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Mutual Decoupling In Quad Band MIMO Slotted PIFA for Wireless Applications

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-Abstract-
Mobile models like Nokia, Sony-Ericsson, Motorola uses Planar Inverted F Antenna (PIFA) inside the mobile to operate in GSM and 3G band. Inorder to overcome the limitation of narrow bandwidth in conventional PIFA, slots are introduced in the radiating patch of PIFA. MIMO PIFA is designed to operate in different operating frequency bands like Digital Cellular System (DCS) band and Universal Mobile Telecommunication System (UMTS) band. U slots are introduced in both PIFAs to operate in multiband for both 3G and 4G applications. Efficiency of dual slotted antenna can be improved by reducing the mutual coupling using techniques such as electromagnetic band gap (EBG), dielectric wall, defected ground plane (DGP) and parallel slot.

Keywords *- PIFA, slot, mutual coupling, dielectric wall, EBG, DGP, parallel slot, 3G, 4G.*

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I. INTRODUCTION

In modern mobile handsets, Planar Inverted F Antennas [1] are generally used as inbuilt antennas. Nowadays PIFA is being used in many mobile models as handset antenna because of its advantages of compact structure, easy fabrication, low manufacturing cost, reduced backward radiation and easy integration with portable devices. However, a major drawback of PIFA is its narrow bandwidth. This limitation is overcome by using slots in the radiating patch of PIFA.

All the facilities available in mobile phone cannot be integrated within a single antenna. Nowadays, multiple antennas [2] are needed to be integrated in the same handset as to support multiple standards such as UMTS band (1920-2170 MHz) or DCS1800 band (1710-1880 MHz). Multiple-Input and multiple-output (MIMO) [3] technology plays an important feature in wireless communication systems. This is because it can increase channel capacity with an increase in the number of antennas.

In mobiles normally the space allocated for the antennas is small. When several antennas are placed in the same handset, there is an exchange of energy between them, which is called mutual coupling [2]. Closely spaced antennas have strong electromagnetic coupling among each other, leading to high spatial correlation and low efficiency. This can result in degradation of the radiation pattern and changes in the input impedance.

The purpose of using a Defected Ground Plane as a technique to improve the isolation between two antennas is to make use of the ground plane itself to provide a filter effect [4]. This effectively suppresses the surface waves, and thus it reduces the mutual coupling between the antennas. Dielectric wall [2] is used as a technique as it blocks the flow of electric field from one antenna to the other.

Electromagnetic band gap [5] is used to suppress the surface wave thereby reducing mutual coupling. Parallel slot [6] provides good coupling between PIFA and slot in ground plane. In this paper, mutual decoupling techniques are introduced between MIMO slotted PIFA and their performance are analyzed.

II. Proposed Antenna Design

Planar Inverted F Antenna [7] consists of an upper patch, a ground plane, a feed, and a stub. The upper patch resonates at the size of nearly its quarter wavelength. MIMO PIFA is used to resonate at two different bands namely DCS band and UMTS band [8]. PIFA is designed based on the formula,

$Lp1+Lp2-Ws= \lambda/4$ (1) where Lp1 is the length of DCS PIFA, Lp2 is the width of DCS PIFA and Ws is the width of the stub. Fig.1 shows the design of MIMO PIFA namely DCS PIFA and UMTS PIFA as per the design formulas set in Table 1. Stub is used to connect the ground plane and suspended patch. The feed is used to excite the patch. The feed is placed at a distance of 6mm from the position of the stub. Stub, feed and patch together forms the shape of an inverted F with the ground plane.

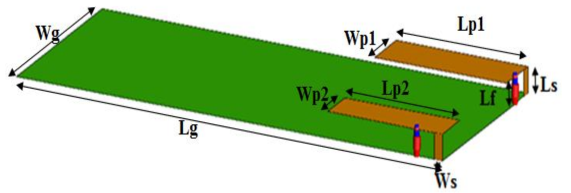

Fig.1 Dual PIFA

In Table 1, Lg, Wg represents the length and width of the ground plane respectively. Lp1, Wp1 represents the length and width of the DCS PIFA patch respectively. Lp2, Wp2 represents the length and width of the UMTS PIFA patch respectively. Ls, Ws represent the length and width of the stub respectively. Lf is the length of the feed.

Table 1. MIMO PIFA Parameters

Parameter	**Value (mm)**
Lg	100
Wg	40
Lp1	31
Wp1	10
Lp2	27
Wp2	8
Ls	4.5
Ws	2
Lf	4.5

Table 2. U slot Dimensions

U Slot (mm)	
L1	15
L2	15
W1	6
W2	8
W	2

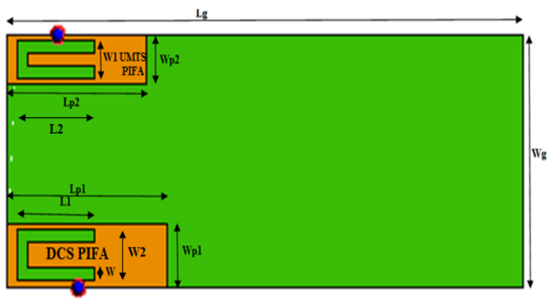

Fig.2 Dual U slotted PIFA

Fig.2 shows the design of proposed MIMO PIFA with U slots. U slot [9] is introduced in both the PIFA to increase the bandwidth. It results in quad band in which lower frequency bands are used in 3G applications and higher frequency bands are used in 4G applications. U slots are designed based on the design values given in Table 2, where L1 and L2 represent the length of the U slot in DCS PIFA and UMTS PIFA respectively. W1 and W2 represent the width of the U slot in DCS PIFA and UMTS PIFA respectively. W represents the thickness of U slot.

III. Mutual Decoupling Techniques

3.1. Dielectric Wall

Dielectric wall is a partially conductive wall which blocks the electric field crossing the wall from one antenna to the other. As the electric field does not cross the wall, mutual coupling is reduced. Fig.3 shows the dielectric walls with relative permittivity ε_r of 10 and dielectric loss factor tanδ of 0.0088 are inserted between the proposed antennas for mutual coupling reduction. Dielectric walls have length 50mm, breadth 2mm and height 10mm.

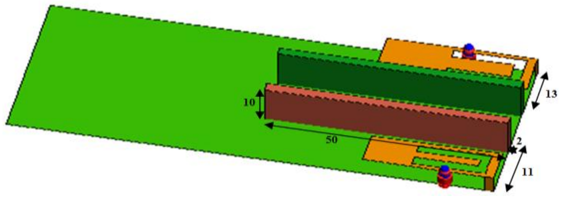

Fig.3 Dielectric Wall in dual slotted PIFA

3.2. Electromagnetic Band Gap

EBG structure is the periodic arrangements of planar conducting patches which are embedded in a slab of dielectric. Mushroom like EBG structure is used in proposed antennas, which introduces an inductor L, which results from the current flowing through the pins, and a capacitor C, which is due to the gap effect between adjacent patches. Surface wave which reduces antenna efficiency, gain and bandwidth are suppressed by this EBG structure which results in reduction of mutual coupling.

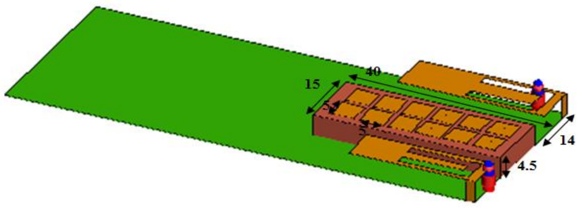

Fig.4 EBG in dual slotted PIFA

Fig.4 show EBG material which consists of a roger board with dielectric property having relative permittivity ε_r of 10.2 and dielectric loss factor tanδ of 0.0088. Dielectric slab have a length of 40mm, breadth of 15mm and height of 4.4mm. Array of square patches spaced at 1mm are placed above the dielectric slab with length 5mm and breadth 5mm. Metal pins are present inside the dielectric slab which is connected to the middle of square patches and the ground plane.

3.3. Defected Ground Plane

In Defected Ground Plane (DGP) technique, ground plane itself provides filter effect such as stop-band characteristics. Slits hinder the passage of current from one side to the other side of the ground plane thereby reducing mutual coupling between the two antennas.

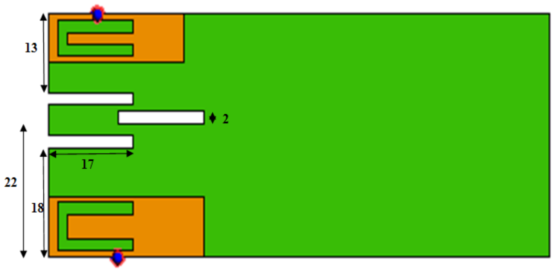

Fig.1 DGP in MIMO slotted PIFA

DGP has simple structure, small size and so it can be used for different application. Fig.5 shows the meander slots having length 17mm, breadth 2mm and spacing 2mm. In the proposed antenna, mutual coupling is reduced by forcing current to follow a meander path.

3.4. Parallel Slot

In the proposed antenna, U slot is cut in the ground plane to enhance the bandwidth [10]. Slots are placed under the antenna to tune the ground plane [11] at low frequencies and to reuse the slot to be a parasitic element at higher frequencies. Fig.6 shows the parallel U slot in which the position and dimension remain the same. So there is a good coupling between both slots which results in reduction of mutual coupling.

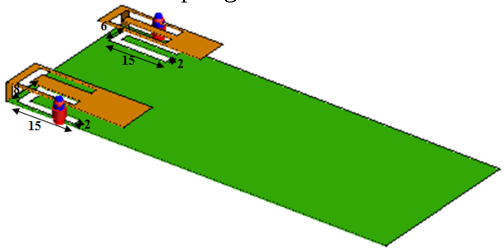

Fig.6 Parallel slot in MIMO slotted PIFA

IV. Results And Discussions

Simulated results of the proposed antenna is shown in Fig.7 and the result shows that at 1.77GHz, bandwidth is increased from 11.6% to 23.26% and at 2.02 GHz, bandwidth is increased from 16.9% to 20.79% when slot is introduced. Fig.7 shows the reflection coefficient of MIMO slotted PIFA. Table 3 shows efficiency, gain and return loss of resonating frequencies.

Table 3 Efficiency, Gain and Return loss values

Resonating Frequency	**1.77 GHz**	**2.02 GHz**	**7.86 GHz**	**8.89 GHz**
Return Loss (dB)	-9.68	-25	-7.5	-6.68
Efficiency(%)	48.93	45.53	77.25	71.39
Gain (dB)	0.5	0.9	3	1.75

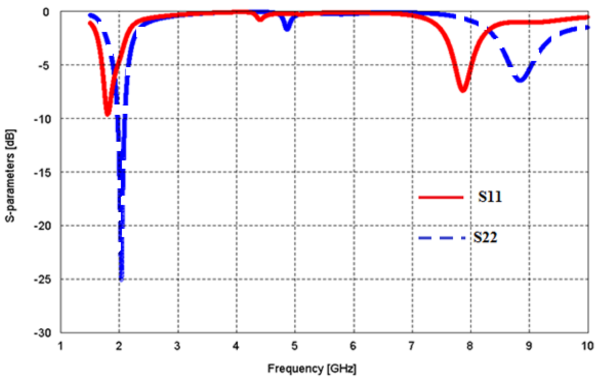

Fig.7 Reflection Coefficient of MIMO slotted PIFA

Fig.8 shows the gain plot of MIMO slotted PIFA in dB at 1.77GHz. From the simulated result, gain is inferred for resonating frequencies 1.77GHz, 2.02GHz, 7.86GHz and 8.89GHz as 0.5dB, 0.9dB, 3dB and 1.75dB respectively. From the simulated result, efficiency at resonating frequencies 1.77GHz, 2.02GHz, 7.86GHz and 8.89GHz is 48.93%, 45.53%, 77.25% and 71.39% respectively.

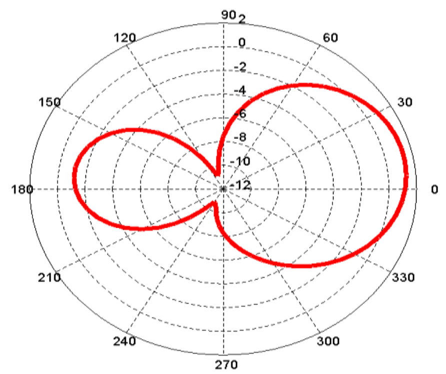

Fig.8 Gain of MIMO slotted PIFA

Fig.9 shows the radiation pattern in which maximum power radiation is found above the PIFA. It is clear that backward radiation is reduced for PIFA and there is no side lobe. Current distribution is obtained when the PIFA is excited. Fig.10 shows the current distribution of MIMO slotted PIFA in which maximum current appears near the 2 ports. From the figure, it is clear that mutual coupling is large between both the PIFA and it has to be reduced.

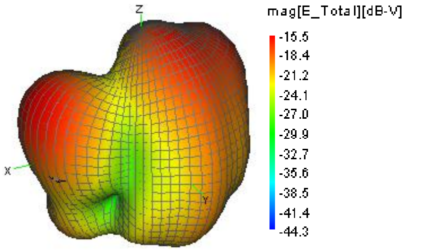

Fig.9 Radiation Pattern of MIMO slotted PIFA

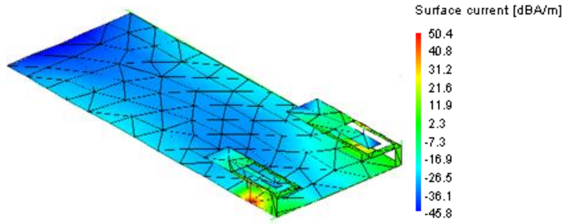

Fig.10 Current distribution of MIMO slotted PIFA

Mutual coupling [12] is reduced by placing a dielectric wall between slotted PIFA and the isolation, S21 graph is shown in Fig.11. S21 varies depending on the permittivity of the dielectric wall. The S21 values are the highest peak at the resonant band of frequency. From the simulated result, S21 values obtained resonating frequencies 1.77GHz, 2.02GHz, 7.86GHz and 8.89GHz are -9.5 dB, -10 dB, -24.6 dB and -22.5 dB respectively.

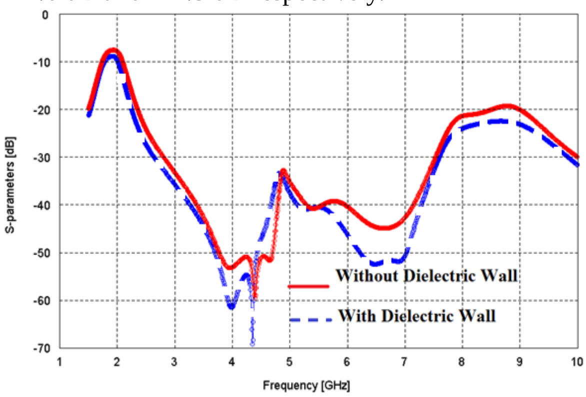

Fig.11 S21 values with and without dielectric wall

Mutual coupling is reduced by placing EBG between slotted PIFA and the isolation, S21 graph is shown in Fig.12. From the simulated result, S21 values obtained at resonating frequencies 1.77GHz, 2.02GHz, 7.86GHz and 8.89GHz are -16 dB, -17 dB, -32 dB and -62 dB respectively.

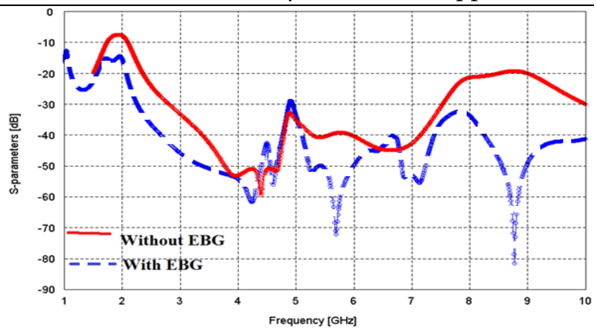

Fig.12 S21 values with and without EBG

Mutual coupling is reduced by placing DGP between slotted PIFA and the isolation, S21 graph is shown in Fig.13. From the simulated result, S21 values obtained at resonating frequencies 1.77GHz, 2.02GHz, 7.86GHz and 8.89GHz are -7 dB, -6.8 dB, -31 dB and -28 dB respectively.

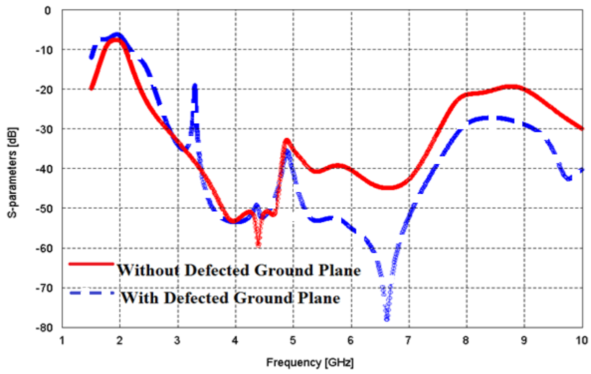

Fig.13 S21 value with and without DGP

Mutual coupling is reduced by introducing parallel slot below PIFA and the isolation, S21 graph is shown in Fig.14. From the simulated result, S21 values obtained at resonating frequencies 1.77GHz, 2.02GHz, 7.86GHz and 8.89GHz are -7 dB, -13 dB, -45 dB and -30 dB respectively. Fig.15 shows the comparison of S21 graph of different mutual decoupling techniques. At 1.77 and 2.02GHz, EBG reduces coupling to -16dB and -17 dB respectively.

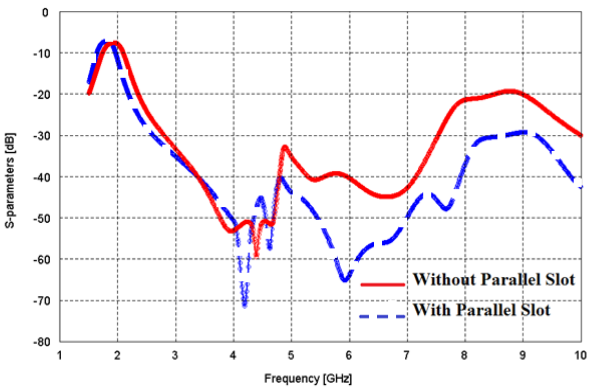

Fig.14 S21 values with and without parallel slot

Table 4 Comparison of S21 values of mutual decoupling techniques

Mutual Decoupling Techniques	**S21 values at different resonating frequencies**			
Frequency	f=1.77 GHz	f=2.02 GHz	f=7.86 GHz	f=8.89 GHz
Without any material	-7.8 dB	-9 dB	-23 dB	-19 dB
Defected Ground Plane	-7 dB	-6.8 dB	-31 dB	-28 dB
Dielectric wall	-9.5dB	-10 dB	-24.6 dB	-22.5 dB
Electromagnetic Band Gap	-16 dB	-17 dB	-32 dB	-62 dB
Parallel Slot in PIFA & Ground Plane	-7 dB	-13 dB	-45 dB	-30 dB

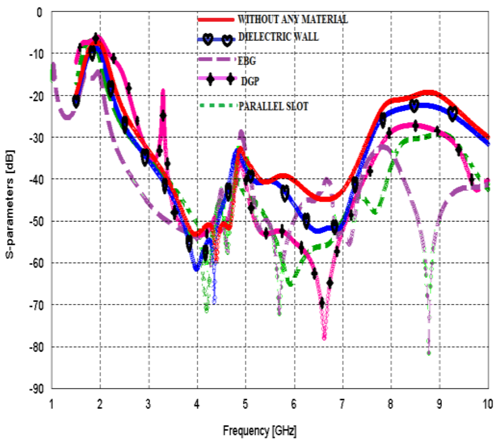

Fig.15 Comparison of S21 values with and without mutual decoupling technique

At 7.86GHz, parallel slot reduces the coupling to -45dB and at 8.89GHz, EBG reduces coupling to -62dB when compared to other techniques. Table 4 shows the S21 values in dB of mutual decoupling techniques. All these values are compared with without any material at each resonant frequency.

V. Conclusion

The mobile industry has grown rapidly, and market demands for small and multifunctional devices. A dual band PIFA antenna is used to operate in low frequency bands to be used for different application. Introducing U slots in MIMO PIFA, not only increases the bandwidth, but also can be used for high frequency applications. Therefore, a multiband antenna with low mutual coupling can be obtained by using different decoupling techniques. It is found that EBG technique is preferable to reduce mutual coupling in both low and high frequency bands.

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