Miniaturised UWB MIMO antenna with improved isolation and band notch capability at 5.5 GHz

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Abstract. A two-element planar UWB-MIMO monopole antenna is proposed utilising complimentary split ring resonator (CSRR) slot to obtain high isolation and notch at 5.5 GHz. The UWB-MIMO system comprises of two identical monopole antennas designed to achieve miniaturized size of 18 x 30 mm². A T-shaped parasitic stub is employed to attain superior isolation among the antenna elements. CSRR slot is etched to achieve notch in WLAN range at 5.5GHz and additionally to improve impedance matching a rectangular slot was inducted on the radiators. The projected design hovers over the range 3.3GHz-14.64 GHz and attained high isolation of ≤ -20 dB for 3.3 GHz -12.4 GHz and -16dB for rest of the band. The antenna system is simulated and fabricated to analyze the performance in terms of reflection coefficient and radiation pattern. The outcome testifies that the proposed design is a vastly miniaturized structure with all the capabilities of being a appropriate candidate for UWB-MIMO systems.

1. Introduction

Wireless technology is encountering turbulence courtesy of signal fading, multipath, amplified interference and narrow spectrum. In order to realised high data rate and to provide efficient solution for avoiding aforementioned problems Ultra-wideband technology needs to be integrated with antenna having multiple input output capabilities [1] [2]. A number of researchers have reported several UWB MIMO antennas for the unlicensed spectrum 3.1 GHz-10.6 GHz as accepted by Federal Communications and commission (FCC) for viable usage [3] [4]. Many MIMO designs have incorporated orthogonally allocated radiators with a familiar ground plane and an assortment of decoupling structures to get better isolation [5]. In [6], a quasi-self-complementary structure was worn to get high isolation. In some structures defected ground formations, quarter wavelength open slots, protruding ground stub are used to attain higher isolation and overall performance of MIMO antennas [7] [8] [9]. In [10] a neutralization line was employed to cancel out the aboriginal coupling. In all aforesaid designs, there is always a compromise between the bandwidth, size and complexity.

In the prescribed UWB range several communication standards are already persisting which can intrude in the operations of UWB systems. In particular WLAN is one such common standard that can cause hindrance to UWB systems and hence needs to be eliminated by creating notches. Many techniques to induce notches as reported in the literature are inserting I, U ,T sized parasitic slots [11], use of electromagnetic band structures [12] , employing CSRR ,SRR and metamaterial designs [13] [14] [15] [16].
To avoid interference and to get the miniaturised structure a UWB-MIMO antenna has been proposed in this paper having a very compact size (18 x 30 x 1.6 mm$^3$), wide bandwidth with high isolation through T-shaped stub on ground plane. Two CSRR slots are inserted on the radiating element to attain band notched characteristics at 5.5 GHz for UWB-MIMO Communication Systems. Antenna geometry is detailed in Section 2. Section 3 highlights the experimental outcomes obtained after the simulation and fabrication of the designed structure.

2. Antenna Configuration

Geometry of the compact and planar antenna band notched at 5.5 GHz is shown in figure1. It is fabricated on a thrifty FR4 substrate, having overall facet of 18 x 30 x 1.6 mm$^3$, with $\varepsilon_r$ of 4.3, and a loss tangent of 0.025. It has a very miniaturized size and high isolation contrary to what is reported in recent literature works. The blend edges are carved onto the rectangular monopole with a diameter of 7 mm through which CSRR slot is etched to achieve the required notch and a rectangular slot is introduced to attain enhanced impedance matching. The radiating elements are suckled by a 50-Ω microstrip line of area (L1 x W8). A T-shaped stub is introduced on ground plane so that surface current distribution changes and further leads to dwindling in the mutual coupling. The dimensions are given in Table1 and Table2.

| Table 1. Vertical Attributes of the designed structure |
|-----------------------------------------------|
| Attribute | Value(in mm) |
|-----------|--------------|
| L         | 18           |
| L1        | 8.36         |
| L2        | 5.5          |
| L3        | 5.64         |
| L4        | 1.9          |
| L5        | 0.5          |
| L6        | 1            |
| L7        | 12.5         |
| L8        | 4.5          |

| Table 2. Horizontal Attributes of the designed structure |
|-----------------------------------------------|
| Attribute | Value(in mm) |
|-----------|--------------|
| W         | 30           |
| W1        | 24.5         |
| W2        | 5.5          |
| W3        | 17.5         |
| W4        | 5            |
| W5        | 1.2          |
| W6        | 1.1          |
| W7        | 1.25         |
2.1. CSRR Slot
The two CSRR slots are designed to eliminate interference in the standard WLAN range (5.15 - 5.85 GHz) by inducing notch at 5.5GHz. The length of the slots is estimated using the following numerical formula [17] [5].

\[
\text{Length} = \frac{c}{2f_{\text{center}} \varepsilon_{\text{eff}}} \quad (1)
\]

\[
\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} \quad (2)
\]

2.2. T-shaped stub
A T-sized parasitic stub is etched on ground plane to accomplish superior isolation.

3. Experimental Results and Discussion
Two-element planar UWB MIMO monopole antennas using CSRR slots was modelled and simulated using CST tool [18]. The designed antenna was fabricated and measurements were done using vector network analyzer. Simulation results were compared with measured results to testify the accuracy of the design. Figure 2 shows the experimental setup.

Figure 1: Antenna Geometry
The following parameters were studied and analyzed.

3.1. Scattering parameters

![Figure 3: Simulated and Measured a) |S11| b) |S21|](image)

The designed UWB-MIMO antenna covers a large bandwidth of 3.3GHz - 14.64 GHz not including the band notch at 5.5 GHz. The fabricated and simulated S11 values in the prescribed frequency range is less than -10 dB except at band notch frequency 5.5 GHz as seen from figure 3a. As a result, the UWB MIMO antenna fulfills the impedance matching requirements in UWB and Ku range and is in accordance with norms prescribed by Federal Communications Commission (FCC). The proposed antenna attained high isolation of |S21| ≤ -20 dB for 3.3 GHz -12.4 GHz and for the rest of the band it is -16dB as seen from figure 3b. Despite the area constraint, the proposed system satisfies the required isolation threshold of -18 dB which is sufficient to ensure good MIMO performance. The variation between the simulated and measured values at certain frequencies is due to the substrate properties of the fabricated and modelled antennas as well as the fabrication tolerances.
3.2. Radiation Pattern

Radiation analysis of Antenna under test (AUT) was carried out in a controlled setup as shown in the figure 4.

![Radiation pattern measurement set up](image)

**Figure 4:** Radiation pattern measurement set up

The radiation pattern in the two planes (E & H) at various frequencies are as shown in Figure 5.

![Radiation Pattern](image)

**Figure 5.** Radiation Pattern
Figure 5 shows the measured and simulated radiation patterns at 3.5GHz, 5.2 GHz, 7.5GHz, and 9.5GHz. The measurements were carried out in anechoic chamber with just port 1 being exited and remaining port matched with 50 $\Omega$ impedance. The H (x-o-z) and E-planes (y-o-z) of the antenna when port 1 is excited are signified in Figures 5 (a) - (d). The patterns observed in H-plane are almost omnidirectional and we get monopole like pattern in the E-plane at 3.5, 5.2, 7.5 and 9.5 GHz to accept the signals from all the directions. The radiation graphs of the antenna at all frequencies have almost stable radiation patterns except at band notch frequencies.

| Ref. No. | Size (W x L mm$^2$) | Frequency range GHz, which satisfies ( S11<-10 dB) | Mutual coupling (Low Correlation level dB) | The geometry of the MIMO Antenna | Complexity |
|----------|---------------------|-----------------------------------------------|------------------------------------------|---------------------------------|------------|
| [19]     | 56 X 56             | 3.1 – 10.6                                    | -20                                      |                                 | Simple     |
| [20]     | 38 X 62             | 3.1 – 10                                       | -23                                      |                                 | Medium     |
| [21]     | 40 X 37.5           | 3.1 – 10.6                                    | -20                                      |                                 | Complex    |
| [22]     | 34 X 48             | 3.1 – 10.6                                    | -20                                      |                                 | Medium     |
| Proposed Structure | 18 X 30             | 3.3 – 14.6 GHz                                | <-20                                     |                                 | Simple     |

The comparative analysis with other existing systems (Table 3) reiterates that the proposed antenna has the most compact size and covers large bandwidth with acceptable mutual coupling.

4. Conclusion

Two-element planar UWB MIMO monopole antennas are presented with CSRR slot to obtain the high isolation and notch at 5.5 GHz. To achieve notch characteristics CSRR slot was etched on the two radiating elements. Rectangular slot was included to improve impedance matching with a T-shaped parasitic stub etched to attain superior isolation. The simulated and measured results are matched and it shows that the structure operates in 3.3 to 14.64 GHz range, with high isolation of < -20 dB and is compact in design. Moreover, the proposed antenna configuration has been compared with various UWB MIMO antenna designs in terms of size, mutual coupling, geometric complexity. The proposed antenna is well suited for portable device applications and satellite communication which is evident from the simulated and measured results and existing research work.

References

[1] C. Abou-Rjeily, N. Daniele, and J.-C. Belfiore, “Space–Time Coding for Multiuser Ultra-Wideband Communications,” IEEE Trans. Commun., vol. 54, no. 11, pp. 1960–1972, Nov. 2006, doi: 10.1109/TCOMM.2006.884830.
[2] T. S. P. See and Z. N. Chen, “An Ultrawideband Diversity Antenna,” IEEE Trans. Antennas Propag., vol. 57, no. 6, pp. 1597–1605, Jun. 2009, doi: 10.1109/TAP.2009.2019908.
[3] Shaik. Kareemulla and V. Kumar, “A novel compact MIMO antenna for ultra wideband applications,” in 2015 IEEE International Conference on Signal Processing, Informatics, Communication and Energy Systems (SPICES), Feb. 2015, pp. 1–5, doi: 10.1109/SPICES.2015.7091539.
[4] P. S. Manage, U. Naik, S. Kareemulla, and V. Rayar, “Dual Band Notched UWB-MIMO Antenna Incorporating CSRR for WLAN and X Band Applications,” in 2020 Third International Conference on Smart Systems and Inventive Technology (ICSSIT), Aug. 2020, pp. 149–152, doi: 10.1109/ICSSIT48917.2020.9214113.
[5] P. Gao, S. He, X. Wei, Z. Xu, N. Wang, and Y. Zheng, “Compact Printed UWB Diversity Slot Antenna With 5.5-GHz Band-Notched Characteristics,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 13, pp. 376–379, 2014, doi: 10.1109/LAWP.2014.2305772.

[6] X.- Liu, Z.- Wang, Y.- Yin, J. Ren, and J.- Wu, “A Compact Ultrawideband MIMO Antenna Using OSCA for High Isolation,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 13, pp. 1497–1500, 2014, doi: 10.1109/LAWP.2014.2340395.

[7] Jian Ren, Wei Hu, Yingzeng Yin, and Rong Fan, “Compact Printed MIMO Antenna for UWB Applications,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 13, pp. 1517–1520, 2014, doi: 10.1109/LAWP.2014.2343454.

[8] B. P. Chacko, G. Augustin, and T. A. Denidni, “Uniplanar Slot Antenna for Ultrawideband Polarization-Diversity Applications,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 12, pp. 88–91, 2013, doi: 10.1109/LAWP.2013.2242841.

[9] Jae-Min Lee, Ki-Baek Kim, Hong-Kyun Ryu, and Jong-Myung Woo, “A Compact Ultrawideband MIMO Antenna With WLAN Band-Rejected Operation for Mobile Devices,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 11, pp. 990–993, 2012, doi: 10.1109/LAWP.2012.2214431.

[10] Tzu-Chun Tang and Ken-Huang Lin, “An Ultrawideband MIMO Antenna With Dual Band-Notched Function,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 13, pp. 1076–1079, 2014, doi: 10.1109/LAWP.2014.2329496.

[11] M. Yazdi and N. Komjani, “Design of a Band-Notched UWB Monopole Antenna by Means of an EBG Structure,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 10, pp. 170–173, 2011, doi: 10.1109/LAWP.2011.2116150.

[12] L. Li, Z.-L. Zhou, J.-S. Hong, and B.-Z. Wang, “Compact dual-band-notched UWB planar monopole antenna with modified SRR,” *Electron. Lett.*, vol. 47, no. 17, p. 950, 2011, doi: 10.1049/el.2011.1874.

[13] I. Buriak, V. Zhurba, G. Vorobjov, V. Kulizhko, O. Kononov, and O. Rybalko, “Metamaterials: Theory, Classification and Application Strategies (Review),” *J. Nano-Electron. Phys.*, vol. 8, pp. 04088–1, Dec. 2016, doi: 10.21272/jnep.8(4(2)).04088.

[14] P. S. Manage, U. Naik, S. Nargundkar, and V. Rayar, “A Survey on applications of Metamaterials in Antenna Design,” in 2020 Third International Conference on Smart Systems and Inventive Technology (ICSSIT), Aug. 2020, pp. 153–158, doi: 10.1109/ICSSIT48917.2020.9214088.

[15] C. Caloz and T. Itoh, *Electromagnetic Metamaterials: Transmission Line Theory and Microwave Applications: The Engineering Approach*. Hoboken, NJ, USA: John Wiley & Sons, Inc., 2005.

[16] M. S. Khan, A.-D. Capobianco, S. M. Asif, D. E. Anagnostou, R. M. Shubair, and B. D. Braaten, “A Compact CSRR-Enabled UWB Diversity Antenna,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 16, pp. 808–812, 2017, doi: 10.1109/LAWP.2016.2604843.

[17] A. A. Yussuf and S. Paker, “Design of wideband MIMO antenna for wireless applications,” in 2017 25th Signal Processing and Communications Applications Conference (SIU), Antalya, Turkey, May 2017, pp. 1–4, doi: 10.1109/SIU.2017.7960203.

[18] S. Mohammad, A. Nezhad, H. R. Hassani, and A. Foudazi, “A dual-band WLAN/UWB printed wide slot antenna for mimo/diversity applications,” *Microw. Opt. Technol. Lett.*, vol. 55, no. 3, pp. 461–465, 2013, doi: https://doi.org/10.1002/mop.27391.

[19] Y. Li, W. x Li, C. Liu, and T. Jiang, “Two UWB-MIMO antennas with high isolation using sleeve coupled stepped impedance resonators,” in 2012 IEEE Asia-Pacific Conference on Antennas and Propagation, Aug. 2012, pp. 21–22, doi: 10.1109/APCAP.2012.633128.

[20] I. Jafri, R. Saleem, M. Shafique, and A. Brown, “Compact reconfigurable multiple-input-multiple-output antenna for ultra wideband applications,” *IET Microw. Antennas Propag.*, vol. 10, pp. 413–419, Mar. 2016, doi: 10.1049/iet-map.2015.0181.
[22] T. Shabbir, R. Saleem, M. Bilal, and M. F. Shafique, “UWB-MIMO doublet with split decoupling structure and defected grounds,” in 2017 IEEE MTT-S International Conference on Numerical Electromagnetic and Multiphysics Modeling and Optimization for RF, Microwave, and Terahertz Applications (NEMO), May 2017, pp. 40–42, doi: 10.1109/NEMO.2017.7964180.