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Design and Implementation of MIMO Antenna Using Swastika Slot for Wireless Applications

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Abstract: MIMO (Multiple-Input Multiple-Output) antenna has gained a lot of attention for research today due to various advantages such as increase in capacity, low signal loss, and less multipath fading. The main objective of this work is to design and implement a compact antenna using MIMO systems to reduce the mutual coupling between the antenna elements and to provide high isolation for Wi-Fi (2.4 GHz to 5 GHz) & Bluetooth (2.4 GHz to 2.57 GHz) and WLAN 802.11(2.4-2.485 GHz) applications. Different shapes of MIMO antennas are implemented but they have some interference with high mutual coupling and low gain. In order to avoid this, "Dumbell" shaped patch is introduced with a 'Swastika' slot between the patches. The antenna is designed over a frequency of 2.51GHz using FR-4 epoxy as a substrate material. The proposed antenna shows better performance than many existing systems with an overall size of 93.02 × 54.72 mm^2 having isolation better than -16 dB, obtained gain of 8.29 dB and envelope correlation coefficient (ECC) is investigated about 0.0092. The proposed MIMO antenna is simulated using HFSS 18.0 (High Frequency Structural Simulator) software and fabricated to validate the results. It is clearly observed that simulated results are close to practical measured results.

Keywords: MIMO System, Compact Antenna, Mutual Coupling reduction, Dumbell shape patch, Swastika slot.

I. INTRODUCTION

Multiple Input and Multiple Output (MIMO) systems are capable of transmitting and receiving signals of same power level in parallel channels and are used to growth demands of the high data rate in the modern communication systems. This is because MIMO system can increase channel capacity at both transmitting and receiving sides without bandwidth addition or transmission power increasing. The potential for MIMO systems to improve reliability and enhance channel capacity in wireless mobile communications has generated great interest [1]. A major consideration in Compact MIMO antenna design is to reduce correlation between the multiple elements, in particular mutual coupling and electromagnetic interactions that exists in between multiple elements [2].

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The effect of mutual coupling on capacity of MIMO wireless channels are studied in [3] and the separation between multiple antenna elements should be 0.5λ. A 2X2 MIMO meander Planar Inverted-F Antenna (PIFA) at 2.6 GHz is reported in [4] to obtain a mutual coupling of -15 dB, with a separation between two elements of 0.23λ. Authors in [5] introduced a U-shaped slot patch antenna operating at 2.6 GHz for mobile handset applications,

With isolation of -20 dB achieved by pattern diversity and capacity loss of 0.2 bits / s/ Hz. On Keen observation of the MIMO antenna structures reported in the above literature, the distance _between the individual radiators and the use of a separate isolation technique are the key factors that decide the size of the overall antenna system [7]. Since the advent of the microstrip patch, different patch shapes like rectangular, circular and triangular are the most extensive antenna @geometries and these geometries are modified to improve their performance [8]-[10]. The antenna characteristics of various shapes like C, E, H, L, T, U and inverted-F have been reported in [11]-[16].

The proposed efficient antenna structure comprises of a ground plane, radiating patch and a slot between the patches. A slot is etched on the ground plane in order to get compact size and desired bandwidth. In addition to this, research task is to design a Compact MIMO antenna to achieve better efficiency with high gain, low VSWR and precision S-Parameters for the required frequency. To study the performance of the MIMO antenna a familiar design called "Swastika" shaped slot is introduced in between the radiating elements. The main aim of this work is to design and develop MIMO antenna for wireless applications which provides high gain and better efficiency with low mutual coupling between the antennas. This paper presents a Compact MIMO "Dumbell" shaped patch antenna with a 'Swastika' slot in between the patches to reduce the mutual coupling and to provide high isolation between the radiating elements. Parametric study is performed on various parameters such as length of the patch, width of the patch, length of slot and width of the slot. The best results of parametric analysis are implemented on the final design for Bluetooth, Wi-Fi, WLAN applications. The parametric analysis is performed using high frequency structure simulator software (HFSS 18.0), it was designed over a frequency of 2.51GHz using FR-4 epoxy as a substrate material for Wi-Fi (2.4 GHz to 5 GHz), Bluetooth (2.4 GHz to 2.57 GHz) & WLAN 802.11 (2.4-2.485 GHz) applications. While designing an antenna for Bluetooth devices, a wideband antenna in wireless communication frequency range must be designed. The dimensions of the proposed antenna are selected as per the physical dimensions of a Bluetooth device, Wi-Fi and WLAN 802.11 frequency bands.

In order to meet the requirements, size reduction and wide bandwidth are becoming major design constraints for designing practical devices.
Section II describes the design of proposed antenna structure. The parametric study and final implementation of the design parameters and their results are discussed in section III. Finally section IV gives the conclusion of this present work.

II. ANTENNA DESIGN AND CONFIGURATION

Antenna design consists of a patch printed on the top layer of a commercially FR4 epoxy substrate with dielectric constant of 4.4, loss tangent 0.02 and thickness of 1.6 mm. The geometry of the proposed antenna structure with a complete dimension of 93.02 × 54.72 $mm^2$is depicted in the figure 1.

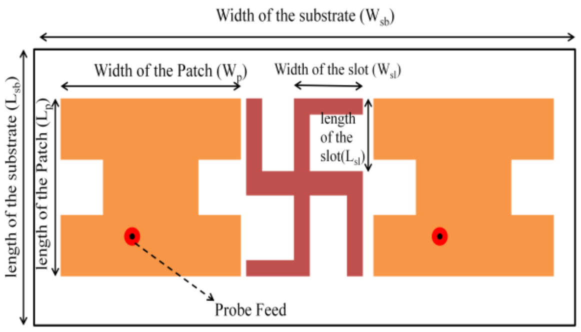

Figure 1: Top view of the Geometrical Structure of Proposed MIMO Antenna

The design comprises of two identical "Dumbell" shaped radiators fed by coaxial probe feeding technique [6] with optimized feed position of length and width of slot dimensions are L_{sl}=29.32 mm and W_{sl}=18.18 mm. The location of feed point is selected so as to get best impedance matching. The main advantage by using coaxial probe feed is that the inner conductor can be positioned at any preferred location so as to have a better impedance matching. All the major parameters are studied to find their influence on the impedance matching of the proposed antenna structure. With this arrangement, the antenna covers frequency range with very less isolation. In order to provide high isolation between the elements and to reduce the mutual coupling between the radiating elements a Swastika Slot is introduced.

A. Antenna Design Equations

Design parameters [6] are calculated by using the following equations.

- Patch width (w_p):

$$w_p = \frac{c}{2 f_0 \sqrt{\frac{(\varepsilon_r + 1)}{2}}} \quad (1)$$

The effective dielectric constant (ε_{reff}) of an antennna

$$\varepsilon_{reff} = \left(\frac{\varepsilon_r + 1}{2}\right) + \left(\frac{\varepsilon_r - 1}{2}\right)\left(1 + 12\frac{h}{w}\right)^{-\frac{1}{2}}$$

(2)

Where ε_{reff}= effective dielectric constant
ε_r= dielectric constant of the substrate
h = height of the dielectric substrate
W = the patch width

- Extension of the length (△L)

$$\Delta L = h * 0.412 \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{w}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{w}{h} + 0.8\right)}$$

(3)

The fringing effect is used to enhance the effective electrical length of the patch longer than its physical length. Thus, the resonance condition depends on L_{eff}.

- Therefore the effective length of the patch:

$$L_{eff} = L_p + 2\Delta L \quad (4)$$

- The actual length of the patch (L_p):

$$L_p = \frac{c}{2 f_0 \sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (5)$$

- Substrate length (L_{sb}):

$$L_{sb} = 12h + L_p \quad (6)$$

- Width of the substrate

$$W_{sb} = 12h + W \quad (7)$$

- Length of Slot (L_{sl}):

$$L_{sl} = \frac{L_p}{\varepsilon_{reff}} \quad (8)$$

- Width of Slot (W_{sl})

$$W_{sl} = \frac{w}{2} \quad (9)$$

The proposed antenna design parameter values are calculated from the equations 1 to 7 and the dimensions of design structure are optimised using parametric analysis that are depicted in Table 1.

Table 1: Geometrical parameters of the proposed MIMO Antenna

S. NO	Parameter	Value (mm)
1	Length of the Patch (L_p)	29.60
2	Width of the Patch (W_p)	36.36
3	Length of the ground (L_g)	48.80
4	Width of the ground (W_g)	55.56
5	Length of the Substrate (L_{sb})	48.80
6	Width of the Substrate (W_{sb})	55.56
7	Length of the Slot (L_{sl})	14.66
8	Width of the Slot (W_{sl})	9.09
9	Feed Point X	14.66
10	Feed Point Y	18.18

Envelope Correlation Coefficient (ECC) is very important criterion determines the MIMO system performance. Typically values of ECC lower than 0.1 is acceptable and sufficient to retain capacity of channel. The Scattering parameter approach is considered to find the value of ECC. The effect of mutual coupling between any of the two ports of MIMO can be seen in terms of two scattering parameters, i.e. S12 and S21. However, all the scattering parameters are involved of ECC while designing the MIMO ECC to show their effects on the correlation coefficient. Lower the value of ECC means less correlation between antenna elements, while a higher value of it shows the negative impact.

For the good diversity behaviour, the value of ECC must be less than 0.5 for mobile applications. The value of ECC can be obtained using the formula given in equation 10. Here, 'N' represents number of radiating elements.

$$|\rho(i,j,N)| = \frac{\left|\sum_{n=1}^{N} s_{i,n}^{*} s_{n,j}\right|}{\sqrt{\left|\pi_{k(=i,j)}\left[1 - \sum_{n=1}^{N} s_{i,n}^{*} s_{n,k}\right]\right|}}$$

(10)

The MIMO behaviour and the mutual coupling between the adjacent elements of the proposed antenna is studied and evaluated in terms of ECC. The ECC curve can be evaluated using S-parameters.

III. RESULTS AND DISCUSSIONS

The proposed antenna design structure is simulated by placing FR4 epoxy as substrate material over a ground plane. Two patches of dumbell shaped are presented on the substrate with a swastika slot between the radiation patches which are depicted in the figure 2. The simulation process is done using High Frequency Structure Simulator (Ansys HFSS Version-18) software.

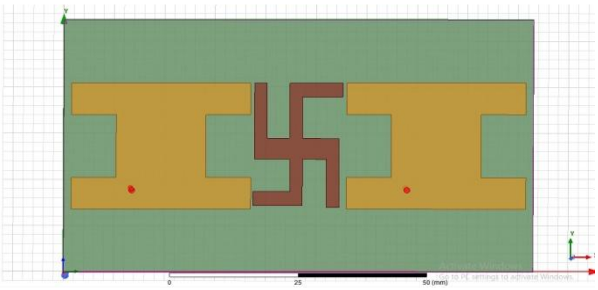

Figure 2: Simulated design of Compact MIMO Antenna Structure

The simulated antenna is operating at a frequency of 2.51 GHz with a return loss of -13.39 dB and measured antenna is operating at a frequency of 2.44 GHz with return loss of -20.40 dB is shown in Figure 3. The fabricated antenna has better return loss than a simulated antenna.

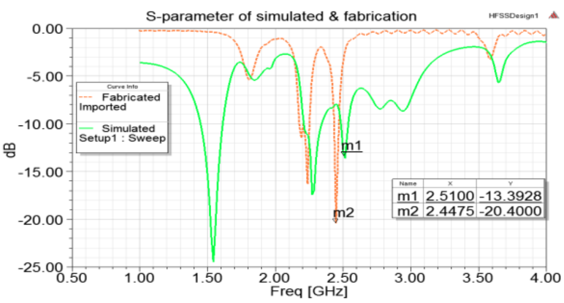

Figure 3: Comparison of Reflection coefficient

The VSWR of simulated Optimized Compact MIMO array antenna is 1.54 at a resonating frequency of 2.51GHz and where as fabricated antenna has a VSWR of 1.21 at a resonating frequency of 2.44GHz are presented in figure 4, both the antennas radiating about 96% of input power and less than 4% of input power is reflected back to the antenna.

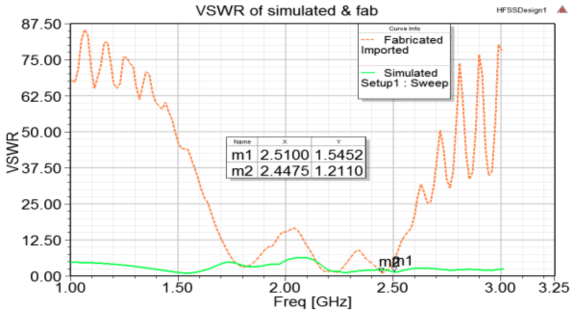

Figure 4: Comparison of VSWR

The mutual coupling of simulated Optimized Compact MIMO array antenna is -12.68dB at a resonating frequency of 2.51GHz and where asfabricated antenna has mutual coupling of -16.26dB at a resonating frequency of 2.44GHz are shown in figure 5. In this, both the antennas have mutual coupling is less than -10dB which means energy radiated from one antenna is not absorbed by the other antenna. But fabricated antenna has better mutual coupling than the simulated antenna which means efficiency is improved.

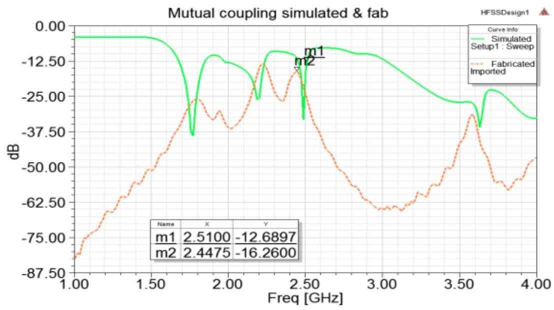

Figure 5: Isolation Variation of simulated and measured MIMO antenna

Table 2: Results Comparison of Simulated and Fabricated antenna

S. No	Type of antenna	Resonate Frequency	Return loss (dB)	VSWR	Mutual Coupling
1	Simulated antenna	2.51 GHz	-13.39 dB	1.54	-12.68 dB
2.	Fabricated antenna	2.44 GHz	-20.40 dB	1.21	-16.26 dB

The compact MIMO array antenna is simulated and fabricated. From the table 2 it is clearly observed that the fabricated antenna is better than that of the simulated antenna but has a frequency shift of 0.07 GHz due to losses occur during fabrication. Even though the frequency was shifted the antenna is still working under application frequency range. The fabricated antenna has a better return loss of -20.40 dB, VSWR of 1.21 and Mutual Coupling of -16.26 dB than a simulated antenna.

The isolation of measured antenna -16.26 dB is better than simulated antenna as shown in Figure 5. The Envelope Correlation Coefficient (ECC) is described by using the equation (8). The acceptable level of ECC is below 0.3 but the desired value 0.0092 is obtained at a frequency of 2.51GHz which is highly desirable for a MIMO antenna and it was depicted in the figure 6. Hence, radiating elements are isolated from each other with a high gain of 8.29 dB and are plotted in the figure 7.

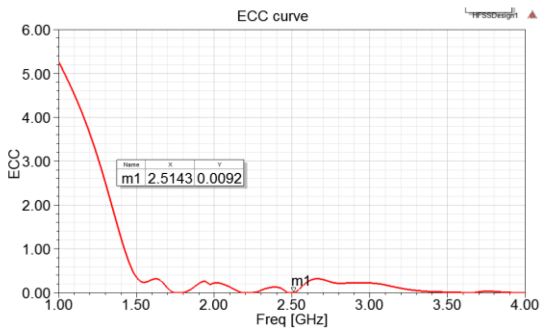

Figure 6: ECC curve of Optimized Compact MIMO array antenna obtained 0.0092 at 2.51 GHz

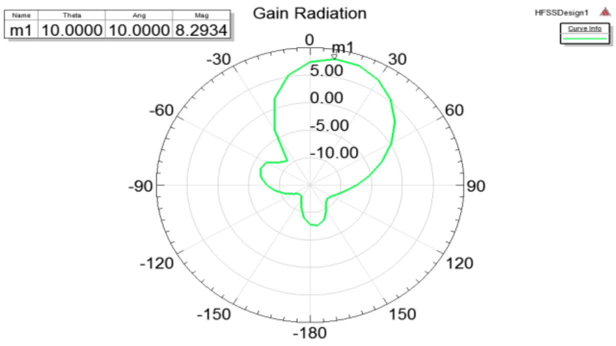

Figure 7: Gain of Optimized Compact MIMO antenna obtained 8.29 dB at 2.51 GHz

The front view and back view of the proposed fabricated antenna design are reported in the figure8 and figure 9.

Figure 8: Front View of fabricated MIMO antenna

Figure 9: Back view of fabricated MIMO antenna

IV. CONCLUSION

The proposed 'Dumbell' shaped compact MIMO array antenna is designed over a range of frequencies for Wi-Fi (2.4 GHz - 5 GHz) and Bluetooth (2.4 GHz - 2.57 GHz) with 'FR-4 epoxy' as a substrate material. In the design of MIMO antennas, high mutual coupling with low gain is observed. To circumvent this problem a "Swastika" slot is introduced between the patches. In order to reduce the surface wave radiation coaxial feeding technique is used. The comparative study is made on few antenna design parameters such as reflection coefficient, VSWR, Gain and Directivity. The compact MIMO antenna design parameters are obtained such that return loss of -13.39 dB, isolation is of -12.68 dB, and gain value 8.29 dB respectively. The measured antenna is resonating at a frequency of 2.44 GHz with return loss and isolation values of -20.40 dB and -16.26 dB respectively.

The designed antenna is simulated at a frequency band (2.43 GHz – 2.47 GHz) with a center frequency of 2.44 GHz and it meets the requirements of practical applications within the range for Wi-Fi and Bluetooth.

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