Design of compact MIMO antenna with improved isolation for UWB application

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Abstract. In this paper, a compact dual port multiple-input-multiple-output (MIMO) antenna with a compact size of 26 ×40 mm² is presented. In this proposed designed antenna two square-shaped with slotted cut radiating elements (Planar monopole) are used and positioned opposite to each other for improved isolation. The operating frequency of the presented antenna is 4.1GHz to 10.6 GHz. Two L-shaped stubs are introduced in the ground plane of the antenna to improve the isolation of the proposed design. The Mutual coupling between the two-port of antenna is less than -15 dB for complex impedance bandwidth and ECC is less than 0.05dB from 3.24GHz - 4GHz and from 4GHz to 12GHz it is almost zero which is within operating frequency in UWB. diversity gain is high i.e., 9.95dB. from 3.7GHz to 4GHz and it is almost 10 dB from 4.1GHz to 12GHz. The efficiency and results of the antenna make it a promising antenna Applicant for use in UWB lightweight applications.

Keywords — Multiple-input-multiple-output (MIMO) antenna, ECC, mutual coupling, planar monopole (PM), Ultrawideband (UWB).

1. Introduction
Over the past few years, significant research work has taken place in the field of MIMO antenna focusing on the wideband. Ultra-wideband (UWB) antennas have become the necessity of today’s world mainly because of their applications in the domain of wireless communication as they can provide high-speed connectivity and large bandwidth transmission [1]. Therefore, the benefits of the UWB system in [2] are easily deployable and cheaper, high data rate, multiple access capability, high multi-path and jamming resistance, improved performance and low energy consumption, low probability of interception or detection, and anti-jam immunity. In [3], Ultra-wideband is a rapidly growing technology that transmits signals at low energy levels using a broad frequency band. UWB has various promising applications wireless audio-video, distribution in communication, medical imaging, military communication. MIMO antennas with their abilities to provide multiple propagations to transmit and receive over the other antennas which provide data rate with limited input and limited output (SISO) [4]. UWB has a good potential for short-range wireless networking technology that offers wireless communication with high speed [5]. In [6] mutual coupling between the two radiating elements is high so the efficiency of the antenna is affected. Isolation enhancement is one of the main challenges MIMO antenna designs. The UWB antenna has enhanced channel capability and improved diversity gain [7].

Many other MIMO antennas for UWB systems have been investigated. In [2], the structures are positioned between two symmetrical elements for a better isolation for different decoupling purposes. Different integration methods such as split-ring resonator, electromagnetic band distance, slots, metamaterial,
neutralization line (NL), faulty ground structure, etc. for the good isolation characteristics in [8]. We can achieve the best performance without adding any extra structure to decrease the complexity of the design. In the context of MIMO antenna architecture, with the port isolation, we studied the various diversity parameters [9]. A proper application band with good port isolation is required for the good output of the antenna for isolation enhancement different techniques are used in [5],[7].

In this paper, two radiating elements (square-shaped with slotted cut) are used and to enhance the MIMO performance in terms of isolation. Two L-shaped long stubs are inserted on the ground plane of the proposed antenna. The proposed antenna is printed on the Rogers substrate RT5880 and it has a smaller size of 26×40 mm². The simulated result validates the antenna for the MIMO UWB application.

2. Antenna Design

For UWB implementations, Figure 1 displays the schematic diagram of the planned MIMO antenna. It is printed with a dielectric constant of $\varepsilon_r = 2.2$, and a substrate thickness of 0.8 mm on the Rogers RT5880 substrate. The antenna measurements are $L \times W = 40 \times 26 \ mm^2$ and the tangent loss is 0.0009. It consists of two matching radiators with a square shape written on the top side of the Rogers RT5880. Square Radiators is Written on the upper side of Rogers RT5880. To achieve greater isolation, square shape radiators have a dimension of 10 x 10 and are mounted opposite each other. PM 1 and PM 2 are represented by these identical square-shaped radiators. For improved insulation, PM 1 and PM 2 have square slot cuts of SL mm. Both the PM1 and PM2 radiators are attached to a 50-microstrip feedline. The feed line dimension is $D_s \times D_L = 1.8 \times 9$. The proposed antenna architecture consists of rectangular shape ground planes and is written on the other side of the substrate. A minute rectangle with a size of $D_f \times D_h$ is cut under each feedline on the upper edge of the ground plane to provide improved insulation. Achieving a small physical antenna structure while balancing low reciprocal coupling between individual antennas in the MIMO antenna architecture for UWB implementation is a difficult task [10]. The job of maintaining the decoupling element in the MIMO antenna is difficult because MIMO spans a wide variety of UWB applications [11].

Fig. 1. Schematic diagram of proposed MIMO antenna front and back.

In the proposed structure, two L-shaped identical stubs are used. stub1 and stub2 are placed on the ground plane of the proposed antenna as shown in the schematic diagram. Due to the L-shape of the stub, the size of the proposed antenna size is minimized. Table 1 lists the measurements for the MIMO antenna.
TABLE 1. PARAMETERS FOR PROPOSED ANTENNA (MM)

|    | L | W | Dr | Ls | Sl | Sw | S1 | sw2 |
|----|---|---|----|----|----|----|----|-----|
|    | 40| 26| 4  | 5  | 4  | 0.5| 15 | 0.5 |
| Ls | Wg| Ds| Lf | Rs | Dh | Lg | Dl |
| 6.1| 8 | 1.8| 5  | 10 | 1  | 24 | 9  |

2.1 Evolution of proposed Antenna

In the proposed MIMO antenna two long L-shape long stubs are placed on the ground plane. These stubs are critical for enriched MIMO performance in terms of isolation and impedance matching. The evolution of the antenna is shown in the below Fig. 2.1 and for observing the effect of the stubs on the proposed antenna it is simulated using EM simulation CST application. The effect of the stub on the proposed antenna is following-

![Fig. 2.1 (a) antenna without stubs](image)

![Fig. 2.1(b) antenna without stub1](image)

![Fig. 2.1(c) antenna without stub1](image)

![Fig. 2.1(d) antenna with both stub (proposed antenna)](image)

2.1.1 Without Stubs

When both stubs are removed from the proposed antenna, the simulated results are shown in Fig.3(c), that there is a minor change in the results as compared to when one stub is removed. The lower cut-off frequency ($S_{11} < -10$ dB) 3.78 GHz and the higher cut-off frequency 10.6 GHz. And the mutual coupling for $S_{21} < -15$ dB from 8.09 – 10.6 GHz and $S_{21} > -15$ dB from 2.74 – 7.95 GHz. It is seen that without a stub the antenna cannot satisfy the UWB requirement.
2.1.2 Without Stub1
In the proposed dual-port UWB MIMO antenna there are two monopoles (PM1 and PM2) with two L-shaped long ground stubs. When the stub1 is removed from the proposed antenna the simulated results show in Fig.3(a), that there are minor effects on the impedance bandwidth for $S_{11} < -10$ dB from 3.55 - 11.12 GHz and the mutual coupling for $S_{21} < -15$ dB from 3.94 – 10.6 GHz and $S_{21} > -15$ dB from 3.14 – 3.89 GHz. It is seen that without stub1 the antenna cannot satisfy the UWB requirement.

2.1.3 Without stub2
When the stub2 is removed from the proposed MIMO antenna, the simulated results are shown in Fig.3(b), that there is a minor effect on the results. The lower cut-off frequency ($S_{11} < -10$ dB) 3.55 GHz and the higher cut-off frequency 10.6 GHz. And the mutual coupling ($S_{21} < -15$ dB) from 3.97 – 10.6 GHz and ($S_{21} > -15$ dB) from 3.17 – 3.86 GHz. It is seen that without stub2 the antenna cannot satisfy the UWB requirements.

Fig 3 (a). Simulated S parameters for without stub1
3. Result and discussions

In this paper, the presented antenna is implemented on CST studio and the simulated results validate the antenna for MIMO UWB applications. Fig. 4. illustrate the S-parameter of the presented antenna and the findings reveal that port 1 has a bandwidth of 4.1 to 10.6 GHz, while port 2 has also a bandwidth of 4.1 to 10.6 GHz. The proposed antenna satisfies the FCC’s specified impedance bandwidth for 86% of UWB. For good efficiency, the mutual coupling $S_{22}$ less than -15dB is considered adequate [12],[13],[14],[15] so the presented antenna is better for MIMO activity throughout the operating band with high port isolation.
For observing and aliasing the performance of the MIMO antenna there are key characteristics parameters such as ECC, DG, multiplexing, and mean effective gain. ECC of planned MIMO is illustrated in fig 5 ECC (Envelope Correlation Coefficient) graph indicates how the radiation pattern of two antennas is independent. Ideally, for two-port MIMO correlation coefficient should be less than 0.05dB. Fig 5 indicates that the ECC is (calculated from S parameters) less than 0.05dB from 3.24GHz - 4GHz and from 4GHz-12GHz it is almost zero which is within operating frequency in UWB MIMO. ECC can be calculated by the given formula as shown in eq. 3.1 [16]

$$\rho_e = \frac{|S_{11}^* S_{22} + S_{21}^* S_{22}|^2}{(1-|S_{21}|^2)(1-|S_{22}|^2-|S_{12}|^2)}$$

(3.1)

Fig. 5. Envelope correlation coefficient
Fig 6 indicates the diversity gain graph which shows diversity gain is very high that is 9.95 dB from 3.7GHz to 4GHz and almost 10 from 4.1GHz to 12GHz. Multiplexing efficiency is characterized as the power penalty of a practical antenna system to achieve a specific capability which is compared to an ideal antenna system with 100% i.e., total antenna efficiency and zero correlation between antennas [17]. The calculated value of multiplexing efficiency is -0.34 dB as shown in the fig 7. In [18], the mean effective gain (MEG) is defined as the capacity of an antenna to obtain electromagnetic power and the MEG is calculated as shown in eq. (3.2).

$$\text{MEG} = \oint \left[ \frac{XPD}{1 + XPD} p_\theta(\Omega) G_\theta(\Omega) + \frac{1}{1 + XPD} p_\nu(\Omega) G_\nu(\Omega) \right] d\Omega$$  \hspace{1cm} (3.2)$$

where XPD is the cross-polarization discrimination of the incident field.

Therefore, the calculated value of the MEG from the graph is -3.24 at frequency 10.7 GHz as shown in fig.8.
To more clearly understand the isolation between the two elements of the MIMO antenna we analyzed the surface current distribution of this antenna. Fig. 9.a and 9.b demonstrate the surface current distribution at the frequency of 10.7 GHz and it clearly shows that when port1 is fed and port 2 is isolated, current passes through port1 and pm1 radiate but current coupled with the L-shaped ground stub and not affected other radiating element i.e., pm2 which resultant good isolation between the pm1 and pm2.

![Fig. 9.a current distribution at 10.7 GHz (port1 excited).](image)

![Fig. 9.b current distribution at 10.7 GHz (port2 excited).](image)
Fig. 10. a. and 10.b radiation pattern at the frequency of 7 GHz., Fig. 10. c. and 10.d radiation pattern at the frequency of 8 GHz.

Fig.10.a shows the radiation pattern at the frequency of 7 GHz when the port is fed and fig 10.b. shows the radiation pattern when port 2 is excited and port 1 is isolated. The result indicates that the far-field at the frequency of 7 GHz for E – plane. It is bi-directional and for H - plane it is Omnidirectional. Fig.10.c shows the radiation pattern at the frequency of 8 GHz when port 1 is fed and fig 10.b. shows the radiation pattern when port 2 is excited and port 1 is isolated. far-field at the frequency at 8 GHz for E - plane it is bi-directional and for H - plane it is Omnidirectional.

4. Conclusion
In this paper, a dual port MIMO antenna is presented with a compact size of 26 mm×40 mm for UWB applications. To increase the isolation two long L-shaped stubs are used. The simulated result shows that the S11 of the antenna is less than -10dB from 4.1GHz to 12GHz. The ECC is less than 0.05dB and the diversity gain of this antenna is high. These key characteristics of the MIMO antenna validate and make a promising candidate for UWB applications.

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