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Design and Analysis of Compact MIMO Antenna for UWB Applications with Reduced Mutual Coupling

Prabhdeep Singh*

India Meteorological Department, India

***Corresponding Author:**
Prabhdeep Singh, India Meteorological Department, India.

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Abstract
A novel, compact multiple-input-multiple-output (MIMO) antenna design, occupying a mere 25 × 39 mm², is proposed for ultra-wideband (UWB) applications. This innovative antenna comprises dual square-shaped radiating elements and a modified T-shaped stub, incorporating a vertical slot to mitigate mutual coupling. Key performance metrics, including impedance matching, inter-port mutual coupling, voltage standing wave ratio (VSWR) and correlation coefficient, are scrutinized. Simulation outcomes reveal an impressive impedance bandwidth spanning 2.5 to 11.8 GHz ($S_{11} \leq$ -10 dB), accompanied by an exceptionally low envelope correlation coefficient (<0.002) across the entire frequency spectrum. Notably, inter-element isolation exceeds -23 dB throughout the operational band. The proposed UWB MIMO antenna efficiently covers prominent frequency bands, encompassing WCDMA, WLAN, WiMax and UWB, making it an attractive solution for multi-standard wireless communication systems.

Keywords: Band Notch, Multiple-Input-Multiple-Output (MIMO) and Ultra-Wideband (UWB) Applications

Introduction:
Ultrawideband (UWB) technology has garnered significant attention due to its exceptional data transmission rates and low spectral power density. The Federal Communications Commission (FCC) allocated the 3.1-10.6 GHz frequency band for unlicensed UWB communication in 2002, ensuring minimal interference with existing wireless systems. Key regulations include a frequency range of 3.1-10.6 GHz, an emitted power limit of -41.3 dBm/MHz (75 nW/MHz) and measures to prevent interference.

UWB technology offers several advantages, notably enhanced immunity and reduced vulnerability to interference via Power Spectral Density (PSD), increased channel bandwidth boosting data transmission capacity and low power consumption minimizing interference and environmental impact. High-speed data transfer supports advanced wireless applications. UWB technology's unique benefits make it suitable for wireless local area networks (WLANs), wireless personal area networks (WPANs) and radar systems. Research focuses on enhancing UWB performance, security and integration with emerging technologies.

Ultra-wideband (UWB) systems leverage vast bandwidths to achieve high data rates. To further enhance reliability, Multiple-Input Multiple-Output (MIMO) technology exploits diversity gain to mitigate fading countermeasures. MIMO's fundamental principle involves utilizing multiple antenna elements to transmit or receive signals with distinct fading characteristics. Combining these signals boosts system reliability as they experience disparate fading effects. However, UWB communication systems are susceptible to multipath fading. MIMO technology addresses this issue by employing multiple transmitting and receiving antennas to provide multiplexing and diversity gains. These gains significantly reduce multipath fading and increase transmission capacity.

Despite its benefits, MIMO implementation faces challenges. Strong mutual coupling arises when multiple antennas occupy small spaces. To combat this, decorrelating antenna patterns minimizes mutual coupling. Enhancing isolation between MIMO antenna access ports is crucial. MIMO implementation methods include beamforming, spatial multiplexing and diversity techniques.

Effective isolation techniques for narrowband MIMO antennas encompass:

- Parasitic components for reverse coupling.
- Electromagnetic Band-Gap (EBG) structures to suppress surface wave propagation.
- Protruded grounds between antennas.
- Decoupling and Matching Networks using Defected Ground Structure (DGS).
- Stub insertion into grounds.

These innovative approaches optimize MIMO performance, overcoming spatial constraints and mutual coupling limitations.

Geometry and Design of the Proposed MIMO Antenna

Figure 1 illustrates the compact geometry of the proposed Multiple-Input Multiple-Output (MIMO) antenna. The design features two square-shaped elements, PM1 and PM2, occupying a mere 8×8 mm² area. Leveraging the advantages of single-patch antennas—compact size and wide impedance bandwidth—the proposed geometry ensures optimal performance. UWB monopole antenna radiators can assume various shapes (rectangular, circular or elliptical) without significant performance differences. However, radiator size is critical to achieve low resonance and a cutoff frequency below 3.1 GHz. Consequently, size optimization poses a significant design challenge. In contrast, achieving ultra-wide bandwidth is relatively straightforward, employing techniques such as ground slotting, adjusting ground-radiator spacing and optimizing feed line dimensions.

The proposed MIMO antenna (Figure. 1) incorporates square-shaped radiators for simplicity. A T- shaped ground stub enhances antenna matching, while a vertical ground slot ensures improved isolation between input ports. Symmetrical architecture ensures identical impedance at both ports, simplifying design by enabling single-port excitation. The MIMO antenna was designed using ANSYS HFSS software on Rogers R3203 substrate ($\mathcal{E}r$ = 3.02, loss tangent = 0.004, thickness = 1.6 mm). Design specifications are outlined in Table I.

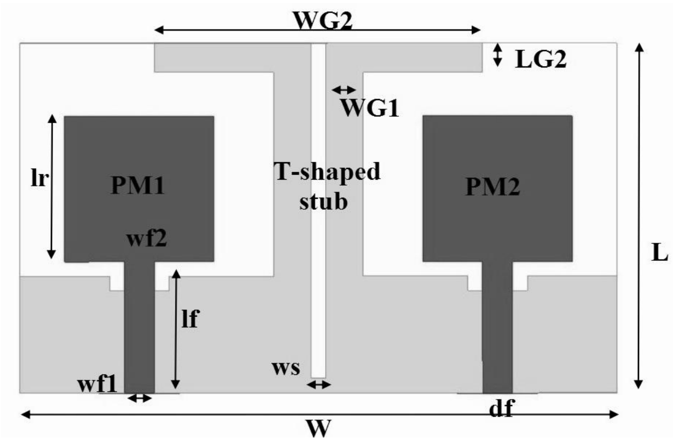

Figure 1: Geometry of Proposed Antenna (Dark Gray: Top Side, Light Gray: Bottom Side)

WG1	2.5
WG2	22
LG2	2
lr	8
lf	9
wf2	2
df	6
wf1	2
ws	1
W	39
L	25

Table 1: Dimensions of Proposed Antenna (Unit: Mm)

Study of MIMO Antenna

The T-shaped ground stub in the proposed MIMO antenna (Figure. 1) serves two crucial functions: enhancing antenna matching and improving inter-element isolation by reflecting radiation. Its compact T-shape maintains antenna size while acting as a reflector. Key benefits include creating a resonance at 3 GHz, lowering the low-cutoff frequency to 2.3 GHz, and significantly suppressing mutual coupling (S21) at high frequencies. The ground slot on the T-shaped stub

(Figure. 1) plays a vital role in enhancing isolation. Simulation results (Figure. 2) demonstrate notable improvements in S-parameters. With the ground slot, impedance matching (S11) and isolation (S21) are significantly enhanced. In contrast, removing the ground slot compromises matching and isolation.

Due to the antenna's symmetrical structure, S22 and S12 mirror S11 and S21, respectively. Thus, Figure. 2 only displays S11 and S21. These design insights underscore the T-shaped ground stub's efficacy in enhancing matching and isolation. The proposed MIMO antenna's simulated performance validates its potential for ultra-wideband applications. Future research directions include exploring material variations and substrate thickness impacts.

It can be seen that the simulated impedance bandwidth (for S11 <−10 dB) of the antenna with and without the ground slot doesn't differ much and is from 2.5 GHz to more than 11 GHz. Be that as it may, without utilizing the ground slot, the mutual coupling between the two input ports of the antenna is greater than −22 dB (i.e., S21 > −22 dB) in the frequency underneath 3 GHz, which is not sufficiently low for good execution. With the utilization of the ground space, a resonance at around 3.6 GHz is produced, letting S21 down to underneath −22 dB from 2.3 GHz to more than 12 GHz (which covers the whole UWB) as shown in Figure. 3.

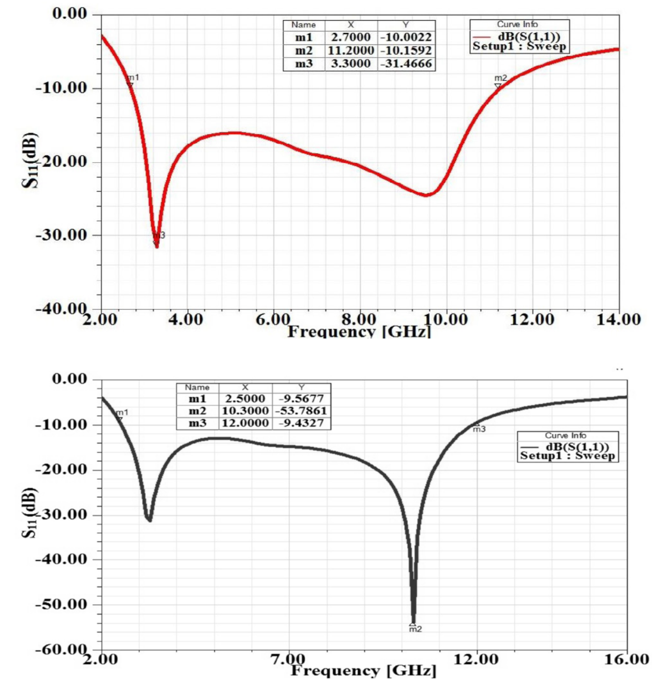

Figure 2: S11 Parameters of Antenna with and Without T-Shaped Ground Stub

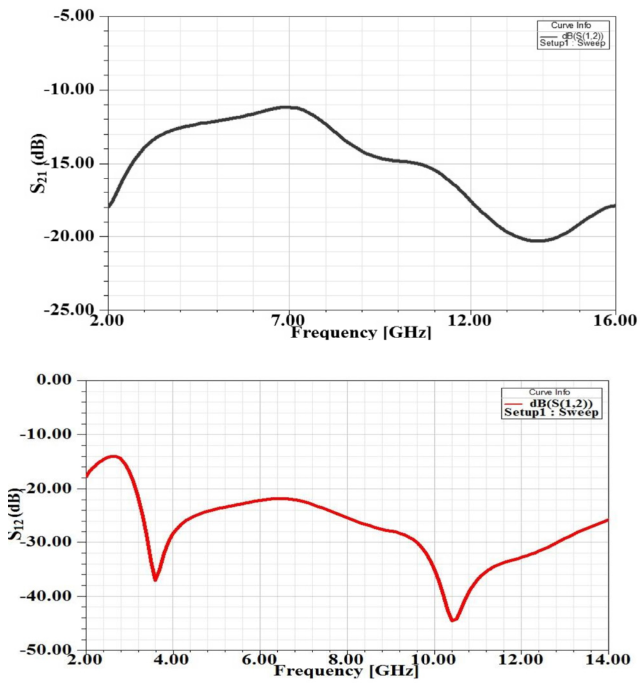

Figure 3: S12 Parameters of Antenna with and Without T-Shaped Ground Stub

Current distribution analysis highlights the ground slot's significant impact on isolation in the proposed MIMO antenna. Figure 3 illustrates this at 3.5 GHz, with port 1 excited and port 2 50- Ω terminated. Without the ground slot (Figure. 3a), strong currents flow from PM1 to PM2 and port 2 via the T-shaped stub, causing high mutual coupling. Introducing the ground slot (Figure. 3b) redirects currents to the left T-shaped section, substantially reducing currents coupled to PM2 and port 2. This optimization minimizes mutual coupling, enhancing isolation. The ground slot effectively mitigates electromagnetic interactions, ensuring improved ultra-wideband performance.

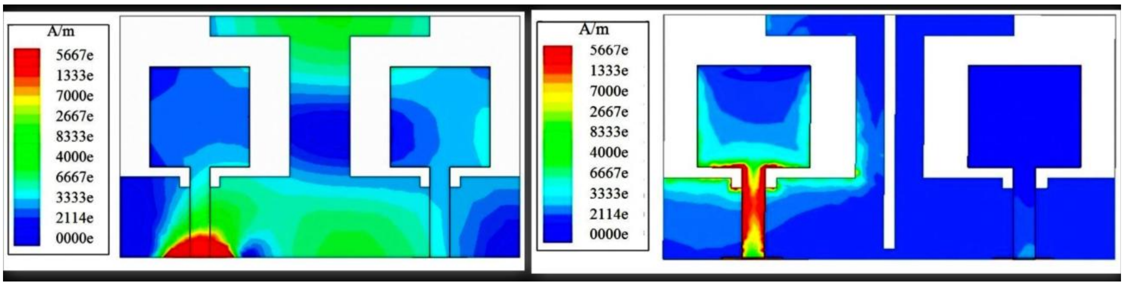

Figure 4: Current Distributions at 3.5 Ghz: (A) Without and (B) With Ground Slot

The proposed antenna boasts exceptional performance, characterized by a voltage standing wave ratio (VSWR) consistently below 2 across its operating band. This metric, dependent on return loss, signifies optimal impedance matching when VSWR is less than 2, corresponding to a return loss below -10 dB. Consequently, impedance matching approaches 100% efficiency, minimizing interference between wireless and ultra-wideband systems while ensuring signal integrity and transmission quality [1-7].

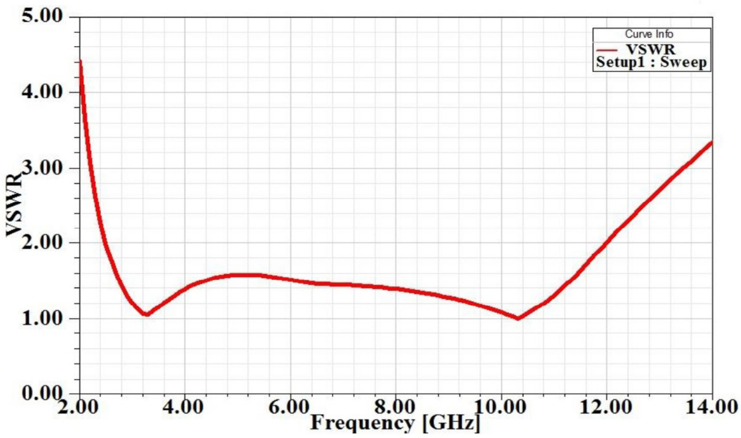

Figure 5: VSWR of Antenna

The diversity performance of the proposed MIMO antenna is rigorously evaluated through the envelope correlation coefficient, calculated from S-parameter equations. Notably, measured correlation coefficients remain below 0.06 across the entire ultra-wideband (UWB) spectrum [8-15]. This exceptionally low correlation between the two ports signifies outstanding diversity performance.

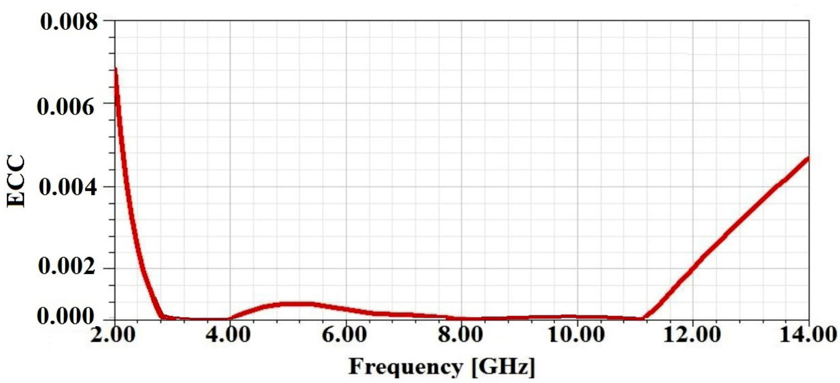

Figure 6: ECC of Proposed Antenna

Conclusions

A novel, compact Multiple-Input Multiple-Output (MIMO) antenna, tailored for ultra-wideband (UWB) applications, has been successfully designed. Measuring a mere 8×8 mm², this antenna ensures seamless integration. Its architecture boasts dual planar monopoles positioned oppositely for optimal isolation, flanked by long ground stubs and a connecting ground strip uniting two ground planes. Simulation results reveal impressive performance metrics. The antenna operates across the entire UWB spectrum (3.1-10.6 GHz), achieving mutual coupling below -16 dB and an envelope correlation coefficient under 0.001. These findings underscore its suitability for compact UWB applications leveraging pattern diversity. Key benefits include reduced size, excellent port isolation, minimal mutual coupling and optimal diversity performance. Potential applications encompass wireless communication systems, radar, sensor networks and portable devices. This MIMO antenna design exemplifies exceptional performance, rendering it an attractive candidate for space-constrained UWB applications. Its compact architecture and impressive metrics make it ideal for high-performance wireless systems.

References

1. Gautam, A. K., Yadav, S., & Kanaujia, B. K. (2013). A CPW-fed compact UWB microstrip antenna. *IEEE Antennas and Wireless propagation letters*, *12*, 151-154.
2. Nguyen, D. T., Lee, D. H., & Park, H. C. (2012). Very compact printed triple band-notched UWB antenna with quarter-wavelength slots. *IEEE Antennas and wireless propagation letters, 11*, 411-414.
3. Khater, E. E. M., & Ghouz, H. H. M. (2013). Novel Compact UWB MIMO patch antenna for 3G/4G Wireless Communication Applications. *International Journal of Engineering Research & Technology, 2*(10), 1295-1298.
4. Lee, J. M., Kim, K. B., Ryu, H. K., & Woo, J. M. (2012). A compact ultrawideband MIMO antenna with WLAN band-rejected operation for mobile devices. *IEEE Antennas and wireless propagation letters, 11*, 990-993.
5. Kim, J., Yoon, T., Kim, J., & Choi, J. (2005). Design of an ultra-wide-band printed monopole antenna using FDTD and genetic algorithm. *IEEE Microwave and Wireless Components Letters, 15*(6), 395-397.
6. Liang, J., Chiau, C. C., Chen, X., & Parini, C. G. (2005). Study of a printed circular disc monopole antenna for UWB systems. *IEEE transactions on antennas and propagation, 53*(11), 3500-3504.
7. Xu, K., Zhu, Z., Li, H., Huangfu, J., Li, C., & Ran, L. (2013). A printed single-layer UWB monopole antenna with extended ground plane stubs. *IEEE Antennas and Wireless Propagation Letters, 12*, 237-240.
8. Liu, L., Cheung, S. W., & Yuk, T. I. (2013). Compact MIMO antenna for portable devices in UWB applications. *IEEE transactions on antennas and propagation, 61*(8), 4257-4264.
9. Bod, M., Hassani, H. R., & Taheri, M. S. (2012). Compact UWB printed slot antenna with extra bluetooth, GSM, and GPS bands. *ieee antennas and wireless propagation letters, 11*, 531-534.
10. Jusoh, M., Jamlos, M. F. B., Kamarudin, M. R., & Abd Malek, M. F. B. (2012). A MIMO antenna design challenges for UWB application. *Progress In Electromagnetics Research B, 36*, 357-371.
11. Ojaroudi, M., Ghanbari, G., Ojaroudi, N., & Ghobadi, C. (2009). Small square monopole antenna for UWB applications with variable frequency band-notch function. *IEEE Antennas and Wireless Propagation Letters, 8*, 1061-1064.
12. Gallo, M., Antonino-Daviu, E., Ferrando-Bataller, M., Bozzetti, M., Molina-Garcia-Pardo, J. M., & Juan-Llacer, L. (2011). A broadband pattern diversity annular slot antenna. *IEEE Transactions on Antennas and propagation, 60*(3), 1596-1600.
13. Behdad, N., & Sarabandi, K. (2005). A compact antenna for ultrawide-band applications. *IEEE Transactions on Antennas and Propagation, 53*(7), 2185-2192.
14. Ahmed, O., & Sebak, A. R. (2008). A printed monopole antenna with two steps and a circular slot for UWB applications. *IEEE Antennas and Wireless Propagation Letters, 7*, 411-413.
15. Zhang, S., Lau, B. K., Sunesson, A., & He, S. (2012). Closely-packed UWB MIMO/diversity antenna with different patterns and polarizations for USB dongle applications. *IEEE Transactions on Antennas and Propagation, 60*(9), 4372-4380.