

Design and development of CPW feed multiband antennas for modern wireless communication

Annu Tiwari, Dinesh Yadav, Muhammed Yasir Yilmaz, and Gaurav Kumar Soni

Abstract—The development of multiband antennas represents significant technological progress, addressing the challenges posed by increasing wireless communication standards. These antennas aim to achieve high performance, reliability, and adaptability across various frequency ranges. In today's world, where many devices and networks operate at the same time, these antennas work smoothly across different wireless standards and frequencies, providing better connectivity and flexibility. This article presents three different antenna designs for modern multiband wireless communication, all using the Rogers RT5880 substrate with a dielectric constant of 2.2 and a thickness of 0.508 mm. The overall size of each antenna is $30 \times 28.4 \text{ mm}^2$. Multiband antennas are crucial for meeting the demands of complex communication networks. This study compares three antennas with CPW (Coplanar Waveguide) feed based on their S-parameter analysis, gain characteristics, radiation patterns, and surface current distributions. The analysis shows that these antennas are optimized for higher frequency bands (5 GHz to 30 GHz), which suits the needs of modern wireless communication systems. Choosing the right antenna based on specific application requirements is essential. This research emphasizes the ongoing improvement of multiband antenna design with CPW feed to meet the changing needs of communication technology.

Keywords—Multiband; Modern Wireless Communication; High Frequency; Return Loss; Surface Current; Gain; CPW

I. INTRODUCTION

IN today's wireless technology, multiband antennas are essential as they offer a versatile solution to the challenges posed by limited spectrum capacity and bandwidth constraints [1-3]. These antennas can transmit and receive signals seamlessly across a broad range of frequencies, making them ideal for various applications, including mobile and satellite communication, radar systems, and wireless data transfer [4-6]. This is particularly important since various communication protocols typically operate within distinct frequency bands [7-8]. As a result, the adoption of a single broadband or multiband antenna has become popular, simplifying the antenna

requirements for multiple systems [9-10]. Additionally, the ever-expanding wireless communication landscape, including GPS, WiMAX, WLAN, GSM, DCS, PCS, UMTS, Bluetooth, and wireless LAN, has increased the demand for multiband antennas [11-12]. These antennas serve as a critical enabler, allowing mobile devices to navigate diverse frequency bands with ease, ensuring efficient and reliable communication across an array of systems and standards in this rapidly evolving wireless technology environment [13-15]. The emergence of multiband antennas in modern wireless communication stands as a significant leap forward in communication technology [10]. These antennas are meticulously designed to operate seamlessly across diverse frequency bands, addressing the multifaceted needs of contemporary wireless communication systems. In Fig. 1 shown that the advantages of multiband antennas.

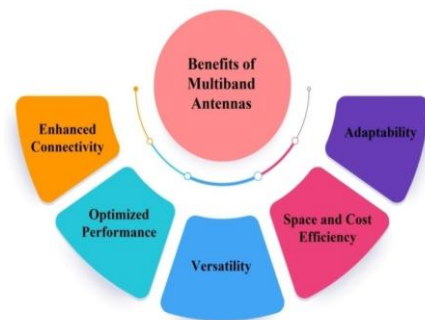


Fig. 1. Advantages of Multiband Antenna.

The advantages of employing multiband antennas encompass:

Enhanced Connectivity: Facilitating communication across various wireless standards and frequencies, ensuring uninterrupted connectivity across a spectrum of networks and devices.

Optimized Performance: Offering heightened signal quality and reliability, facilitating efficient transmission and reception of data across multiple bands concurrently.

Versatility: Capable of functioning across different frequency bands, rendering them adaptable for diverse communication applications, including Wi-Fi, Bluetooth, cellular networks, and other wireless systems.

Space and Cost Efficiency: Combining multiple functionalities within a single unit reduces the necessity for numerous antennas, thereby economizing space and cost in device designs.

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Adaptability: Engineered to evolve alongside communication standards and technologies, ensuring compatibility with forthcoming wireless communication systems.

The field of electromagnetic engineering and wireless communication systems is constantly changing, and finding antenna designs that can meet the complex demands of modern communication networks is a major challenge. Multiband antennas have become essential components in today's communication infrastructures because they can operate across a range of frequencies. This article examines three different antennas - Antenna 1, Antenna 2, and the most advanced, Antenna 3 - and compares their performance.

II. BASIC MULTIBAND ANTENNA DESIGN AND ANALYSIS

The design stages for the basic multiband antenna are shown in Fig 2. All dimensions shown in Fig 5 and their value in Table 2 are valid for Antenna 1, Antenna 2, and Antenna 3. The proposed CPW feed antenna structure is designed and has

an overall size of $30 \times 28.4 \text{ mm}^2$, as shown in Fig 5(a). It is situated on the x-y plane, with its normal direction parallel to the z-axis. The antenna is crafted on a Rogers RT5880 substrate with dielectric constant (ϵ_r) of 2.2, loss tangent ($\tan\delta$) of 0.0009, thickness of 0.508 mm and fed by a 50- Ω microstrip line. The feed line is optimized to a fixed length of 15 mm and has a gap of 0.25 mm from the ground.

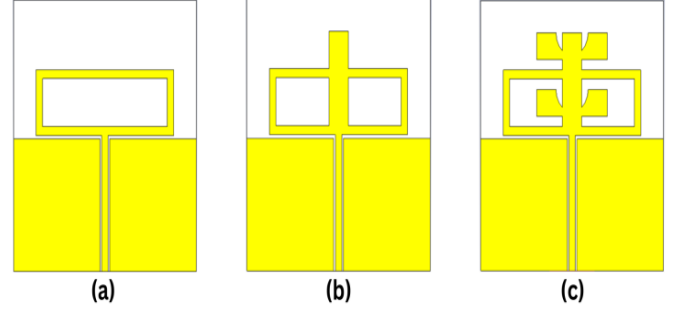


Fig 2. Evolution stages of basic multiband antenna. (a) Antenna 1. (b) Antenna 2. (c) Antenna 3

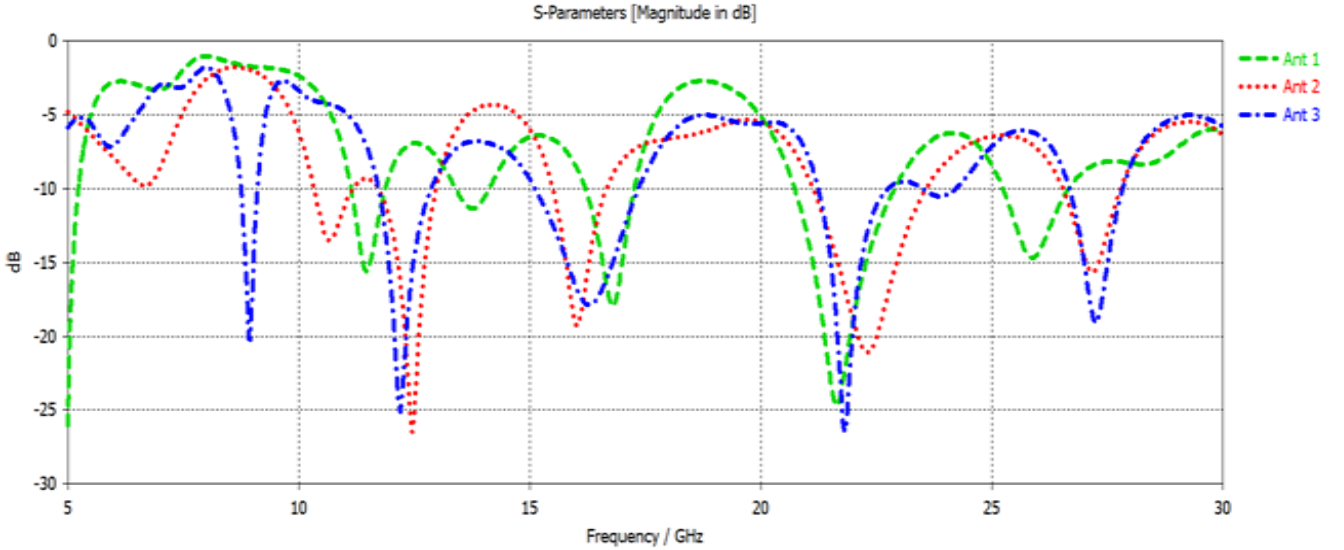


Fig 3. Comparing S-Parameter Results of Antenna 1, 2 and 3

S-parameters serve as crucial metrics for assessing the performance of multiband antennas within radio frequency systems. They delineate the antenna's behavior in terms of transmitting and receiving signals across diverse frequency bands. The data presented in Fig 3 compares the S-Parameter results for three different antennas. The S-Parameter values, represented by $|S_{11}|$, provide important insights into impedance matching and performance of each antenna. When analyzing the data, it becomes clear that Antenna 2 consistently has lower $|S_{11}|$ values across all tested frequencies, indicating superior impedance matching when compared to Antenna 1 and Antenna 3. Table 1 provides a more focused examination of $|S_{11}|$ and Gain values at the resonant frequencies of the three antennas. The data indicates that Antenna 2 not only achieves lower $|S_{11}|$ values but also exhibits higher Gain values at its resonant frequencies, highlighting its exceptional performance characteristics.

TABLE I.
S11 AND GAIN VALUES AT RESONANT FREQUENCIES OF ALL THREE ANTENNAS

Antenna	Frequency (GHz)	$ S_{11} $ (dB)	Gain (dB)
Antenna 1	11.47	-15.6	4.23
	16.8	-17.95	6.55
	21.65	-24.68	7.02
	25.88	-14.69	6.41
Antenna 2	12.45	-26.5	5.32
	16.03	-19.27	4.48
	22.3	-21.11	7.04
	27.18	-15.66	6.95
Antenna 3	8.94	-20.2	2.04
	12.18	-25.1	3.14
	16.23	-17.87	5.21
	21.81	-26.44	7.47
	27.27	-19.07	5.46

Fig 4 shifts the focus to showcase the frequency gain relationship for all three antennas. It reveals that as frequency increases, Gain tends to rise, indicating that these antennas are designed for enhanced performance at higher frequencies. Antenna 2 consistently outperforms the others in terms of Gain, making it an ideal choice for applications that demand superior signal amplification. Taking all the data into account, Antenna 2 emerges as the standout option with excellent impedance matching, higher Gain, and versatility across a range of frequencies. However, when selecting an antenna, it is important to consider specific application requirements, such as frequency range and desired performance traits, to guide the optimal choice. Antenna 3 stands out as it demonstrates resonance at five distinct frequencies, while Antenna 1 and Antenna 2 exhibit resonance at four frequencies each. This suggests that Antenna 3 may possess a broader operational bandwidth, making it versatile for applications requiring communication or signal reception across a wider range of frequencies. In contrast, Antenna 1 and Antenna 2, with resonance at fewer frequencies, may be more specialized for specific frequency bands. In the end, the selection among these antennas should be determined by the particular needs of the application.

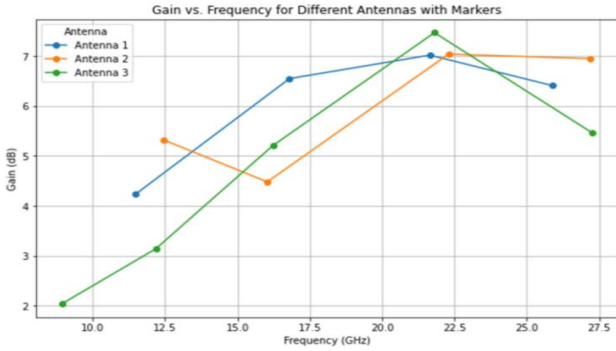


Fig 4. Frequency Gain line table for three antennas

This investigation is focused on analyzing the S-parameter characteristics of three antennas. S-parameters, also known as scattering parameters, are a set of complex coefficients used in electromagnetic engineering to describe how an electrical circuit or component, such as an antenna, interacts with external connections, typically through coaxial cables. These parameters quantify the relationship between the electromagnetic waves incident upon the component and the waves reflected and transmitted by it. In essence, S-parameters provide valuable information about the behavior and performance of the component under test within a specific frequency range [16]. This analysis lays the foundation for our comparative study, where we assess the gain performance of each antenna. The antenna's gain, which includes both its directivity and efficiency, is measured by comparing the intensity in a specific direction to the intensity that would result if the antenna's received power were uniformly distributed in all directions, referred to as absolute gain. This relationship is mathematically expressed as the ratio of power input to the antenna divided by 4π [17]. Furthermore, in this study delves into the electromagnetic field patterns of each antenna, examining their E-field and H-field distributions at resonant frequencies. This helps us understand the radiation

characteristics, polarization, and directivity exhibited by each antenna. Additionally, we investigate surface current distributions at resonant frequencies, which aid our comprehension of the operational principles underlying the performance of multiband antennas.

III. PROPOSED MULTIBAND ANTENNA DESIGN AND ANALYSIS

In this academic investigation, Antenna 3 is presented as the ultimate result of a continuous design process, incorporating the valuable knowledge gained from Antenna 1 and Antenna 2. This ultimate form symbolizes the integration of theoretical comprehension and practical creativity, providing a preview of what the future holds for multiband antenna design. In Fig 5 shown the proposed antenna design (Antenna 3) and its used parameters are shown in the Table 2.

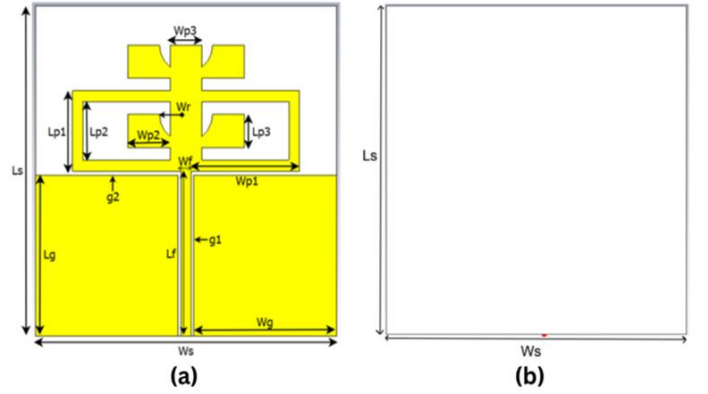


Fig 5. Antenna 3 Structure, Front Side (a), Back Side (b)

TABLE II.
USED PARAMETERS VALUE TO DESIGN THE PROPOSED ANTENNA (ANTENNA 3)

Parameters	Values (mm)
L_{p1}	7.3
L_{p2}	5.3
L_{p3}	3
W_{p1}	10.2
W_{p2}	4
W_{p3}	3
W_f	2.5
L_s	30
W_s	28
L_g	14.642
W_g	13.45
L_f	15
W_f	1
g_1	0.25
g_2	0.358

S-Parameter Analysis

Fig 6 displays S-parameter magnitude data expressed in decibels (dB) for a proposed antenna operating from 5 GHz to 30 GHz. The results demonstrate the antenna's impressive performance in terms of reflection coefficient (S11) at various frequencies, where all S11 values are below -10dB. This indicates well-matched impedance with the 50-ohm transmission line and efficient power radiation. Additionally, the antenna shows five resonant frequencies at 8.94 GHz, 12.18 GHz, 16.23 GHz, 21.81 GHz, and 27.27 GHz, covering communication bands like GSM, X-band, Ku-band, and Ka-

band. The antenna is achieved by switching its radiating elements, suggesting its potential for versatile multi-band and wideband applications. However, at lower frequencies like 5 GHz, the S-parameter magnitude shows moderate signal attenuation, while at higher frequencies like 8.94 GHz, 16.23 GHz, and 21.81 GHz. It indicates increased signal loss,

possibly due to resonant effects or impedance mismatches. Therefore, further analysis and potential tuning may optimize performance across the entire frequency spectrum.

Radiation Patterns

Fig 7 offers a detailed portrayal of the E-field and H-field patterns observed during Antenna 3's resonant frequencies. This visualization is crucial in understanding how the antenna interacts with electromagnetic fields during operation. By closely examining these patterns, we can obtain essential information about the antenna's radiation characteristics, including how it transmits and receives signals at critical frequencies. This analysis can be helpful in optimizing the antenna's placement and orientation for various applications, ensuring efficient transmission and reception of signals within the desired frequency range.

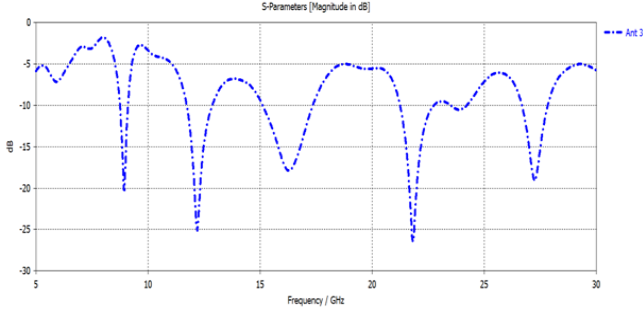


Fig 6. S-parameter magnitude data expressed in decibels for Antenna 3.

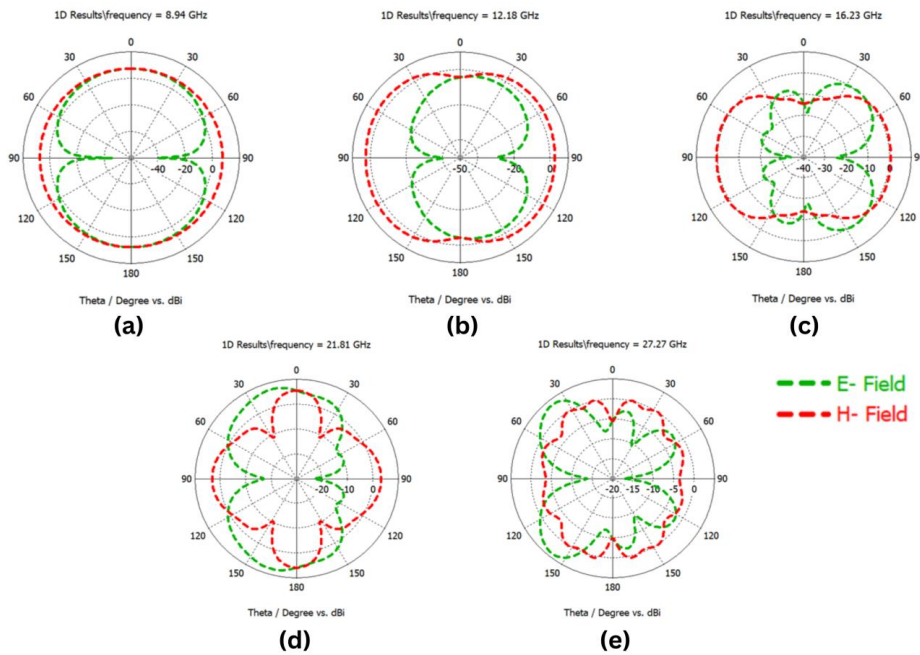


Fig 7. E-field and H-field Patterns for resonant frequencies for Antenna 3. (a) 8.94 GHz. (b) 12.18 GHz. (c) 16.23 GHz. (d) 21.81 GHz. (e) 27.27 GHz.

Surface Current Distributions

Surface current distributions within multiband antennas illustrate the paths and strengths of electrical currents traversing the antenna's surface. These distributions play a critical role in comprehending the antenna's functionality across diverse frequency bands, contributing to the enhancement of its performance attributes. The images in Fig 8 show an interesting representation of how surface currents are distributed at different resonant frequencies for Antenna 3. At 8.94 GHz, we see a concentration of current along the upper part of the inner wing, suggesting that this area is preferred at this particular frequency. As we move to 12.18 GHz, we see a shift in focus to the lower section of the rectangular wings, indicating a unique pattern of electromagnetic activity.

Similarly, at 16.23 GHz, the middle area beneath the rectangular wings shows an increase in surface current distribution, demonstrating the antenna's ability to adapt to specific frequencies. This pattern continues at 21.81 GHz, where the lower part of the rectangular wings becomes the favored location for surface current, highlighting the antenna's versatility across the electromagnetic spectrum. Finally, at 27.27 GHz, the middle section beneath the rectangular wings once again becomes prominent, showcasing the antenna's complex response characteristics. This Fig demonstrates the antenna's dynamic nature and its ability to adjust its electromagnetic interaction patterns according to changing frequencies, making it a valuable tool for various communication and signal reception applications.

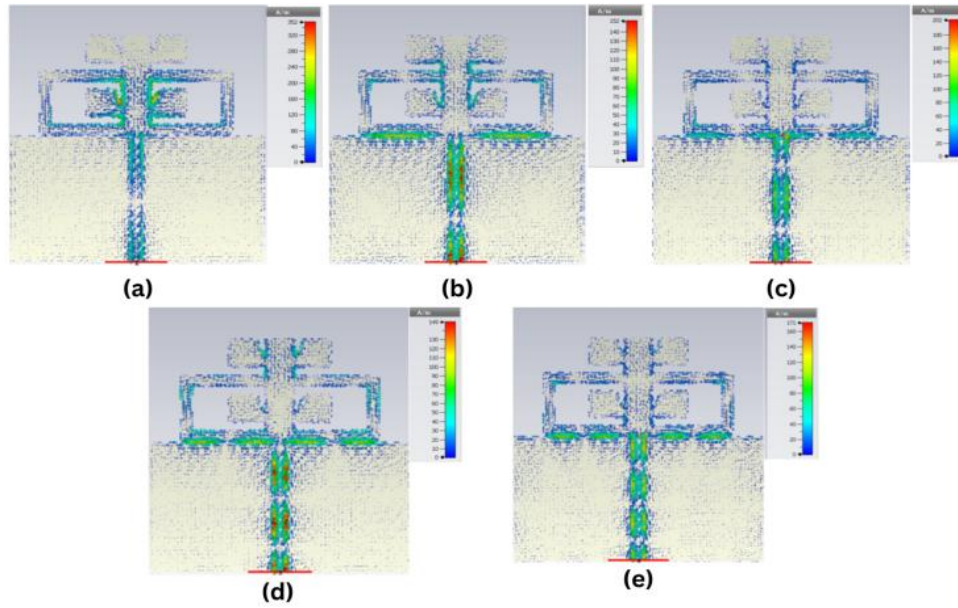


Fig 8. Surface current distribution for resonant frequencies for Antenna 3. (a) 8.94 GHz. (b) 12.18 GHz. (c) 16.23 GHz. (d) 21.81 GHz. (e) 27.27 GHz.

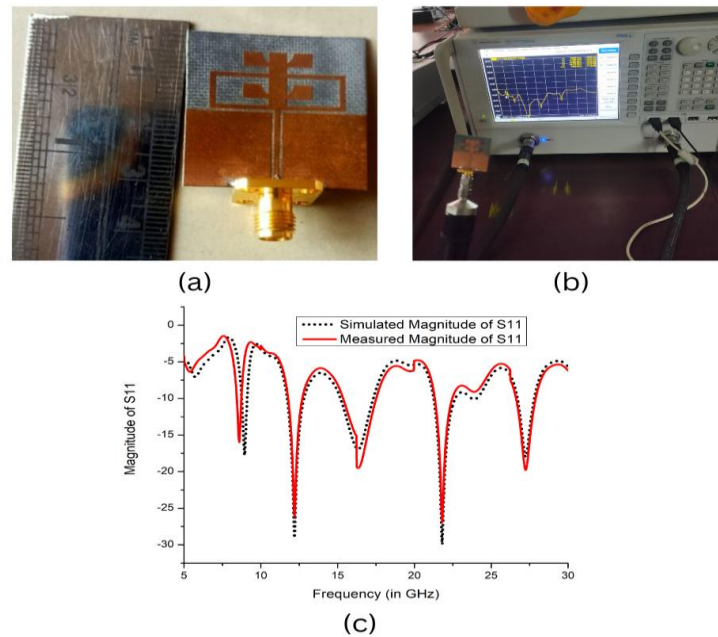


Fig 9. (a) Fabricated antenna design, (b) VNA measurement setup for return loss (S11) and (c) magnitude of S11: simulated and measured.

Furthermore, Fig 8 showcases the distribution of surface currents at various resonant frequencies for Antenna 3. The fact that these current distributions are dynamic highlights the antenna's capability to adjust to changing frequencies, thus making it an essential tool for various communication and signal reception situations.

In Fig 9, the following are shown: (a) the fabricated antenna design, (b) the VNA measurement setup for return loss (S11), and (c) the graphical representation of the magnitude of S11 for both simulated and measured values. Fig 10 illustrates the anechoic chamber setup used for measuring the radiation pattern.

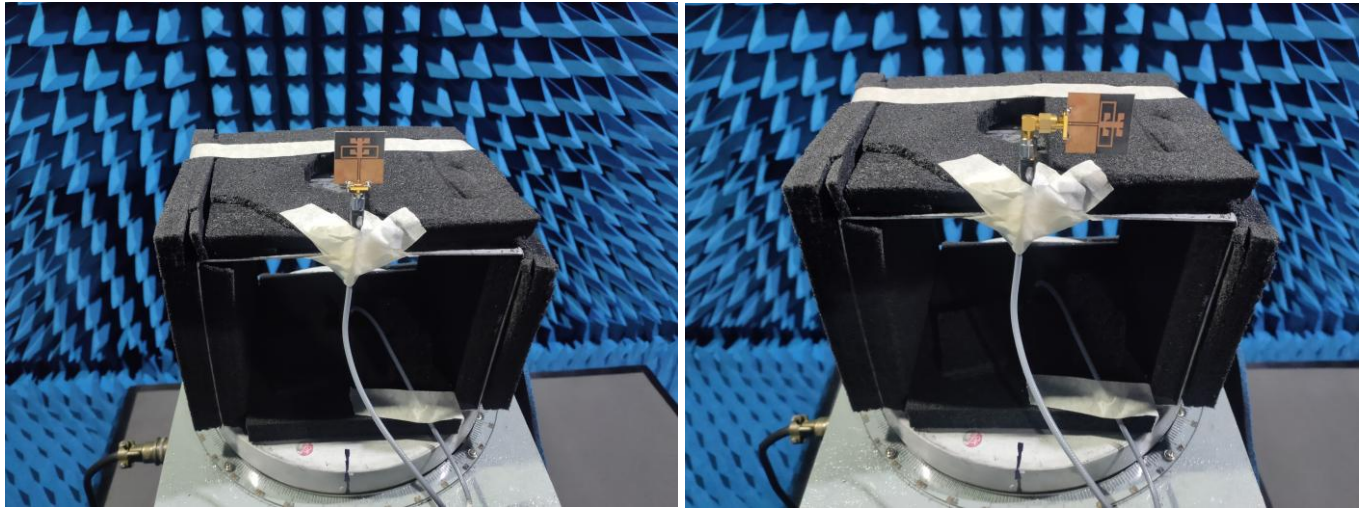


Fig 10. Antenna Measurement setup in aniconic chamber.

In table III represent the comparative analysis of the presented work with related with done by the different authors.

TABLE III
COMPARATIVE STUDY OF PRESENT WORK WITH OTHERS WORK

Ref No.	Frequency (GHz)	S ₁₁ (dB)	Gain (dBi)
[7]	26	-14.82	12.2
	28	-21.95	8.28
	29	-30.04	8.32
	30	-14.19	8.72
[18]	27	-12	5.49
	30	-11	5.23
	33	-15	5.83
[19]	26	-10	3.8
	28	-18.5	5.2
[20]	24	-23.9	4.5
	28	-25	12.5
Presented Work (Antenna 3)	8.94	-20.2	4.19
	12.18	-25.1	5.29
	16.23	-17.87	7.36
	21.81	-26.44	9.62
	27.27	-19.07	7.61

IV. CONCLUSION

Multiband antennas are essential in modern wireless communication, providing flexible functionality across various frequencies and standards. They ensure smooth connectivity, better performance, and flexibility within the dynamic wireless technology environment. In this study, three different antennas were designed using the Rogers RT5880 substrate with a dielectric constant of 2.2 and a thickness of 0.508 mm. All three antennas have the same overall size of 30×28.4 mm² and use a CPW feed.

After comparing Antenna 1, Antenna 2, and Antenna 3, found that each has unique strengths. Antenna 2 excelled in impedance matching and gain performance, making it ideal for applications requiring strong signal reception and amplification. Antenna 3 showed great versatility with its wide operational bandwidth and adaptable electromagnetic interaction patterns, making it suitable for various communication and signal reception needs. The best antenna choice depends on the specific application requirements, such

as frequency range and desired performance. These findings highlight the potential for further development of CPW feed multiband antenna designs in the evolving field of wireless communication technology. The analysis shows that these antennas are optimized for the 5 GHz to 30 GHz frequency bands, meeting the needs of modern wireless communication systems.

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