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

T Vidhyavathi, G S N Raju, M Satyanarayana, N Balasubrahmayam,

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 x 54.72 mm² 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]. 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.

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Dr. Thota Vidhyavathi, Assistant Professor in the department of ECE, Gayatri Vidya Parishad College of Engineering (A), Visakhapatnam, Andhra Pradesh, India.

Dr. Gottumukkala Suryanarayana Raju, Professor in department of Electronics and Communication Engineering, AU College of Engineering (A), Andhra University.

Dr. Moturi Satyanarayana, Professor, Dept. of ECE, MVGRCE (A), Vijayanagaram.

Dr. N Bala Subrahmayam, Professor of Electronics and Communication Engineering, Gayatri Vidya Parishad College of Engineering (Autonomous) Visakhapatnam, India.

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 x 54.72 mm² is depicted in the figure 1.

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:
  \[ L_{eff} = L_p + 2\Delta L \]  

- The actual length of the patch ($L_p$):
  \[ L_p = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} - 2\Delta L \]  

- Substrate length ($L_{sb}$):
  \[ L_{sb} = 12h + L_p \]  

- Width of the substrate:
  \[ W_{sb} = 12h + W \]  

- Length of Slot ($L_{sl}$):
  \[ L_{sl} = \frac{L_p}{\varepsilon_{reff}} \]  

- Width of Slot ($W_{sl}$):
  \[ W_{sl} = \frac{W}{2} \]

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.

![Figure 1: Top view of the Geometrical Structure of Proposed MIMO Antenna](Image)

### Table 1: Geometrical parameters of the proposed MIMO Antenna

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

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.

\[ \Delta L = h \times 0.412 \left( \frac{\varepsilon_{reff} + 0.3}{h + 0.264} \right) + \left( \frac{\varepsilon_{reff} - 0.258}{h + 0.8} \right) \]

- $\varepsilon_{reff}$ represents effective dielectric constant
- $h$ = height of the dielectric substrate
- $W$ = the patch width

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

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 2: Simulated design of Compact MIMO Antenna Structure](image)

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 3: Comparison of Reflection coefficient](image)

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 4: Comparison of VSWR](image)

The mutual coupling of simulated Optimized Compact MIMO array antenna is -12.68dB at a resonating frequency of 2.51GHz and where as fabricated 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](image)

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.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Type of antenna</th>
<th>Resonate Frequency</th>
<th>Return loss (dB)</th>
<th>VSWR</th>
<th>Mutual Coupling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Simulated antenna</td>
<td>2.51 GHz</td>
<td>-13.39 dB</td>
<td>1.54</td>
<td>-12.68 dB</td>
</tr>
<tr>
<td>2</td>
<td>Fabricated antenna</td>
<td>2.44 GHz</td>
<td>-20.40 dB</td>
<td>1.21</td>
<td>-16.26 dB</td>
</tr>
</tbody>
</table>

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.
IV. CONCLUSION

The proposed ‘Dumbbell’ 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 – 2.37 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.

REFERENCES

AUTHORS PROFILE

Dr. Thota Vidhyavathi received her B.Tech. degree from JNTU Hyderabad in the department of Electronics and Communication Engineering during the year 2006 and the Master of Technology in Radar and Microwave Engineering from Andhra University College of Engineering (A) in the year 2008. Her Ph.D degree awarded in the year 2015 from the department of Electronics and Communication Engineering, Andhra University College of Engineering (A). Currently, she is working as an Assistant Professor in the department of ECE, Gayatri Vidya Parishad College of Engineering (A), Visakhapatnam, Andhra Pradesh, India. Her Research interests include Array Antennas, Electromagnetic Theory and Wave Propagation, Radar Engineering, Microwave Engineering, EMI/EMC, Computational Electromagnetics and Soft Computing. She is a member of IEEE and Member of Antennas and Propagation Society in IEEE; she is life member of Society of EMC Engineers, SEMCE (India) also a member of International Association of Engineers (IAENG). Presently she is working in the area of antennas design by using HFSS software simulation. She has guided several B.Tech. and M.Tech. projects in the area of Antennas and Wireless Communications. She has published in various reputed national and international journals.

Dr. Gottumukkala Suryanarayana Raju received his B.E, M.E with distinction also first rank from Andhra University and Ph.D, from IIT, Kharagpur. At present, he is the Honorary Distinguished Professor in department of Electronics and Communication Engineering, AU College of Engineering (A), Andhra University. He was the former Vice – Chancellor of Andhra University. He is in teaching and research for the last 35 years in Andhra University. He guided 49 Ph.D.s in the fields of Array Antennas, Electromagnetics and Wavepropagation, EMI/EMC, Microwave and Radar Communications, Electronic circuits. Published about 394 technical papers in National/ International Journals/ Conference Journals and transactions. He is the recipient of The State Best Teacher Award’ from the Government of Andhra Pradesh in 1999, ‘The Best Researcher Award’ in 1994, ‘Prof. Aiya Memorial National IETE Award’ for his best Research guidance in 2008 and Dr. Sarvepalli Radhakrishnan Award for the Best Academician of the year 2007, He was a visiting Professor in the University of Paderborn and also in the University Karlsruhe, Germany in 1994. He held the positions of Principal, Andhra University College of Engineering (A), Visakhapatnam, Chief Editor of National Journal of Electromagnetic Compatibility. Prof. Raju has published 11 textbooks on Antennas and Wave Propagation, Electromagnetic Field Theory and Transmission Lines, Electronics Devices and Circuits, Microwave Engineering, Radar Engineering and Navigational Aids. Prof. Raju has been the best faculty performer in Andhra University with the performance index of 99.37%.

Dr. Moturi Satyanarayana completed his M. Tech degree from Andhra University in 2004 and Ph. D. degree from Andhra University in 2012. He is now working as Professor, Dept. of ECE, MVGRCE (A), Vijayanagaram. He has published several papers in various journals and conference papers in the field of Microstrip Antennas, Array Antennas and VLSI.

Dr. N Bala Subrahmanyam received B.E and M. E from Birla Institute Technology Ranchi and Ph.D from Andhra University, India. He has 27 years of teaching experience and is presently Chairman of Board of Studies and Professor of Electronics and Communication Engineering, Gayatri Vidya Parishad College of Engineering (Autonomous) Visakhapatnam, India. He has published more than 20 technical papers in National/International Journals/Conference proceedings. His fields of interest are Antennas, Communications, Signal Processing, Microwave Communications and EMI/EMC.