MIMO Dual Sensing Antenna with Notch Characteristics

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Abstract: - Design of MIMO antenna with having notch band characteristics between 2.5 GHz-3.7 GHz and 7.7 GHz-8.6 GHz in the Ultra-wide band operating range from 2.3 GHz-9.96 GHz. For getting notch bands in UWB frequency bands, parallel stubs are kept in the ground to separate the radiating patch elements. The parallel stubs placed in the ground plane improved isolation to 18 dB. The ECC less than 0.01 at the frequency band and the DG is close to 9.5 dB. As the antenna is designed on the flexible polyimide substrate it undergone for bending analysis for different angles like 30°, 60° and 90°. The prototyped antenna measured results providing good agreement with the simulated once obtained from commercial HFSS tool. The obtained band notching characteristics will object some of the frequency applications like WLAN, WiMAX and X-band satellite communication.

Keywords: - Envelope Correlation Coefficient (ECC), Ultra-wide band (UWB), Multiple Input Multiple Output (MIMO).

1. Introduction

The demand of high-speed data rates, high capacity devices and good throughput as per the current technology is not possible with single element antenna. To overcome such drawbacks, MIMO antenna with number of antenna elements providing better solutions. The MIMO technology has gained importance because of low co-channel interference, higher data rates and low signal loss. The challenging task in MIMO antennas design is to achieve good isolation between the elements. Isolation became the serious issue because all the devices in recent technology are compact in nature and where one element will affect the performance of other elements. Several isolation techniques are presented in the literature like Neutralization lines, meta-materials, defected ground structures and Decoupling strips.

The major challenge occurred in MIMO antenna is reduction of coupling among the antenna elements [1]. By maintaining the spacing, which leads to increase the volume of the antenna. Mutual coupling is because of electro-magnetic interaction among elements [2]. A dual band antenna has been designed by Qin which uses DGS method yielding high port isolation [3]. A MIMO Diversity antenna is designed using Split-rings that helped to get desired band rejection [4]. A U-shaped geometry is used in open loop resonators to obtain desired band rejection. A defected ground structure has been etched to obtain ultra-wide band resonance. To produce Notch band characteristics at 5 GHz, a crescent ring has been etched on the two circular patch antenna elements [5]. Third Notch from 3.3 GHz-3.7 GHz is obtained placing strips. Two long ground stubs and a short ground strip are etched on the antenna to increase isolation [6-7]. The antenna is designed with monopoles separated by distance of 0.106 λo [8-10].
By adding a stub to feed line and by integrating the stub in ground plane achieved 20 dB isolation [12]. Through the introduction of resonance paths E-shaped antenna, five resonance bands are obtained at different frequencies [13]. A semi annular ring slot is introduced and square steps above the semi-circular monopole are modified to form curved steps for the improvement of impedance bandwidth and coupling -20 dB [14]. The designed antenna has ECC less than 0.03 and gain greater than 9.8 dB [15]. A modified T-shaped stub is employed on ground plane to enhance impedance and a slot is etched on the modified stub to improve isolation. Because of this, the antenna operates from 2.9 GHz to 12 GHz having coupling lower -15 dB and ECC is 0.3 [16-17].

In this paper, UWB MIMO antenna with Notch band characteristics is presented. It consists of two flower shaped monopoles placed orthogonal to each other. Each monopole consists of the circular ring loaded with four petals which are in the shape of tetrameric flower with each petal is separated by an angle of 90°. The dimensions of MIMO antenna are 40 x 40 x 1.6 mm³ and kept on the polyimide substrate. To enhance the impedance bandwidth, the ground plane is modified to half curvature slot. Increase in the radius of the circular slot leads to change in inductive effect. A rectangular block is added for the reduction of mutual coupling between the elements. Antenna is further modified with circular slot in the center of the monopoles to obtain notch band characteristics.

2. Design of proposed antenna

The MIMO antenna having 2 elements is shown in the Fig 1(a) which consists of 50 Ω microstrip line feed with feed length of \( L_f = 8 \) mm and feed width of \( W_f = 2.5 \) mm and a circular ring monopole with partial ground structure. The radius of circular ring patch is considered with dimensions of \( C_1 = \frac{\lambda}{14} = 8.2 \) mm, where \( \lambda \) is the guided wavelength. The polyimide substrate material is used with permittivity of 3.5 is used. The overall dimensions of MIMO antenna considered are 40 x 40 x 1.6 mm³. Proposed antenna has the circular ring loaded with four petals which are in the shape of tetrameric flower with each petal is separated by an angle of 90°. The partial ground structure is considered in the ground plane with dimensions of \( L_g = 6 \) mm and \( W_g = 40 \) mm.

\[ \text{(a) Designed antenna (b) Top view (c) Back view of the proposed Notch band antenna.} \]
To attain the UWBrange, ground plane is further modified with half circular curvature slot just below the radiating patch resulting in enhancement of antenna impedance. The radius of half circular slot is given by the $S=3$ mm, increase in the half circular slot leads to increase in the current path in the ground structure and resulting to vary inductive effect. In the partial ground structure, a rectangular block is added to reduction of coupling in the elements with added length of $L_{g1}=2.5$mm. To attain the band notch properties, antenna is modified with circular slot $C_3=2$mm on the radiating patch. In the ground plane, stubs are added in between the elements with dimensions of $L_b=5$mm, which are separated by gap of 1 mm. The placement of stubs in the ground plane reduces the coupling effect.

3. Results and Discussions

Fig 2 presents reflection coefficients of proposed UWB and Notch antenna characteristics. The UWB antenna shows the wide band performance with small frequency band at low frequencies ranging from 1.28 GHz – 1.58 GHz with minimum $S_{11}$ of -17.2 dB at 1.47 GHz. Similarly, wide frequency band is covered from the frequency ranging from 2.36 GHz – 9.96 GHz bandwidth of 7.6 GHz and covers UWB frequency range. The UWB antenna resonates at 2.87 GHz, 4.24 GHz and 6.57 GHz with minimum $S_{11}$ of -38.8 dB, -32 dB and -41.2 dB respectively. Similarly, notch band antenna performance is also presented in the same plot. The observed characteristics presents notch band frequencies ranging from 2.5 GHz-3.7 GHz and 7.7 GHz-8.6 GHz in which most of WLAN and X-band satellite application frequencies are objected.

![Figure 2: Operating characteristics UWB antenna and Notch antenna](image)

![Figure 3: Simulated $S_{21}$ of UWB antenna and Notch band antenna.](image)
The $S_{21}$ isolation characteristics of UWB Notch band antenna given in Fig 3. The mutual coupling $S_{21} < -18$ dB is observed because of the stubs in ground. It improved the impedance matching of antenna and reduced mutual coupling. In this plot, $S_{21}$ characteristics of UWB antenna which shows -13 dB mutual coupling, but for the notch band antenna it reduced to -18 dB and low over the operating band. The additionally added stubs in the ground act as resonator and control the notch frequency. To obtain notch band frequencies proper tuning of width and length of the stubs are done.

3.1 **Parametric Analysis**

3.1.1 **Effect of Circular Slot**

The radius of the grounded slotted structure is varied from $S=1$-2.5mm with variation of 0.5 mm. When the slot radius is equal to 1 mm, antenna shows the triple notch at 1.8-1.88 GHz, 2.54-3.7 GHz and 7.6-8.4 GHz. For the different values of ‘S’ there is less variation is observed. A minimum reflection coefficient is observed when $S=2$mm at 4.8 GHz as shown in Fig 4.

![Figure 4: Parametric analysis for varying circular slot.](image)

3.1.2 **Effect of Annular ring**

To obtain the optimized parameters, parametric analysis is carried out for annular ring dimensions also. The outer circle radius (C1) is varied from $C1 = 7.2$-8.8 mm with step size of 0.4 mm. Antenna covers three multiple frequencies with two notch band characteristics. At the lower frequency, the bandwidth coverage for different values of C1 is from 1.05-2.8 GHz, which covers different application bands like GPS, UMTS, DSC and Bluetooth.

![Figure 5: Parametric analysis for varying (a) circle 1 (b) circle 2.](image)
At the second operating frequency, a minimum reflection coefficient is observed at $C_1=8.2$ mm with minimum $S_{11}$ of -36 dB at 4.8 GHz as shown in Fig 5(a). When $C_1=8.8$ mm, antenna shows a small resonating peak at 5 GHz with $S_{11}$ of -12 dB. For the third resonating frequency we observed minimum reflection coefficient of -38 dB at 9.4 GHz. when circle($C_2$) is increased, the antenna doesn’t show much variation on the resonating frequency. The inner circle radius is varied from the $C_2= 5.4 -5.8$ mm with step size of 0.2mm as shown in the Fig 5(b). When the circle radius is increased, the ring structure becomes narrow and the elimination of the first resonating band is observed. For different values of $C_2$ there is no significant variation.

### 3.1.3 Effect of Feed Width:

Similarly, feed with ($W_f$) is changed from 1mm to 2.5 mm with change of 0.5 mm step shown in Fig 6. The antenna shows dual notch bands at 2.54-3.7 GHz and 7.6-8.4 GHz. When the width of the feed is 2 mm the minimum reflection coefficient is found at 2.1 GHz and 4.8 GHz with $S_{11}$ of -28 dB and -36 dB.

![Figure 6: Variation of feed width ($W_f$)](image)

### 3.2 Radiation Patterns

Fig 7 presents the radiation pattern of antenna. The patterns are plotted in E and H-plane. Because of symmetry, the characteristics are taken terminated with 50Ω load for single port is excited at a time. The patterns observed at the four resonating frequencies like 1.3 GHz, 2.1 GHz, 4.8 GHz, and 9.4 GHz. In E-plane the radiation patterns are focused in angle of 240°-330°. As the frequency increases the back lobes in the radiation pattern are observed at 9.4 GHz. The semi-directional at high frequency values in H-plane.

![Figure 7: Patterns for (a) E plane (b) H plane](image)
3.3 **Surface current distribution**

This study provides the having coupling between antenna elements. The ground stubs and slot between the stub’s effects of surface currents. Port 1 is made excited with 1W input power and other port with load 50Ω impedance as show in Fig 8(a). The added parallel stubs lead to reduce of current distribution at second monopole antenna. The Fig 8(b) represents the surface current distribution when the second port of the antenna is excited.

![Figure 8: Current distribution (a) when port 1 is excited (b) when port 2 is excited](image)

3.4 **Peak Gain Vs Frequency**

The peak gain Vs frequency of antenna is presented in the Fig 9. The maximum gain is observed to be 3.4 dBi, 3.3 dBi and 7.4 dBi for simulated results and measured results are 1.8 dBi, 3.2 dBi, 7.6 dBi at three different frequencies like 2.1 GHz, 4.8 GHz, and 9.3GHz respectively. A sharp fall of peak is observed at the two notch frequency bands. At 2.7 GHz, antenna shows the negative gain of -2.5 dBi for measured and nearly 0 dB for simulated. Similarly, at second notch band between 7.7 GHz-8.6 GHz a sharp fall of gain is observed as 2 dBi for measured and nearly 3 dBi for simulated case.

![Figure 9: Simulated and measured results of Peak gain Vs Frequency](image)

3.5 **Radiation Efficiency of antenna**

The Fig 10 represents the comparison of results both simulation and measured. At first notch band , the radiation efficiency falls to 48% for simulation and 10% for measured case. For the second notch band 58% for simulation and 44% for measured radiation efficiency obtained. Fig 11 represents the fabricated antenna models.
3.6 Comparison of Simulated and Measured Results

Fig 12 and 13 represent results ($S_{11}$ & $S_{21}$) of the designed antenna. The antenna model is fabricated using the Nvis72 antenna prototype machine and tested using the Anritsu combinational analyzer. The results of the proposed antenna in Fig 12 show $S_{11} < -10\text{dB}$ over the entire UWB band having notch bands ranging from 2.5 GHz-3.7 GHz and 7.7 GHz-8.6 GHz in which most of WLAN and X-band satellite application frequencies are objected. The measured results have notching from 2 GHz-4 GHz and 7.8 GHz-9 GHz. Fig 13 depicts the $S_{21}$ results of the designed antenna. The reduction in mutual coupling $S_{21} < -18 \text{ dB}$ is observed because of the stubs placed in the ground structure.
3.7 Envelope correlation coefficient

The ECC is an effective value analyze the MIMO antennas performance. To optimized value for the correlation coefficient should be less than 0.5 dB. The first method to calculate correlation coefficient is by using far field pattern formula [10].

$$\rho = \frac{\iiint F_1(\theta, \phi).F_2(\theta, \phi)d\Omega}{\left( \iint F_1(\theta, \phi)d\Omega \right)^2}$$  \hspace{1cm} (1)

It is observed values of ECC which are lower 0.01 for the operating bands and at the notch band ECC is raised to 0.02 value. The obtained values of ECC show the strong diversity of MIMO antenna.

3.8 Diversity Gain (DG)

The DG of antenna, observed values of diversity gain is ranging from 8-9.5(dB) over the operating frequency as shown in Fig 15. The formula for the diversity gain is given by [7]

$$DG=10\sqrt{1-ECC^2}$$  \hspace{1cm} (2)
3.9 Bending analysis of the designed antenna

The antenna designed on polyimide is undergone for bending analysis at different angles like 30°, 60°, and 90° shown in the Fig 16. As the antenna is bent at different angles the notch performance of the antenna is improved. For the angles like 30° and 60° their shift in the frequency. By increasing the bending angle, the notch performance of antenna is increased which is above -5dB on average.

Figure 16: Bending analysis of the antenna (a) Reflection coefficient at different bending angles (b) Bent structure of antenna.

The antenna placed on the flexible material which is undergone for bending analysis ECC and DG is done for different bending angles, like 30°, 60°, and 90° shown in the Fig.18. The observed ECC values of the antenna observed in around the 0.025 to 0.015 dB. At the higher frequency for bending angle 300 ECC values touches the 0.03dB line for the bending angles like 600 and 900 the values are in the range of 0.02dB which is shown in Fig.17(a).

Figure 17: Bending of antenna (a) ECC (b) Diversity Gain.
Similarly, DG of antenna is observed, different angles normally diversity gain antenna is observed to 9.3dB but for the flexible structure DG of the antenna is reduced to 8.1 on the average shown in Fig.17(b). The reduction of the diversity gain is because, as the bending increases the orientation of the fields are going to change when compared to planner structure.

3.10 **Antenna placed on the human**

The antenna is placed near the shoulder of human. The distribution of radiation is observed in the Fig.18 and shows omnidirectional characteristics in the XY-plane. In the 3D pattern of the diagram, radiation is focused outside the human body and the radiation observed in that YZ and XZ-planes it shows dipole type of radiation patterns.

Table.1 The previous literature with the proposed antenna. The antenna shows the low isolation values and high gain at the operating frequencies.

| Ref. No | size [mm³] | Frequency Range (GHz) | Impedance bandwidth (%) | Isolation (dB) | ECC | Peak gain |
|---------|------------|-----------------------|-------------------------|----------------|-----|-----------|
| 1       | 14x14x0.25 | 2–12                  | 142                     | 10             | 0.054 | 4.8       |
| 2       | 26x40x0.8  | 2.2-11.4              | 135                     | 20             | 0.008 | 7.5       |
| 4       | 29x38x1.6  | 5.15-5.85             | 12                      | 21.5           | 0.01  | 1.8-4.7   |
| 6       | 18x21x0.8  | 2.8-12.2              | 125                     | 25             | 0.013 | 2-5       |
| 7       | 30x16x0.79 | 3.1-4.7               | 42                      | 20             | 0.03  | 2-5.2     |
| 8       | 26x28x0.8  | 2.9-10.8              | 115                     | 15             | 0.08  | 1.64      |
| 14      | 29.5x27x0.8| 1.8-6.5               | 113                     | 14             | -     | 2.5       |
| 16      | 38x33.4x1.6| 2.1-12                | 141                     | 20             | 0.02  | 1.4-4.8   |
| 17      | 30x26x1.6  | 3.2–3.8               | 17                      | 20             | 0.03  | 2.8       |
| 18      | 22x33x0.125| 3.43-7.1              | 73                      | 15             | 0.3   | 2.31      |
| Proposed antenna | 40 x 40 x 1.6 | 1.28-1.58 2.36-9.96 | 21                      | 116            | 18    | 0.02      |

**Figure 18**: 3D Far field characteristics of the antenna

**Table 1**: Comparison of literature

| Ref. No | size [mm³] | Frequency Range (GHz) | Impedance bandwidth (%) | Isolation (dB) | ECC | Peak gain |
|---------|------------|-----------------------|-------------------------|----------------|-----|-----------|
| 1       | 14x14x0.25 | 2–12                  | 142                     | 10             | 0.054 | 4.8       |
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| 18      | 22x33x0.125| 3.43-7.1              | 73                      | 15             | 0.3   | 2.31      |
| Proposed antenna | 40 x 40 x 1.6 | 1.28-1.58 2.36-9.96 | 21                      | 116            | 18    | 0.02      |

Proposed antenna
4 Conclusions

A notch band MIMO designed to exclude WiMAX, WLAN, and X-band notching is proposed. This is a simple to design and fabricated on polyimide and having 40 x 40 x 1.6 mm3 dimensions. $|S_{11}| < -10$ dB is achieved by using semi-annular ring, and $|S_{21}| < -18$ dB is achieved because of the stubs placed in the ground structure. The structure has ECC less than 0.02, peak gain more than 7.4 dB and diversity gain ranging from 8-9.5 dB. Practically results showing good correlation with simulation results and performance characteristics make proposed antenna a good candidate for MIMO applications.

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