Design and Analysis of Dual Port Super WideBand Antenna Set for MIMO Applications

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Abstract. A planar monopole antenna with a super wideband frequency range covering a wide range of applications and compatible with MIMO applications is duly proposed. Compactness, i.e., reduction of size, is achieved following compatibility with MIMO application and also with SWB (Super Wide Band) applications. The bandwidth achieved is in the band range from 2 GHz to 20 GHz with a ratio of 1:10. Compactness in terms of size of the antenna is achieved, dimensions being 40mm*30mm. FR4 substrate is used in the design of the antenna, having a relative permittivity of 4.4. A hexagonal structure with an ellipse added on top is made as to the radiating element with a per feed having a width of 3.1mm feeding an input of 50ohm into the antenna. Parasitic elements are introduced on the substrate for the design of the antenna. DGS techniques have been used in the semicircular structure of the partial ground plane of the antenna. A dual-port antenna supporting MIMO applications is therefore achieved by replicating the antenna described above on a horizontal plane with a 90-degree shift and hence accommodating both the vertical and horizontal polarization at the transmitting and receiving side as well.

Keywords: multiple inputs, multiple outputs, super wideband, defected ground structures, high bandwidth dimension ratio

I. Introduction

With the growing and advancing of technology today in different fields, including wireless communication, devices supporting multiple application services are in dire need. Antennas are playing a major role in changing the whole communication process's performance is realized, and growing research in the given field is looked forward to [1]. Antennas with a wider range of frequency handling used in multiple applications, simultaneously such as audio, video both at the same time is becoming a necessity. Moreover, accommodating them in portable devices is required making a call for more compact designs. The efficiency and performance of antennas that can cover multiple frequency bands is to be increased. Analysis carried out in frequency domain performance [2] resulted in low-frequency achievement of 640 MHz to 2.04 GHz and impedance bandwidth of 25:1, whereas the stated paper has a frequency range of 2.0079 GHz to 20 GHz [3]. The two major areas as a determining factor for the increase in performance and efficiency can be traced to the compactness in the design and a broad bandwidth range. And hence the popularity of super wideband antennas (SWB) strengthened because of its having bandwidth ratio of 1:10.
replacing the other wideband frequencies [4,5].

![Proposed Antenna Design](image)

**Figure 1: Proposed Antenna Design**

The proposed paper suggests a design with higher compactness in the SWB frequency band supporting MIMO applications, as shown in figure 1. Literature survey carried out [3-4] had a compact size of 50 mm * 45 mm, whereas the resulted paper has better compactness of 40 mm * 30 mm. The design has a high bandwidth ratio (BDR) with more spectral efficiency. In accordance with reference [2], the omnidirectional radiation pattern is achieved at low frequency, which leads to cross-polarization with a gradual increase in frequency leads to change in radiation pattern; hence it produces slight differences in results [6]. Dumbell shaped radiation pattern is achieved with more than 90% of the radiation pattern is omnidirectional, which shows fewer deviations from the simulated results. The Y-shaped parasitic element is present in reference [7], which produces an isolation constant less than -22 dB. We have achieved an isolation constant of less than -15 dB by introducing a parasitic element with orthogonal alignment. It aims for easy installation with other communication devices and for multiple applications like Wi-Fi, 5G technology, Wi-Max, and other MIMO devices [8]. Reflection coefficient below -10dB is expected, and envelop coefficient below 0.5, 0 be the value for ideal situations. The radiation design is made as such to ensure high diversity gain and BDR (1:10) allowing the devices to get connected with high data speed. The calculated diversity gain is close to 10dB, 10dB being the ideal case [9]. A dual-port antenna is further suggested replicating the above-mentioned design in the horizontal plane that is radiating more than 90 percent in the bandwidth range of 2.0079 GHz to 20 GHz [10].

**II. Antenna Design and Configuration**

The proposed antenna consists of a hexagonal radiating element with an ellipse placed on top to increase the entire structure area. The feed of the antenna is tapered, and the ground plane is semicircular in shape with defects introduced [11]. This technique of introducing defects in the ground plane is known as DGS or Defected Ground Structures. The dimensions of the proposed unit cell have been shown below in figure 2. The radiating element, as well as the ground plane has been explained.
The size of the proposed unit cell is 40 x 30 mm$^2$. The substrate used for manufacturing the given antenna is FR4 or Flame Redundant grade 4. The thickness of the substrate is 1.6 mm. The relative permittivity of the substrate is 4.4 and the loss tangent is 0.025. Figure 2(a) gives us the dimensions and the detailed configuration of the radiating plane along with the feedline. The width of the feed line is 3.1 mm. This is done to achieve 50 Ohm impedance matching for a substrate thickness of 1.6 mm. The feed has been tapered, and small triangular cuts have been introduced to increase the tapering furthermore. Two parasitic elements have been introduced in the radiating plane to bring the lower cut-off frequency of operation further below 2.0079 GHz [12,13].

The ground plane is semicircular in shape with three significant defects introduced. A deep triangular cut has been introduced in the middle of the semicircular structure. Another triangular cut has been made on both sides of the deep triangular cut [14]. The dimensions of the triangular cuts have been mentioned in Table 1. One-fourth of a circle of radius 4.00 mm has been cut from both ends of the semicircle, making the ground plane more tapered. The steps involved in the design of the proposed unit cell are shown in figure 3.
A hexagonal shape is designed in the first stage of the antenna with a rectangular feed with a triangle on top, as shown in figure 3. The ground plane is semicircular. The ground plane is modified by adding defects (a triangular slot in the middle, triangular slots on the side, and one-four a circle on both sides). In the final stage (3e), parasitic elements have been introduced into the radiating plane to bring down the lower cut-off frequency to 2.0070 GHz. Hence the antenna designed can be used for super wideband applications with a band range of 2.0079 to 20GHz [15].

The depth of the triangular slot in the middle has been increased, and the unit cell has been replicated twice. The antennas had been placed orthogonally to avoid mutual coupling. This leads to the formation of a MIMO (Multiple Input Multiple Output) set with the dimension 85x40mm². This enables the electromagnetic waves to be detected by the antenna in any polarization. The proposed MIMO antenna design removes the drawback in the literature survey paper, reference.

III. Results and Discussion
The proposed antenna has been simulated at initial stages using CST (Computer Simulation Technology) Studio Suite software. After measurement of various antenna parameters, the antennas were fabricated on FR4 substrate, and a hardware model was delivered. The simulated results and the measured results were
compared for both the unit cell as well as the MIMO set. There were differences in the results because of various environmental factors, losses in connectors, and errors during the fabrication process. Thus, the real-time measurements differ from the ideal results of the simulation. Figure 2 and figure 4 show the fabricated antenna-unit cell and MIMO set. The various antenna parameters will be discussed.

A. Impedance Parameters
The S parameters are simulated for the unit cell first and represented in the figure 5 shown below. The S parameters are how the bandwidth is obtained by the antenna. Also, the figure shows that the gain of the antenna throughout the desired bandwidth range is below -10 dB. This value of gain signifies that the antenna is a good radiator with above 90% radiation. The bandwidth obtained is 2.00-20 GHz. The simulation has been done till 20 GHz as FR4 can support till frequency of 20GHz.

![S parameter graph of the unit cell](image)

The MIMO set has been designed, and the two antennas have been placed orthogonally so that waves in all polarization—both E and H planes can be detected by the antenna.

B. Mutual Coupling
Each unit cell has separate impedance parameters—S11 and S22 are shown in figure 6, and they show how the antennas individually perform and their individual gain due to their excitation. The two graphs have a -10 dB gain which shows that the antenna radiates 90% or more. Antenna 1 shows a bandwidth from 2.0079-20GHz while antenna 2 giving a bandwidth of 1.797-20GHz.

![S-Parameters graph](image)
C. Mutual Coupling

The current flowing through an antenna depends not only on its own excitation but also on the antenna elements in the vicinity of the antenna. Mutual coupling for a two-port MIMO antenna set is denoted by S12 and S21, which represent the mutual coupling on antenna one due to 2 and mutual coupling on antenna two due to 1, respectively. This graph provides an idea of the isolation between the two antennas. The isolation is maintained below -15 dB throughout the bandwidth of the graph in figure 7.

Figure 6: S parameter of MIMO set antenna 1

Figure 7: S21 and S12 parameter showing coupling of one antenna due to another


D. Envelope Correlation Coefficient

The envelope correlation coefficient (ECC) shows how two different antennas can work independently. Ideally, the value should be close to zero, denoting the two antennas can work independently. The calculation of ECC is from the s parameters, post-processing. The ECC for the MIMO set is obtained as a near perfect value of below 0.018. Figure 8 shows that the proposed MIMO set gives a very good ECC.

![Figure 8: Envelope correlation coefficient graph](image)

E. Diversity Gain

Different diversity schemes are used for increasing the SNR or the signal-to-noise ratio. This helps in the reduction of transmission power without any loss in the performance of the antenna. Different diversity schemes are applied for this and diversity gain is a measurement parameter. Figure 9 shows the diversity gain to be almost 10 dB, this being the ideal value. This shows that the proposed antenna has a good diversity gain.

![Figure 9: Diversity Gain graph](image)
F. VSWR
The ideal value for VSWR for the proposed antenna is less than 2. It is seen from the figure10 that the value is below 2. For a monopole antenna, half of the substrate should be the ground plane. The square ground plane was first changed to circular to reduce the lower cut-off frequency. Defective ground structures were added to the ground plane to achieve the desired VSWR and reduce the gain below -10db. Slots were introduced by inductive loading, which in turn provided better impedance matching.

G. Radiation Pattern
The far-field radiation patterns were obtained for the frequencies of 2 and 5GHz with \( \phi \) value varying from 0° to 90°. The radiation pattern in the H plane shows a circular pattern, while the radiation in the E plane is slightly dumbbell-shaped. It is also observed that the pattern of radiation is comparatively omnidirectional at low frequencies with respect to the two higher frequencies. The figures 10 and 11 shows the radiation pattern for the unit cell as well as the MIMO antenna.

![Figure 10: Radiation pattern at 2GHz for \( \phi \) equal to 0 and 90 degrees](image1)

![Figure 11: Radiation pattern at 5GHz for \( \phi \) equal to 0 and 90 degrees](image2)

H. BANDWIDTH DIMENSION RATIO
Bandwidth dimensional ratio (BDR) is a measure of how compact the antenna is along with giving a high bandwidth. The higher the BDR, the more compact the antenna is at the same time giving a high bandwidth. The higher the BDR, the better the antenna design is as the objective of our project is to obtain a super wideband with considerable compactness. The designed antenna's electrical dimension is \( 0.2\lambda \times 0.26\lambda \), and the fractional bandwidth is 163.63%. Thus, the BDR calculated is 3146.72. The table 2 gives a comparison of the existing super wideband antennas and the ones used for the literature survey.

\[
\text{BDR} = \frac{\text{FRACTIONALBANDWIDTH(ASAPERC)}}{\text{ENTAGE}} \\
\text{length} \times \text{width}
\]
Table 2: Dimensions and comparison of BDR

| REFERENCE | BW%    | DIMENSION      | BDR   |
|-----------|--------|----------------|-------|
| 1         | 0.64-2 GHz | 0.32λ X 0.21λ | 1533.18 |
| 2         | 2.42-32.93 GHz | 0.2λ X 0.21λ | 4107.14 |
| 3         | 1.42-90 GHz  | 0.16λ X 0.27λ | 4483.76 |
| 4         | 1.45-18.6 GHz | 0.09λ X 0.09λ | 21119.0 |
| 5         | 1.9-30 GHz   | 0.31λ X 0.28λ | 2024.60 |

III. Measured Results

The antenna has been fabricated, and the results are measured. A comparison between the reflection coefficient has been drawn in the figures below. The fabricated MIMO antenna is given in figure 12. Figure 13 shows the reflection Coefficient plot of unit. Figure 14 is real time measurement using a VNA cell (measured). Figure 15 shows the comparison between measured and simulated results of unit cell antenna, and figure 16 represents the mutual coupling of the MIMO pilot. Figure 17 shows the real-time measurement of MIMO, and figure 18 illustrates a comparison between mutual coupling of the antenna using a VNAMIMO antenna-measured and simulated.

Figure 12: Front and rear view of the MIMO antenna
Figure 13: Reflection Coefficient plot of unit

Figure 14: Real-time measurement using a VNA cell (measured)

Figure 15: Comparison between measured and simulated results of unit cell antenna
IV. Conclusion

A planar monopole super wideband antenna is designed with extreme compactness of size 40 mm x 30 mm with a frequency range of 2GHz to 20GHz. The main proposal of the project is to achieve a compact size with a super wideband frequency range incorporated with MIMO applications. The proposed design of the antenna has parasitic elements that are orthogonally aligned to reduce mutual coupling so that polarization of E and H plane can be detected. Achieved gain is -10db, and isolation is kept below -15db,
which shows that radiation of antenna is more than 90%. ECC obtained for MIMO set is 0.018 shows the good individuality of the antenna. Diversity gain is 10dB, which indicates that the power losses are minimum. VSWR is less than 2; dumbbell shape far field has been achieved. BDR ratio is 1:10, which indicates that we have obtained a compact antenna with super-wide bandwidth.

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