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ANALYSIS OF A NOVEL COMPACT ULTRA-WIDE BAND MULTIPLE-INPUT MULTIPLE-OUTPUT ANTENNA

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Keywords:

far field, MIMO, channel capacity, voltage standing wave ratio, radiation efficiency, and impedance matching.

ABSTRACT

A compact six-port Multiple-Input Multiple-Output (MIMO) antenna that operates in the whole license-free Ultra-Wideband (UWB) spectrum of 3.1–10.6 GHz is shown in this research study. The six antennas are arranged in a way that allows for spatial variety. Conventional rectangular patch UWB antennas make up the antenna elements. This innovative MIMO antenna took into consideration and addressed the four main issues with antennas: low radiation efficiency, high mutual coupling, low impedance, and poor voltage standing wave ratios (VSWR). The microstrip patch approach was used in a Computer Simulation Technology (CST) environment to build the antenna. The antenna substrates were designed and all simulations were carried out using CST. The patch antenna material is copper, and the antenna's ground plane is FR-4 for the substrate design. The antenna has a 50-impedance feedline and measures 30 x 25 x 0.3 mm. After the performance characteristics of the antenna were examined, the S-parameters showed a broad frequency response ranging from 3.1 to 10 GHz. With a radiation efficiency of less than -1dB (68%) over the frequency range, the system as a whole loses less power than is absorbed, making it extremely dependable. The system can have a positive maximum reflection since the antenna's VSWR is more than 1 and less than 2. As a result, this architecture works well for communication systems that need to transmit signals quickly and effectively.

I.INTRODUCTION

MIMO (Multiple-Input Multiple-Output) technology has become a rapidly developing technology that can increase the capacity and quality of a network by providing multiplexing gain and diversity gain respectively [1] and [2]. When paired with MIMO technology, the UWB system can give data speeds of up to 100 Mbps 1Gb/s [3] and [4]. Because UWB systems have a bandwidth of up to 7.5GHz, UWB MIMO technology plays an important part in today's wireless communication system, effectively increasing receiver signal capturing capacity by adding signals from different paths and instances; making the antennas work smart. These smart antennas use spatial diversity technology where spare antennas are put to good use.

Multiple-Input Multiple-Out (MIMO) system employs improved transmission quality and system capacity, numerous antenna elements are used at both the transmitter and receiver, thus [5] defined MIMO as a wireless system that employs 2 or more transmitters and receivers to send and receive more data at once. For instance, the 5G base station can support over a hundred ports with each array accommodating much more antennas capable of sending and receiving signals from as many users at a time, thereby increasing the mobile capacity [5]. In other words, MIMO solves the multipath-fading problems in UWB systems. MIMO technology can send transmitted messages to the receiver repeatedly because of signal reflections from walls, ceilings etc. [6]. It increases spectrum efficiency while maintaining bandwidth and power consumption.

According to [7], the research paper introduced a unique UWB MIMO antenna. The use of various types of antenna elements has resulted in great isolation without the use of a decoupling structure. A ground stub was placed between the two antenna parts, and a slot line transition was added to improve impedance matching between them. The suggested antenna has an impedance bandwidth that covers the whole UWB band and isolation of less than 18dB (according to the simulation and measurement data). A tiny ultrawideband (UWB) multiple-input-multipleoutput (MIMO) antenna with good isolation was developed where a rectangular monopole antenna and a slot antenna fed by two microstrip lines are used in their MIMO antenna. The antenna's desirable performance is confirmed by simulation and measurement, which reveals a wide impedance bandwidth of 3.1–10.6GHz.

According to [8], two diverse UWBMIMO antennas with stepped impedance resonators were presented. The UWBMIMO antennas were designed to offer a wide bandwidth ranging from 3.1GHz to 10GHz. To achieve high isolation, a sleeve-connected rectangle stepped impedance resonator (R-SIR) and a sleeve roundness stepped impedance resonator (RD-SIR) were used in the ground plane. This article investigates and discusses return loss, isolation, and radiation patterns.

The paper presents two printed ultrawideband (UWB) antennas with stepped impedance resonators for Multiple Input Multiple Output (MIMO) communication applications. Two simply printed microstrip-fed monopole antennas make up the MIMO antenna. On the ground plane, sleeve-coupled rectangular stepped impedance resonator (R-SIR) and sleevecoupled roundness stepped impedance resonator (RD-SIR) are used to provide high isolations.

According to [9], the S-parameter, gain, radiation patterns, and ECC of a small UWB were examined in the MIMO design and the findings meet the specification for UWB transmission. A Y-shaped notch in the ground plane of the antenna improved the isolation between the antennas. It also reduced the multipath fading caused by reflection and refraction in MIMO systems by improving inter-port isolation and lowering ECC in portable UWB systems such as satellites, radars, sensors, and wireless communications. The performance parameters of this antenna were studied in terms of reflection coefficient, transmission coefficient, radiation pattern, and peak gain.

In the work of [10], a compact dual-band Multiple Input Multiple Output (MIMO) antennae with good isolation for WLAN and X-band satellite applications. The MIMO antenna has strong isolation (S21 22.5dB) at the two target bands, with impedance bandwidths of 4.15% (5.19– 5.41GHz) and 4.81% (7.30–7.66GHz), according to the simulation results. The envelope correlation coefficient (ECC), diversity gain (DG), Total Active Reflection Coefficient (TARC), realized gain, and efficiency was also studied.

A dual-band MIMO antenna with good performance and a compact size of 2721mm2 was shown in this research. For WLAN and X-Band satellite applications, the compact MIMO antenna was constructed with one rectangular Defected Microstrip Structure (DMS) slot on the upper layer and two symmetrical rectangular Defected Ground Structure (DGS) slots on the ground plane. The measured findings demonstrate that this antenna spans two frequency bands suitable for wireless applications, 5.09– 5.29 and 7.38–7.87GHz. Using orthogonal polarization, a high isolation of roughly 19dB in both frequency ranges was achieved.

According to [11], a modern vehicle communication system was designed and analyzed, a planar ultra-wideband (UWB) multiple-input-multiple-output (MIMO) antenna. The suggested unit cell antenna structure was created using modified elliptical radiators on a Rogers RO3003 substrate with dimension 22220.76mm3 having an impedance bandwidth (S11 10) of 3.14 GHz to 12.24 GHz. The unit cell prototype's max gain and efficiency are 5.1dB and 81%, respectively. Later, the unit cell evolves into a MIMO antenna configuration with four orthogonal elements positioned in a plane of 50500.766 mm3. More than 20dB of isolation was recorded between the antenna elements. The MIMO antenna's measured Envelope Correlation Coefficient (ECC) was less than 0.004 and its Diversity Gain (DG) was greater than 9.67dB.

The works of [12] analyzed the standard rectangular microstrip patch antenna and the effects of utilizing Defected Ground Structure (DGS), which consists of a Complementary Split Ring Resonator (CSRR) and Complementary Split-Ring Resonator with Dumbbell (CSRR-D) structures, on electrical size, percentage bandwidth, efficiency, directivity, and gain for the rectangle microstrip patch antenna are explored. The result of their research demonstrates that while both DGS-based antennas were investigated to reduce the electrical size, they also reduce gain due to poorer directivity when compared to the reference antenna due to back radiation induced by the faulty ground design. The DGS antenna with CSRR-D gave better Electrical Size Reduction (ESR) but lower gain values than the antenna with DGS with CSRR.

According to [12], for rectangular microstrip antennas, the effects of defected ground structures (DGS) constitute a Complementary Split Ring Resonator (CSRR) and a CSRR with Dumbbell (CSRR-D) were explored. Their aim was to compare the usual rectangular patch antenna, Antenna A with two different antennas; Antenna B with CSRR etched DGS and Antenna C with CSRR-D etched DGS. CSRR structures are etched in the same position as the ground planes in Antenna B and C. Antenna D on the other hand is a regular microstrip antenna with the same resonance frequency as Antenna C. The resonance frequencies, voltage standing wave ratios, percentage bandwidths, gains, ka values, and gain radiation patterns are examined.

II.MATERIALS AND METHOD

When radiation power drops, it reduces the radiation efficiency of the antenna and thus causing the Voltage Standing Wave Ratio to have a negative reflection. Also, Poor impedance matching in antennas can lead to inefficiency of the antenna and high Voltage Standing Wave Ratio (VSWR) and this usually results in delayed transmission of signals as well as poor output and interference in data transfer. Though the design of the large size of antennas can affect their propagation characteristics, they are very expensive and take up much space

Design of the 6-Element UWB Mimo Compact Antenna

The study covers the design of the substrates, the design of the ground plane, the design of the antenna elements as well as the design of the microstrip ports of the antennas. This MIMO design comprises only six-element UWB antennas. All designs, simulations and analyses are carried out on the Computer Simulation Tool (CST) software. In designing the antenna, CST considers certain parameters like the substrate length (L), substrate width (W), substrate thickness (Th), etc. where;

$$L = \frac{c}{2f_r\sqrt{\varepsilon_r}}$$

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

Where $f_r = 3.1$ GHz, $\varepsilon_r = 4.3, L = 38\ mm, W = 51\ mm$

So that the length and width of the ground plane are.

$$g_l = \frac{L}{3}$$

$$g_w = W$$

Then, the width and length of the microstrip antenna on the substrate can be defined as;

$$p_w = \frac{W}{2} \quad (5)$$

$$P_l = \frac{L}{2} \quad (6)$$

Table 1: Design Parameters of the Compact UWB MIMO Antenna System.

Dimension	Value
Substrate width (mm)	30
Substrate length (mm)	25
Ground width (mm)	30
Ground length (mm)	7.5
Ground thickness (mm)	0.3
Patch width (mm)	15
Patch length (mm)	12.5
Feed line length (mm)	30
Feed line width (mm)	2.5
Substrate thickness (mm)	3
Patch/Feed line thickness (mm)	0.5

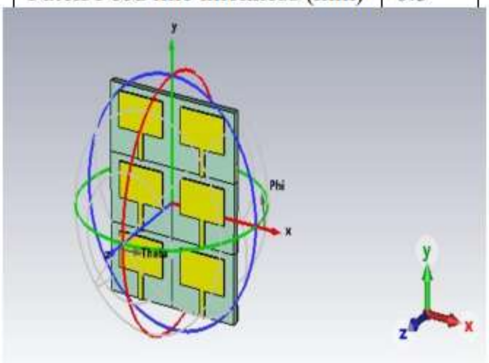

Fig. 1: 3D View of the Six Elements Array MIMO Antenna

The antenna operates on a functional bandwidth of 3.1GHz and 10.6GHz while the antenna's dimension is 30×25×0.3mm3 . The FR-4 (εr = 4.3) substrate is used. The distance between the radiator and the ground plane has a significant impact on the monopole's impedance bandwidth. A parasitic stub between the monopole and slot antenna is introduced for bandwidth extension and better isolation. The fundamental resonant frequency can be found in the original monopole antenna construction by [7] and [13], where:

$$f_r = \frac{14.4}{l_1+l_2+g+\left(\frac{A_1}{2\pi l_1\sqrt{\varepsilon_{re}}}\right)+\left(\frac{A_2}{2\pi l_2\sqrt{\varepsilon_{re}}}\right)+\left(\frac{A_3}{2\pi l_3\sqrt{\varepsilon_{re}}}\right)+\left(\frac{A_4}{2\pi l_4\sqrt{\varepsilon_{re}}}\right)}$$

where l1, l2, l3, l4, l5, l6 are the ground plane and monopole antenna patch lengths and g is the distance between them. The areas of the ground plane and monopole antenna patch are A1 and A2, A3, A4, A5, and A6. εre= εr +1/2 is the eff ective dielectric constant. The slot antenna is designed based on [14]. Figure 2 shows a 6 elements array of the compact UWB antenna front view while the back view can be seen on figure 3

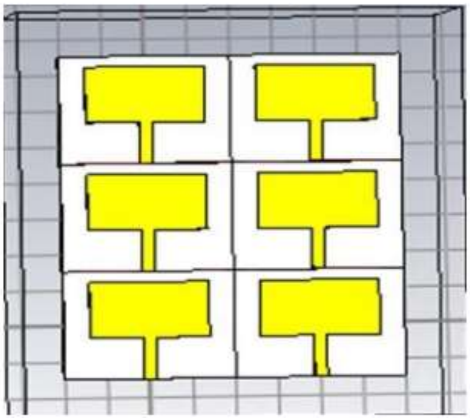

Fig. 2: Front View Six Elements Array Compact UWB MIMO Antenna.

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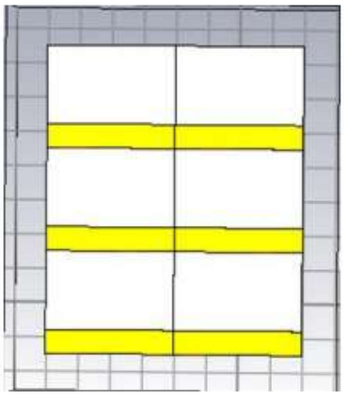

Fig. 3: Back View Six Elements Array Compact UWB MIMO Antenna.

The ground plane slot of the MIMO UWB antenna is designed to obtain an ultrawideband omnidirectional pattern, and a compact size for the antenna. The size of the antenna ground plane slot influences the impedance bandwidths of the antenna. The resonant frequency is influenced more by the slot. Increasing the length of the slot but not above half of the substrate will reduce the resonant frequency. Because the resonant frequency is inversely proportional to slot length, keeping the slot length at half or lower than the size of the substrate will result in better radiation efficiency of the UWB antenna

$$k \times S_h$$

where k= 5.21 and $S_h = 3mm$
Ports width= 6mm
Port height= 4mm
Dielectric properties, $\varepsilon_r = 4.3$.

MIMO Performance of Scattering Parameters

Certain measures such as Channel Capacity Loss (CCL), Envelope Correlation Coefficient (ECC), Diversity Gain (DG), and Total Active Reflection Coefficient are used to evaluate the diversity performance of MIMO antennas (TARC). CCL and ECC should be less than 0.5 for acceptable MIMO performance, whereas TARC should be less than 0dB. The relationship used to determine ECC, DG, and TARC according to [16-18] in equation 8 is thus;

$$ECC = \frac{|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}|^2}{(1-(|S_{11}|^2-|S_{21}|^2))(1-(|S_{22}|^2-|S_{12}|^2))} \quad (8)$$

When many antennas are actively participating in transmission or reception in MIMO systems, they affect each other, changing the total operating bandwidth and efficiency. TARC is a novel metric that incorporates the overall combined effect of all antennas in a MIMO system and its chevalier evaluated in Equation 9.

$$TARC = \sqrt{\frac{[illegible]}{6}} \quad (9)$$

Where S is the scattering parameter of the UWB MIMO compact antenna. The computed ECC value of the MIMO antenna system is related to Diversity Gain (DG) in equation 10.

$$DG = 10\sqrt{1-|E_{cc}|^2} \quad (10)$$

For each of the six antenna placement options, all of the parameters have values within the acceptable range. The suggested MIMO antenna has a CCL of less than 0.3 and an ECC of less than 0.2 ensuring diversity performance. TARC calculates the MIMO system's total match as an 8dB value. Other aspects of the antenna's system performance, such as radiation efficiency and peak gain, are also highlighted.

UWB MIMO Antenna Radiation Efficiency

The radiative efficiency of the antenna can be denoted as [19]:

$$E = \frac{P_{radiated}}{P_{input}} \quad (11)$$

Where ER is the antenna radiated efficiency $Pinput$ isthe input power and $Pradiated$ is the radiated power.

The total efficiency is thus;

$$E_T = M_L \times E_R \quad (12)$$

Where M_L is the mismatched loss.

Evaluation of the Voltage Standing Wave Ratio of the Antenna (VSWR)

The Voltage Standing Wave Ratio [20-24]:

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{1+p}{1-p} \quad (13)$$

$$V_{min} = V_{fwd} - V_{rev} = V_{fwd} - p^{v}{}_{fwd} = V_{fwd}(1-p) \quad (14)$$

$$V = V_{fwd} - V_{rev} = V_{fwd} - p^{v}{}_{fwd} = V_{fwd}(1+p) \quad (15)$$

Where pv is the forward peak voltage of the signal pv is the reverse peak voltage of the signal $vfwd$ is the forward voltage of the signal $vrev$ is the reverse voltage of the signal $vmax$ is the maximum voltage $vmax$ is the minimum voltage $(1 + p)$ is the positive forward voltage and $(1 - p)$ is the negative reveres voltage. The reflected wave and forward wave C□

- $Cr = -1$: When a line is short-circuited, maximum negative reflection occurs.

- $Cr = 0$: When the line is completely matched, there is no reflection.

- $Cr = +1$: When the line is completely matched, there is no reflection.

Only the magnitude of Cr, represented by p is important when calculating VSWR. As a result, we define [22-24]:

$$p = C_r \quad (16)$$

$$C_r = \frac{V_{rev}}{V_{fwd}} \quad (17)$$

In figure 4, the responses of each of the 6 elements antenna is seen, the curves from each of the radiating patterns of the antennas shows the wideband nature of the UWB MIMO antenna system and illustrates that the antenna spans the entire wide frequency range from 3.1GHz to 10GHz authenticating the system as an Ultra wideband antenna.

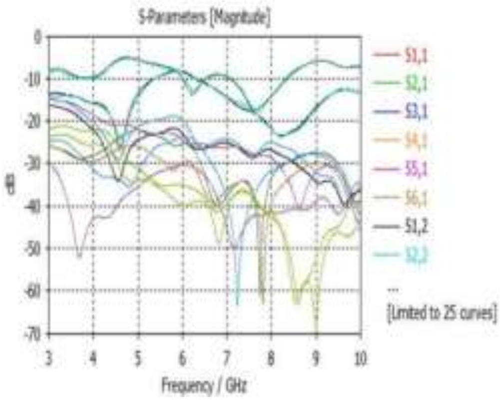

Fig. 4: The Six Elements Scattering Parameters of the UWB Antenna.

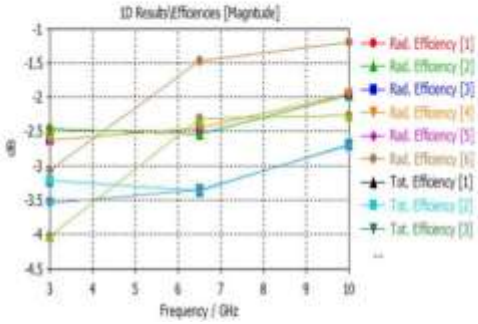

Fig. 5: Radiation Efficiency.

Figure 4. illustrates the radiation efficiency of the 6 element UWB MIMO antenna. The results show that the radiation of each of the antenna elements fall below -1dB from 3GHz to 10GHz. As the frequency increased uptimally, the magnitude of the S-parameters of the antenna reduced.

Far field Radiation Pattern of the UWB Antenna

Figure 5 shows the antenna's farfield radiation pattern at 3GHz, with a total efficiency of -3.221dB and a radiation efficiency of -2.471dB of the antenna which is approximately 60% efficiency. Figure 6 shows the far field radiation pattern at 6.5GHz with a -2.449dB radiation efficiency and -3.353dB total efficiency which is over 60% efficiency. Figure 7 illustrates the farfield radiation pattern at 10GHz with a -1.205dB radiation efficiency and -2.263.353dB total efficiency which is over 68% efficiency. Figure 8 shows the farfield directivity pattern of 3GHz, 6.5GHz and 10GHz respectively at PHI=0. Figure 9 described the features of the farfield directivity pattern of 3GHz, 6.5GHz and 10GHz at PHI=90

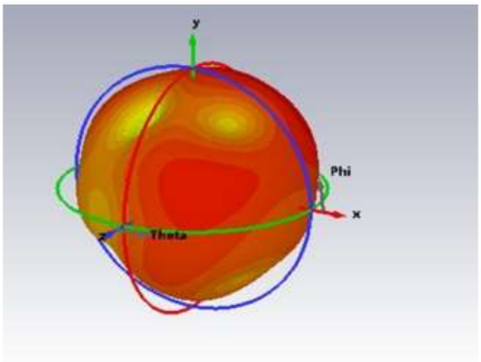

Fig. 6: Farfield Radiation at 3GHz.

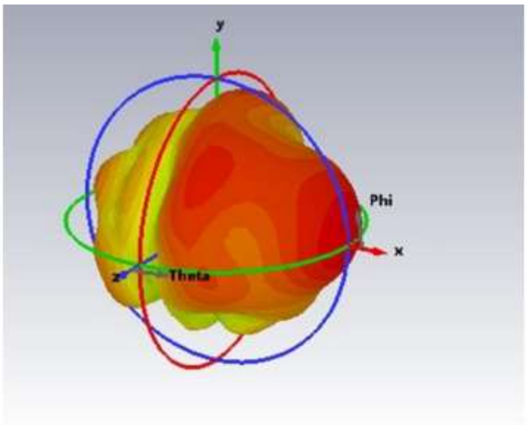

Fig. 7: Farfield Radiation of 6.5GHz.

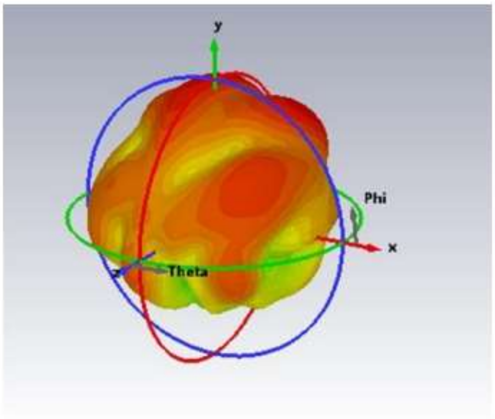

Fig. 8: FarField Radiation of 10GHz.

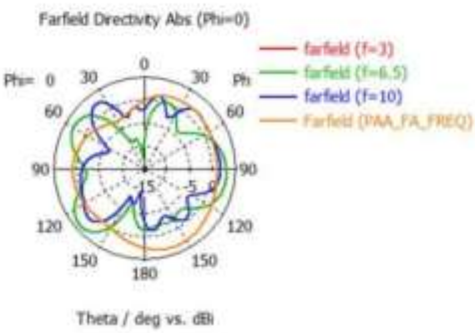

Fig. 9: Farfield Directivity at PHI=0.

Table 2: VSWR Comparative Analysis of the 6 Elements of the UWB MIMO Antenna.

S- Parameters	Return Loss	Reflection Coefficients	VSWR
S1,1	1	0.18	1.33
S1,2	2	0.16	1.33
S1,3	3	0.14	1.33
S1,4	4	0.13	1.33
S1,5	5	0.11	1.33
S1,6	6	0.10	1.72

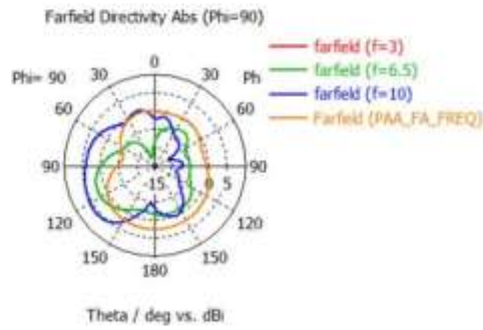

Fig. 10: Farfield Directivity at PHI=90.

Figure 10 represents the farfield pattern of the 3GHz, 6.5GHz and 10GHz respective radiation patterns at theta=90.

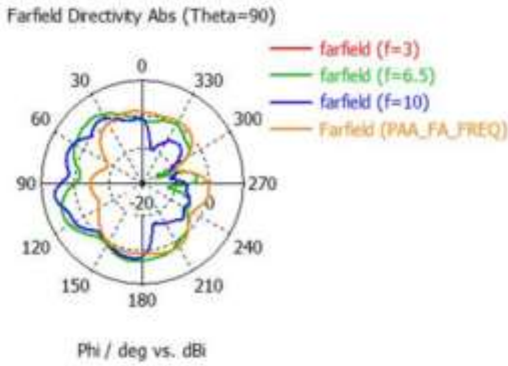

Fig. 11: Farfield Directivity at Theta=90.

Voltage Standing Wave Ratio of the Compact 6 array UWB Antenna

The Voltage Standing Wave Ratio of the 6 element UWB MIMO compact antenna is displayed below. Table 2 shows that the VSWR is less than 2 and greater than 1 in all the 6 radiated antenna and the VSWR results show maximum positive reflection satisfying the standard VSWR match.

Voltage Standing Wave Ration Comparative Analysis

It can be seen from the result in figure 10 that the Voltage Standing Wave Ratio of this compact six elements UWB antenna has a very good impedance matching, where the VSWR is lesser than 2.

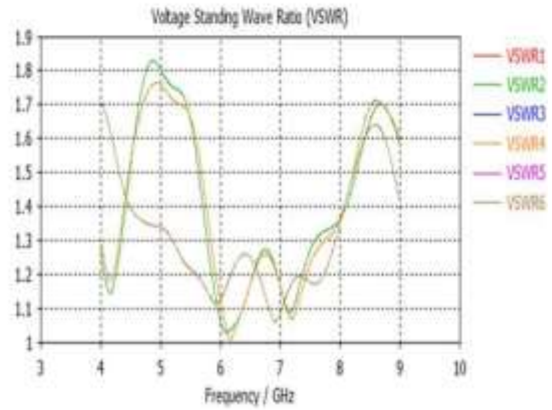

Fig. 12: VSWR of a 6 Element Array Compact UWB MIMO Antenna

III.CONCLUSION

This study resulted in the creation of a single-band, highly effective, tiny six-element UWB MIMO antenna array that measures only 30 x 25 x 0.3 mm. The fr-4 material serves as the antenna substrate, and copper is utilized for both the ground plane of the antenna and the microstrip patch. Six ports on the antenna patch were also created with the same specifications. This study examined the UWB MIMO antenna's radiation efficiency, far-field radiation pattern, voltage standing wave ratio (VSWR), and antenna feeding line impedance. The study also examined the antenna's radiating power, power losses, accepted power, and absorbed power. With a voltage standing wave ratio greater than 1 but less than 2, this research study has achieved a 60% radiation efficiency at 3GHz and a 68% radiation efficiency at 10GHz on a 50Ω impedance feedline.

The simulation program used to build the system and conduct all experimental simulations and analysis is called the Computer Simulation Tool (CST). This gadget is dependable, accurate, and quick. This suggests that it will be simple to build the MIMO. This small-sized UWB MIMO antenna is appropriate for wireless uses. In contrast to the traditional QUAD and dual UWB antenna systems, this research effort has provided a six-element UWB MIMO antenna system. The findings show that the six-element array may transmit signals in a variety of communication systems with effectiveness. It facilitates better communication and speeds up internet browsing. The six-element array has a radiation efficiency of 68% and a voltage standing wave ratio of less than 2. For communication systems, UWB MIMO antenna will be a superior substitute. The small UWB-MIMO is well suited for wireless applications and is simple to manufacture. This system is appropriate for high-speed transmission in WLANs and other communication applications. This upgraded UWB MIMO antenna has a higher voltage standing wave ratio, lower power consumption, and good efficiency.

REFERENCES

1. Abdalla, M. A., Wahba, W. W. & Allam, A. A. (2020). Analysis and design of a compact CRLH inspired—defected ground resonators for Triple band antenna applications. Engineering Science and Technology, an International Journal, 23(1), 114–122.

2. Imran, A. I., & Elwi, T. A. (2017). A cylindrical wideband slotted patch antenna loaded with frequency selective surface for MRI applications. Engineering Science and Technology, an International Journal, 20(3), 990–996.

3. Behdad., N., Li, M., & Yusuf., Y. (2013). A Very Low-Profile, Omnidirectional, Ultra wideband Antenna. IEEE Antennas Wireless Propagation Letters, 12, 280–283.

4. Aqeel, S., Jamaluddin, M., H., Khan, A.A., Khan, R., Kamarudin, M. R., Kazim, J. U. R., & Owais, O. (2016). A dual-band multiple input multiple output frequency agile antenna for GPSL1/Wi-Fi/WLAN2400/LTE applications. International Journal of Antennas and Propagation.

5. Vijetha, T., RamaKrishna, D., & Barath, K. (2023). Design and analysis of tri-band monopole ultra wide band (UWB) antenna. Telecommunications and Radio Engineering, 82.

6. Liu, P., Sun, Y., Liu, T., Li, Q., & Wang, X. (2020). Wideband 10-Port MIMO Antenna Array for 5G MetalFrame Smartphone Applications. Progress in Electromagnetics Research C, 104, 229-240.

7. Wu, Y., Ding, K., Zhang, B., Li, J., Wu, D., & Wang, K. (2018). Design of a compact UWB MIMO antenna without decoupling structure. International Journal of Antennas and Propagation, 2018.

8. Li, Y., Xing Li, W., Liu, C., & Jiang, T. (2012), Two UWB-MIMO antennas with high isolation using sleeve coupled stepped impedance resonators. In 2012 IEEE AsiaPacific Conference on Antennas and Propagation (p.p. 21-22). IEEE.

9. Avnish D. (2017). Design of a compact UWB- MIMO Antenna. IEEE Transaction on Antennas Propagation. 45(10), 2884–2887.

10. Dkiouak, A., Zakriti, A., & El Ouahabi (2020). Design of a Compact dual-band MIMO antenna with high isolation for WLAN and X-Band satellite by using orthogonal polarization. Journal of Electromagnetic Waves and Applications, 34(9), 1254-1267.

11. Arumugam, S., Manoharan, S., Palaniswamy, S. K., & Kumar, S. (2021). Design and Performance Analysis of a Compact QuadElement UWB MIMO Antenna for Automotive Communications. Electronics, 10(18), 2184

12. Kucukoner, E. M., Cinar, A., Kose, U., & Ekmekci, E. (2021). Electrical Size Reduction of Microstrip Antennas by Using Defected Ground Structures Composed of Complementary Split Ring Resonator. Advanced Electromagnetics, 10(1), 62-69.

13. Beniysa, M., Dkiouak, A., El Janati El Idrissi, A., Zakriti, A., & El Ouahabi, M. (2022, December). Design and Performance of a Compact Two Inset-Fed Patch MIMO Antenna for 5G Networks. In The 16th International Conference Interdisciplinarity in Engineering: Inter-Eng 2022 Conference Proceedings (pp. 828-835). Cham: Springer International Publishing.

14. Ali, A.M. & Jassim, A.K. (2022). Design UWB antenna with notch band for WiMAX application. Bulletin of Electrical Engineering and Informatics, 12(2), 815~821.

15. Yousef, B.M., Ameen, A.M., El Swiefy, B.H. & Arnous, R. (2023), A Compact Ultra-Wide Band Antenna with a Notched Band for Wireless Communication Systems. Progress In Electromagnetics Research Letters, 108, 31-39.

16. Nahas, M. (2022). Design of a highgain dual-band LI-slotted microstrip patch antenna for 5G mobile communication systems. Journal of Radiation Research and Applied Sciences, 15(4), 1-8. https://doi.org/10.1016/j.jrras.2022.1 00483.