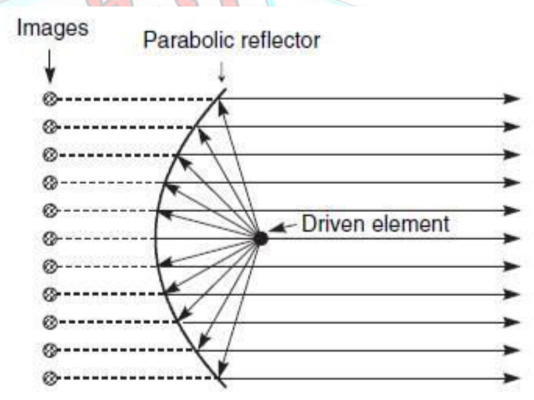

Figure 2: A Parabolic Reflector Antenna

So, in order to attain compact planar structure for broadband applications Parabolic antennas may be used . The parabolic antenna Figure2 extends the reflector antenna concept to curved reflectors. In this case the number of images is effectively infinite and the locations of the images are such as to produce a parallel beam from the reflector, provided that the driven element is placed at the focus of the parabola. It is the parabolic reflector which helps the antenna to accomplish high directivity and covers broad bandwidth which makes it apt for the MIMO systems. Moreover,

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parabolic antennas are appropriate for high gain applications for point-to- point communications. For narrow beam width applications parabolic antennas should be larger than the wavelength and hence compactness can be achieved for wide spectrum applications. The reflector helps to obtain unidirectional radiation at the lower band ,is also designed to be concave parabolic to reduce the antenna size while maintaining the same directivity as that of using a traditional straight reflector. Highly directive pencil beams are produced by placing directive systems like Dipole unit above the concave parabolic reflector. For satisfactory antenna pattern , it is important to ensure that antennas pick up maximum power from an incident wave and that it radiate the power delivered to it by a transmission line without reflecting an appropriate portion of it back to the transmitter. So ,there should be proper impedance matching for each antenna element.

B. MEANDER DIPOLE

Directive systems employed in the antenna elements leads to high directivity. Most commonly used directive system is a dipole unit. In order to accomplish a highly compact antenna element we could use a folded dipole which works at half wavelength mode. Half wavelength dipole is the most widely used antenna or dipole unit where the length of the dipole is equal to half wavelength of the operating frequency. Half wave dipole is formed from a conducting element which is wire or metal tube which is an electrical half wavelength long. It is typically fed in the centre where the impedance falls to its lowest. In this way , the antenna consists of the feeder connected to two quarter wavelength elements in line each other.

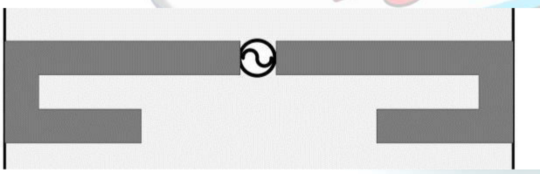

Figure 3: Meander Dipole

By meandering or simply twisting a half wave dipole further reduction in antenna size can be achieved. The distance between the meander dipole and parabolic reflector can be adjusted to obtain a suitable resonating frequency(here we need to make it 2.4GHz for WLAN which works from this

frequency). The length could be made considerably small so as to minimize the antenna size , while maintaining proper impedance matching. Further decrease in distance increases the input resistance and inductive reactance of the antenna. Consequently, the impedance matching between resonating frequency becomes poor due to change of the coupling between dipole and the reflector.

C. PARASITIC STRIP

For the purpose of improving the impedance bandwidth while keeping the compact size, a parasitic strip can be introduced to place between the dipole and reflector. Adding the parasitic strip may brings a capacitive coupling between the dipole and reflector ,and can improve the impedance matching . If the length and position of the parasitic elements are chosen appropriately, then the radiation from the parasitic and driven elements add constructively in one direction producing an increase in directivity.

Figure 4: Rough Layout of the antenna element

Thus induced capacitive coupling cause shift in the original resonant mode down to about 2.4 GHz in addition to the generation of a new resonance. Actually, the new resonance could be attributed to a half-wavelength meander dipole. It can be inferred that impedance matching could be adjusted by altering the length of the parasitic strip.

In fact, the wide operating bandwidth could be obtained by properly combining the dipole, reflector, director and parasitic strip together. Moreover, the impedance matching in lower band can be improved dramatically by adding the parasitic strip as the $|S11|$ comparison with and without parasitic element. In summary, a folded end dipole is tolerant of how it is folded and tolerant of how it is folded. It performs like a straight dipole and is simple to tune and can be up to 50% shorter.

D. RECTANGULAR METAL STRIP

For ensuring the directivity in upper band and to enhance impedance bandwidth we could make use of a metallic strip which is rectangular in shape. Rectangular shape is chosen so as to reduce the antenna size and the strip is placed above the meander dipole ,i.e., the upper side of the antenna . The strip act as a metal director which may lead to the final design achieving a wide impedance that could be extended up to 3GHz. It may help to

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further widen the impedance bandwidth and may produce good directivity than other reported designs.

Figure 5 : Layout of the proposed antenna element.

III. ANTENNA ARRAY DESIGN

Compact antenna with wide bandwidth and good directivity is necessary to build a MIMO array. Also the antenna array should have a low correlation between antenna elements. Therefore, each element should be arranged in a right position to reduce the coupling among the antenna elements.

Hence, for an effective MIMO antenna system mutual coupling between the antenna elements should be low. Various MIMO antenna designs have been reported for wireless applications. The main challenge in designing MIMO antennas is to arrive at high isolation amid the antenna elements. Some techniques used are the introduction of decoupling elements, utilization defected ground structures and meta materials. Of these techniques, utilization of meta materials are considered as the most efficient one. Various isolation methods for MIMO antenna system have been reported in the literature. They have been convened into four classifications in this paper and are explained in detail subsequently.

A. DECOUPLING NETWORKS

Mutual coupling is defined as the interaction between the electromagnetic field between the antenna elements. It changes the radiation pattern, received element voltages and the matching characteristics of the antenna element. The mutual coupling can be minimized by using decoupling networks. They decouple the input ports of the adjacent elements by providing negative coupling such that it cancels the coupling caused between the adjacent antennas. Lumped elements along with the distributed elements have been successfully applied to reduce the coupling thereby enhancing the isolation between the adjacent antenna elements. In [14], decoupling networks constructed using lumped elements will not work for frequencies less than 700MHz, since the transmission line gets longer for a decoupling network and hence lumped elements are realized using hybrid couplers solves the space issue[15]. Decoupling networks have been used frequently due to their advantage of spatial efficiency. Though conventional decoupling networks have a disadvantage of narrow bandwidth , broad band is achieved in decoupling networks using parallel resonant circuit, which is suitable for small spaces such as mobile devices[16] .

B. PARASITIC ELEMENTS

Parasitic elements are not actually connected to the antennas. These elements are used amid the antennas to terminate part of the coupled fields between them by creating an opposite coupling field thus minimizing the total coupling on the target antenna. They can be of a resonator type, floating or shorted stubs[17] . Also, parasitic elements are designed to control the bandwidth, range of isolation and the amount of coupling. A T-shaped ground stub with a slot is used amid the two square monopole elements to minimize mutual coupling[19]. The stub improves the matching of antenna and the slot within it reflects the radiation from the elements and improves the isolation. Strips in the ground plane are used to create a stop band to suppress interference in the WLAN band. In[18] , Rectangle Stepped Impedance Resonator (R-SIR) and Roundness Stepped Impedance Resonator (RD-SIR) on the ground plane provides isolation of over 23 dB for a wide range from 3.1GHz to 10 GHz. A -37.2 dB mutual coupling reduction was obtained by placing the parasitic tape over the microstrip patch antenna[20]. The Electromagnetic Band Gap (EBG) structures are

metallic or dielectric elements arranged periodically which exhibits one or more forbidden frequency bands. EBG structures are used for reducing the mutual coupling, although, they are complicated and require a large structure. In [21], Mushroom EBG structure acts as parasitic element and it is introduced between two antenna elements which supports either Transverse Electric (TE) or Transverse Magnetic (TM) waves acting like a band-notch filter. A mushroom EBG structure is

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equal to parallel LC resonant circuit. The capacitance is introduced from the gap and inductance from the current along the neighbouring cells. Thereby surface waves are prohibited to propagate thus decreasing coupling between elements.

C. DEFECTED GROUND STRUCTURES

The current created on the ground plane can be coupled to neighbouring elements causing high coupling which worsen the MIMO antenna system isolation and correlation6. The coupling between neighbouring antenna elements can be minimized by modifying the ground plane [22]. Modification can be introduced as slits]or it can be of dumble-shaped defects etc. It acts as band stop filter and suppresses the coupled fields between the neighbouring antenna elements by decreasing the current on the ground plane. A DGS is categorized by its band stop characteristics with which it prevents the propagation of electromagnetic waves. A DGS is placed below a transmission line which cancels the EMF fields around the defect. Electric fields near the DGS gives rise to the capacitance effect and the superficial currents around a defect cause an inductance effect. DGS acts as band stop filter and suppresses the higher harmonics. In [29][30], mutual coupling was reduced using etching slits and slots on the ground plane called a defected ground structure ,but a large ground plane is required in order to achieve this reduction. Furthermore, DGS systems have disadvantages in practical implementation due to their complicated ground structures.

D. METAMATERIALS

Metamaterials (MTM) are materials that have negative permittivity or permeability or both. Based on the literature, metamaterial based antennas are classified into two types. One that make use of ENG (Epsilon Negative), MNG (μ-negative) or DNG (Double Negative) substrate are called MTM-based antennas and the other that only utilise the MTM unit cell such as the SRR (Split Ring Resonator), CSRR (Complementary Split Ring Resonator) are referred to as MTM-inspired antennas.

Metamaterials (MTM) are used for isolation enhancement between adjacent elements due to the existence of a band gap in their frequency response. The band gaps can destroy mutual coupling between neighbouring antenna elements. The most widely used MTM basic structures for isolation enhancement between adjacent elements are the use of the Split Ring Resonator (SRR) and Complementary Split Ring Resonator (CSRR)or the use of Capacitively-Loaded-Loops (CLL). EM fields from the neighbouring antenna can be obstructed using SRR if the external magnetic field is at right angles to the rings of the resonator. The Split-Ring Resonators (SRRs) can function as insulators to block EM waves, thus reducing mutual coupling between the elements . CSRRs are the negative image of SRRs (Babinet's principle), and an axial time varying electric field is essential to excite the rings that create an effective negative ε medium and prevent signal propagation at resonance. The array built on the metamaterial substrate exhibits major size reduction, less mutual coupling and significant channel capacity improvement. Still efficiency is lower in the metamaterial substrate due to the copper losses in the unit cells and there is bandwidth deterioration in the metamaterial substrate due to increased permittivity in the substrate. SRR and 1-D EBG structures were acting as reflector and wave trap can be seen in many literatures.

From these isolation techniques discussed above, it is observed that better isolation is achieved using meta materials than others such as decoupling networks, parasitic elements and defected ground structures. Utilization of meta materials not only provides high isolation but also a major antenna size reduction is achieved.

Along with the discussed methods above, there are other methods for reducing the coupling. Feed points connected together by line are used to cancel the coupling in ports. Polarization diversity (need not be 90˚) can be achieved by tilting the antenna beams at various angles with respect to each other. Slots introduced in the ground plane also improve the isolation. Adjacently placed antennas of distance less than λ/4 cause high coupling. Mutual coupling can be minimized by employing the antennas with some separation distance within the mobile terminal. It can be placed either on top two edges or one at the upper part and other at the lower part. The positioning of the antennas also disturbs the phase of the coupling currents along with bothering the polarization of the radiated fields. The ground coupling and field coupling can be

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decreased if the adjacent antennas are oriented perpendicularly to each other (i.e., 90˚). Linearly polarized antennas located orthogonally to each other, increase the isolation and provide polarization diversity. However, they require a large antenna space and ground. Various isolation methods for MIMO antenna systems have been reported in the literature. Figure 6 illustrates two different ways to place the directional antenna elements. Due to the square loop configuration of Array-1, the mutual coupling between opposite elements is much reduced. Besides ,the overall size of Array-1 is much reduced than Array-2, which has an increased mutual coupling between adjacent and opposite antenna elements.

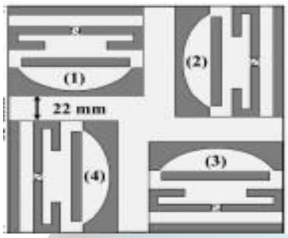

Figure 6(a) : Array-1 (orthogonal arrangement)

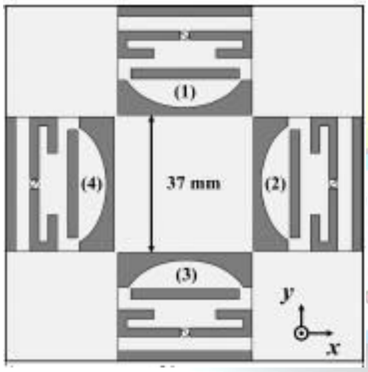

Figure 6(b) : Array-2 (square arrangement)

Mutual coupling degrades the system performance in terms of pattern diversity and hence mutual coupling reduction is a vast and an interesting area of research which has direct application for next generation wireless, i.e., 5G and beyond.

IV. CONCLUSION

Many investigators have contributed towards the improvement of channel capacity, Bit Error Rate (BER), diversity and gain of the multi element antennas for MIMO systems. However there are still plenty opportunities for the researchers to work on various technique to design a compact planar antenna structure and reduction in mutual coupling between the elements.

A broadband planar MIMO antenna design with compact size is proposed. By introducing a parasitic strip between driven dipole and reflector, the impedance matching of the single element can be greatly improved. Meanwhile, a metal director is also introduced to address the low gain at upper band and widen the operating bandwidth. By placing the antenna element in a right way, a four-element MIMO array can be formed to obtain a wide bandwidth, low correlation as well as compact size. The MIMO array has a compact size, hence the low profile planar structure which makes it suitable for various wireless portable devices applications.

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