



A High-Efficiency Compact UWB Antenna with Modified Defected Ground Structure for Defense Applications

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Abstract: Modern defense communication and radar systems require a compact, wideband, and high-efficiency antennas those are capable of operating across multiple frequency bands. The paper presents the design and realization of a compact semi-circular ultra-wideband (UWB) microstrip antenna with a modified defected ground structure (DGS), consisting of a rectangular notch to enhance impedance bandwidth and radiation characteristics. The proposed antenna simulated in CST studio and also fabricated on FR-4 substrate of size $30 \times 15 \times 0.8 \text{ mm}^3$, providing a lightweight structure suitable for portable defense equipment and also in the radar system. The antenna operates within two broad frequency regions, 2.74-3.37 GHz and 5.62-20.07 GHz, covering portions of the S, C, X, and Ku bands widely used in radar, surveillance, and satellite communication systems. Structural modifications, including chamfered patch edges and a C-shaped slot, collectively improve the surface-current distribution, suppress surface-wave effects, and enhance the impedance bandwidth, resulting in two distinct operating bands of 2.74–3.37 GHz and 5.62–20.07 GHz, with fractional bandwidths of 20.62% and 112.5%, respectively, and a peak gain of 4.4 dB, and maximum simulated total efficiency of approximately 98%. The measured and simulated results show reasonable agreement, validating the antenna's ultra-wideband behavior and stable radiation performance. Due to its compact size, coverage across portions of multiple microwave bands, and high efficiency, the proposed antenna is a strong candidate for next-generation multi-band defense communication and sensing applications.

Keywords: Compact Antenna, Defense Systems, Defected Ground Structure, Multiband Communication, Ultra-Wideband (UWB).

1. Introduction

Ultra-Wideband (UWB) antennas with low cost, compact size, stable performance, and wide frequency operation are increasingly needed for present-day wireless and electronic systems. UWB antennas are useful in IoT, sensing applications, portable devices, wearable systems, and high-data-rate communication because they can operate over a wide range of frequencies. The demand for compact antennas has also increased because many modern electronic systems have limited space for antenna installation. Therefore, achieving wide frequency operation without increasing the antenna size is an important design requirement.

In modern defense environments, military operations use communication, radar, navigation, and surveillance systems for different purposes. The increased use of electronic and wireless systems in defense platforms creates a need for antennas with

small size, good reliability, and operation over more than one frequency band. Antennas are an important part of these systems because they support communication and help in monitoring the surrounding environment [1, 2]. Radar systems also require antennas with suitable bandwidth, gain, and radiation characteristics for signal transmission, reception, detection, and tracking. In these applications, a compact antenna capable of operating over more than one frequency band can be useful for reducing the space required by the antenna system.

For defense applications, an antenna needs wide impedance bandwidth, good gain, and stable radiation characteristics. However, reducing the antenna size can lead to changes in impedance matching, gain, and radiation efficiency. Hence, getting a small antenna with good performance is difficult. Therefore, maintaining good antenna performance while reducing its size is a challenge. The problem becomes more difficult when the antenna is required to cover several frequency bands. An antenna designed for a single

frequency band can be optimized more easily, whereas a wideband or multiband antenna requires proper control of the current distribution and resonant behavior. UWB antennas are particularly attractive for such applications because of their wide operating frequency range. The UWB frequency range used for communication applications is 3.1–10.6 GHz [3–6]. Among different antenna types, microstrip patch antennas are particularly attractive because of their planar configuration, lightweight structure, ease of fabrication, and ability to be integrated into compact platforms [7–9]. These features make them suitable for portable communication equipment and other space-limited systems. However, obtaining a wide bandwidth from a small microstrip antenna is not easy.

One method used to control the antenna response is the Defected Ground Structure (DGS). A DGS is formed by introducing a defect or modification in the ground plane. Although several UWB antennas and DGS-based designs have been reported, there is still a need for a compact antenna that combines wide frequency coverage, good efficiency, suitable gain, and a simple structure. Many reported antennas are designed for particular frequency ranges or applications, while some require larger dimensions or additional structures to obtain the required bandwidth. Different slotting, stub loading, and ground-plane techniques have been used to improve the frequency response. However, obtaining wide frequency coverage from the S-band to the Ku-band within a compact FR-4 antenna while maintaining good performance remains a challenge. The related literature survey is discussed in Section 2. The novelty of the proposed work is mainly based on the combination of a compact semi-circular radiator with a modified Defected Ground Structure, chamfered patch edges, and a C-shaped slot. The DGS consists of a rectangular notch that modifies the ground-current distribution and introduces additional equivalent inductive and capacitive effects. The C-shaped slot and chamfered patch edges further modify the current path on the radiator. These modifications are used together to obtain the required dual-band response within the compact antenna dimensions.

The proposed antenna is simulated using CST Studio and fabricated on an FR-4 substrate with dimensions of $30 \times 15 \times 0.8 \text{ mm}^3$. It operates over two distinct frequency bands of 2.74–3.37 GHz and 5.62–20.07 GHz, with fractional bandwidths of 20.62% and 112.5%, respectively. The antenna provides a peak gain of 4.4 dB and a maximum simulated total efficiency of approximately 98%. The main objective of this work is to obtain wide frequency coverage within a compact antenna structure while maintaining suitable gain, efficiency, and radiation characteristics. Another objective is to study the effect of the modified DGS, C-shaped slot, and chamfered patch edges on the antenna response. The simulated and measured results are compared to verify the performance of the fabricated

antenna. The obtained characteristics make the proposed antenna suitable for compact defense communication, radar, surveillance, and sensing applications.

2. Related Work

The related research has been carried out in recent years to develop Ultra-Wideband (UWB) antennas that achieve compact size, wide impedance bandwidth, and reliable performance for the defense and sensing applications; Various structural modifications and techniques have been explored, including slotting and ground-plane shaping to enhance the gain and multi-band behavior.

In [10], a slotted rectangular monopole antenna was introduced that covers the entire UWB spectrum except for the WiMAX and WLAN bands, providing a maximum gain of 3.28 dBi at 4.25 GHz. A dual-slot Vivaldi antenna employing a non-resonant metasurface was presented in [11], achieving 3–8 GHz operation with a peak gain of 9 dBi and 80% efficiency, although its overall size of $110 \times 96 \text{ mm}^2$ limits portability. A low-cost rectangular patch UWB antenna with trimmed corners, designed in HFSS, was reported in [12], offering an 8.73 dB gain and a 19.91 GHz bandwidth. Similarly, [13] demonstrated an antenna achieving 10 GHz impedance bandwidth between 4.1 and 14.1 GHz with VSWR < 2. A hexagonal loop antenna operating over 3.33–19.94 GHz with an average gain of 4 dBi was developed in [14], while a miniaturized diamond-shaped radiator [15] and a stepped-slot monopole [16] provided passband-specific coverage for Wi-Fi, ISM, and UWB devices. Reconfigurability for switching between UWB and notched-UWB modes also observed.

Further enhancements have been proposed through coplanar and flexible antenna configurations. A coplanar waveguide-fed teardrop antenna integrated with an FSS [17] achieved 5–17 GHz operation. A parachute-shaped flexible monopole fabricated on a polymer substrate [18] achieved a frequency span of 7–12.8 GHz and a 4.5 dBi gain at 12.33 GHz, while inherently rejecting WiMAX and WLAN interference—an attribute desirable for wearable and on-body sensing. In [19], a toothed sprocket-ring radiator achieved 3.1–10.6 GHz coverage with a Bluetooth-rejection notch at 2.4–2.48 GHz, offering 1.5–5 dBi gain and up to 97% efficiency. Flexible antennas made on polymer materials have also been explored for compact and wearable systems.

A PDMS-based tri-band design using multiple stubs was reported in [20], showing good performance for Wi-Fi 6E/7/8 applications with low SAR. Another bendable antenna using a CNT–PDMS composite was presented in [21], offering stable dual-band WLAN and Wi-Fi 6E operation with high efficiency even under bending. In [22], a small PDMS-based UWB antenna

was designed using stub loading. The antenna covered a wide frequency range and provided suitable gain for body-area network applications. The use of a flexible PDMS substrate also made the design suitable for applications where a flexible antenna is required.

Another approach was presented in [23], where a compact FR-4 antenna used PIN diodes to change the antenna response. The design could provide normal UWB operation as well as single- and dual-band-notched responses. In [24], an arrow-shaped filtenna with a flexible CPW-fed structure was investigated. The design provided harmonic suppression along with size reduction and good efficiency for ISM-band applications. A CPW-fed slotted antenna was reported in [25] for operation at 2.4 GHz and 5.4 GHz. The antenna used a simple patch and stub arrangement to obtain the required frequency bands.

From the above studies, different methods such as stub loading, slotting, filtering, and PIN-diode switching have been used to obtain the required frequency response and reduce antenna size. However, most of these designs are intended for particular frequency bands or applications. Designing a compact antenna that covers the S, C, X, and Ku-bands over a wide frequency range, while also maintaining good efficiency and a simple structure, is still a challenge. This provides the motivation for investigating a compact UWB antenna with wide frequency coverage. The proposed approach, is a compact dimensions of $30 \times 15 \text{ mm}^2$, offers dual-band UWB operation from 2.74–3.37 GHz and 5.62–20.07 GHz, efficiently covering multiple defense bands used for satellite links, radar, surveillance, and missile tracking. The design achieves a balance between compactness, bandwidth, and gain and making it suitable for defense and radar platforms.

3. Antenna Design and Optimization

To design an antenna that performs well over an ultra-wide range of frequencies for defense systems, a basic design is evaluated, and parameters are optimized step by step.

3.1 Antenna Design and Theory

A semi-circular, wine-glass-shaped UWB microstrip antenna is simulated, incorporating a C-shaped slot of varying width on the upper surface of the patch, a defected ground radiator on the lower side, as illustrated in Figure 1. The antenna supports dual operating bands: 2.74–3.37 GHz covering the S-band, and 5.62–20.07 GHz spanning the portion of C band, X-bands with corresponding fractional bandwidths 20.62% and 112.5%. The prototype is realized on an FR-4 epoxy substrate measuring $30 \times 15 \text{ mm}^2$, with a height of 0.8 mm, dielectric constant (ϵ_r) of 4.4, and loss tangent ($\tan \delta$) of 0.024. A 50 Ω microstrip feedline is employed for

excitation. Table 1 summarizes the design parameters obtained using CST Studio.

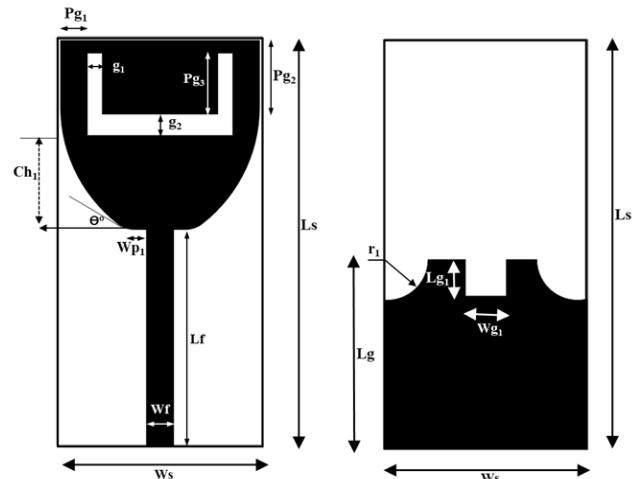


Figure 1. Proposed Antenna (a) front view (b) back view.

Table 1. Antenna Dimension of various Parameters.

Parameter	Parameter Interpretation	Dimensions(mm)
Ws	Substrate Width	15
Ls	Substrate Length	30
Wf	Feedline Width	2
Lf	Length of Feedline	16
Ch1	Camphor height	3.5
g1	Vertical slot width	1
g2	Horizontal gap width	1.5
Θ(degree)	Camphor angle	58°
Lg	Destructive ground length	14
Lg1	Length of rectangular DGS	2.7
Wg1	Width of Rectangular DGS	3
r1	Radius of circular DGS	3

Among the structural variables, the patch length and width are particularly significant, as they have a direct influence on the resonant frequency and radiation behavior of the antenna. For a rectangular patch configuration, the patch width can be estimated using the standard relation given in [26–28].

$$W = \frac{c}{2fr} \sqrt{\frac{2}{\epsilon_r + 1}} \quad (1)$$

Where, c = Light speed = $3 \times 10^8 \text{ m/s}$; f_r = Resonant frequency and ϵ_r = Dielectric constant of substrate (e.g., FR4 ≈ 4.4)

At low frequency, the effective dielectric constant (ϵ_{eff}) remains nearly constant. As the frequency increases to intermediate levels, its value steadily rises and eventually gets closer to the actual dielectric constant of the substrate [29]. Effective dielectric constant can be considered using the following equation (2) [30]:

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12 \frac{h}{w}\right)^{-1/2} \quad (2)$$

Here, h is substrate height, i.e., 0.8 mm, and effective Patch Length (L_{eff}). In a microstrip antenna, radiation mainly arises because of fringing fields on the corner of the element. This field expansion causes the electrical length to be slightly longer than the actual length. The amount of fringing depends on the factors such as the patch width and the height of the substrate [31]. The extended electrical length can be calculated using the following expression, and the change in length due to the fringing field (ΔL) [32] is given below, where w is the width of the substrate.

$$L_{eff} = \frac{c}{2fr\sqrt{\epsilon_{eff}}} \quad (3)$$

$$\Delta L = 0.412h \frac{(\epsilon_{eff} + 0.3) \left(\frac{w}{h} + 0.264\right)}{(\epsilon_{eff} - 0.258) \left(\frac{w}{h} + 0.8\right)} \quad (4)$$

Overview of a C-shaped slot on the radiating surface effectively alters the current distribution and increases overall electrical path without increasing its actual dimensions. The alteration introduces additional resonant modes and improves the impedance matching, thereby enhancing return loss (S_{11}) and bandwidth.

The slot width and length contribute:

$$L_{eff} = L_{patch} + \Delta L_{slot}(g_1, g_2) \quad (5)$$

Where ΔL_{slot} is the added electrical length due to slot dimensions g_1 (vertical cut) and g_2 (horizontal cut).

The slot acts like a combination of inductance and capacitance. The gap (g_1, g_2) introduces discontinuities that affect the input impedance, which is directly related to return loss (S_{11}).

The slot introduces additional equivalent reactance [33] X_{slot} , altering the input impedance.

$$Z_{in} = R + j(X_{patch} + X_{slot}) \quad (6)$$

The bandwidth of an antenna is typically expressed as absolute bandwidth (ABW) for narrowband antennas and fractional bandwidth (FBW) for broadband antennas, as represented by Equations 7.

$$FBW = 2 \frac{f_h - f_l}{f_h + f_l} \quad (7)$$

3.2 Structural Evolution of Antenna

To achieve ideal performance across a wide frequency range, the antenna design evolves through a systematic, and multi-stage process. At each step, specific structural modifications are introduced based on the electromagnetic theory and also supported by key design formulas related to effective length, impedance matching, and bandwidth enhancement.

3.2.1 Ant 1: Standard rectangular microstrip patch antenna with a semi-grounded surface.

The initial version of the antenna contained a simple rectangular patch with a semi-ground plane as shown in Figure. 2(Ant 1). Operating over frequency bands: 2.92 – 3.69 GHz, resulting in a total bandwidth of approximately 770 MHz. Due to its limited coverage, this configuration is suitable only for narrowband applications.



Figure 2. Evolution of antenna structure.

3.2.2 Ant 2: Rectangular microstrip patch antenna with a trimmed ground plane

The Ant 2, a Defected Ground Structure (DGS) is introduced by etching slots into the ground plane [34–36]. This modification alters the surface-current distribution and introduces additional inductive and capacitive effects in the ground plane. The S_{11} response shows that, while the original low-frequency operating region is retained at 2.77–3.55 GHz, a new high-frequency operating region appears from 6.57–20.45 GHz. This indicates that the modified ground structure plays an important role in introducing the additional high-frequency impedance response and supporting the multiband operation, yielding a total bandwidth of around 0.78 GHz and 13.88 GHz for respective bands. The inclusion of DGS effectively enhanced both the impedance matching and multiband capabilities of the antenna.

3.2.3 Ant 3: Curved edges patch antenna design with truncated ground structure

Consequently, the antenna exhibited operating regions of 2.78–3.57 GHz and 6.43–20.07 GHz. Compared with Ant 2, the high-frequency region is slightly modified, indicating that the chamfered patch primarily influences the current distribution and impedance response without eliminating the high-frequency region introduced by the modified ground.

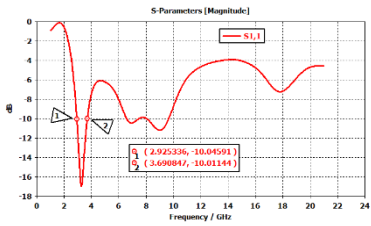
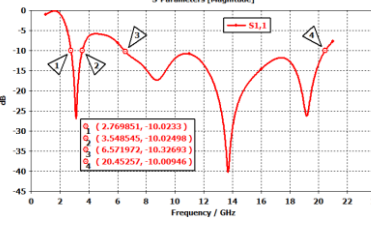
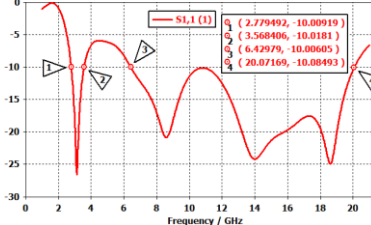
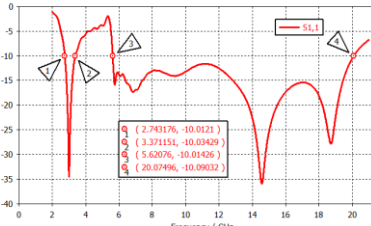
3.3.4 Ant 4: Proposed UWB antenna

The final proposed design, Ant 4, incorporated a C-shaped slot in the radiating surface by applying the antenna theory discussed in Section 3.1. The slot increases the effective electrical length and modifies the capacitive coupling on the radiating patch without increasing the overall antenna dimensions. The S₁₁

response shows that the low-frequency region remains at 2.74–3.37 GHz, while the lower edge of the high-frequency operating region is shifted from 6.43 GHz in Ant3 to 5.62 GHz in Ant 4, extending the high-frequency operating region to 5.62–20.07 GHz. This indicates that the C-shaped slot primarily contributes to the additional impedance matching and resonance behavior in the higher-frequency region.

The proposed antenna was simulated using the Time Domain Solver in CST Studio Suite over a frequency range of 2–21 GHz. A hexahedral mesh was employed with a solver accuracy of –40 dB. The antenna was excited using Waveguide Port 1 (Mode 1), and the S-parameters were referenced to 50 Ω. Open (add space) boundary conditions were applied in all six directions to represent free-space radiation. Adaptive mesh refinement was not enabled.

Table 2. Bandwidth and Frequency band analysis for each antenna stages

Steps	Frequency band		Bandwidth
Ant 1	2.92 – 3.69 GHz		770 MHz
Ant 2	2.77–3.55 GHz & 6.57–20.45 GHz		780 MHz & 13.88 GHz for respective bands
Ant 3	2.78–3.57 GHz & 6.43 - 20.07 GHz		790 MHz & 13.64 GHz for respective bands With dip S ₁₁
Ant 4	2.74–3.37 GHz & 5.62– 20.07 GHz		630 MHz & 14.45 GHz bandwidth for respective bands

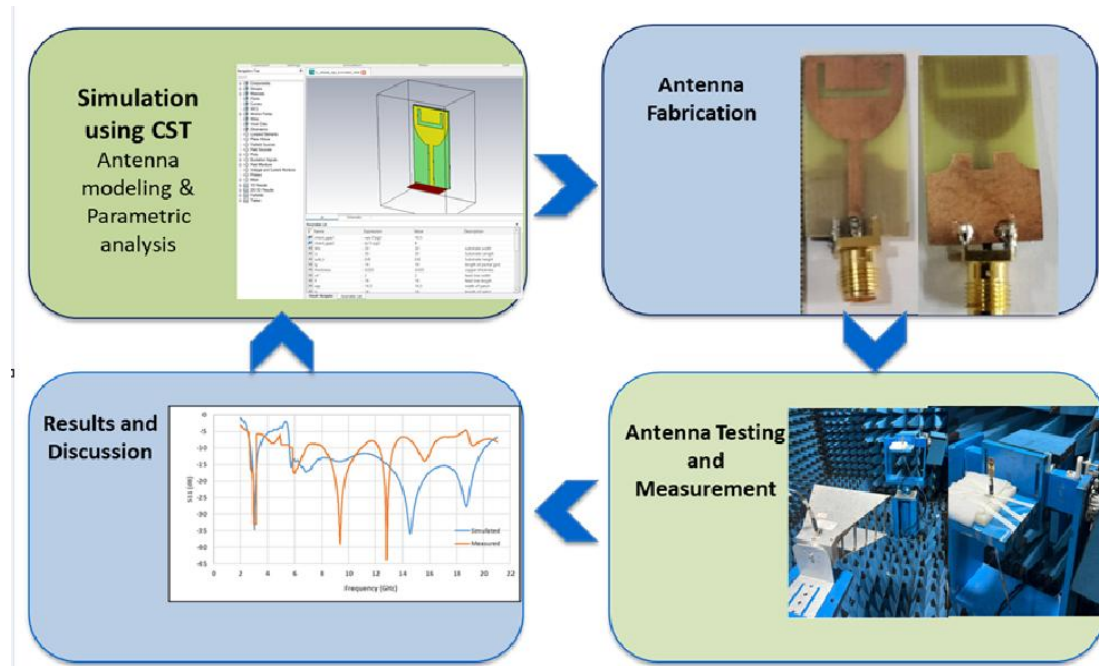


Figure 3. Graphical process flow diagram.

The FR-4 substrate was modeled as a loss-free dielectric with a relative permittivity of 4.3 and relative permeability of 1. The metallic parts were modeled using lossy pure copper with an electrical conductivity of 5.96×10^7 S/m.

Figure 3 presents the complete flow used to design, fabricate, and experimentally validate the compact wideband antenna. Process starts with simulation in CST Microwave Studio, where the antenna geometry is designed, analyzed and optimized to achieve the desired bandwidth, gain, efficiency and impedance characteristics. The improved design is then fabricated on FR4 substrate using s PCB photolithography and etching techniques. Followed by fabrication, the prototype is tested using a Vector Network Analyzer inside an anechoic chamber to measure S-parameters, gain and radiation behavior, and overall antenna performance. Finally, the measured results are compared with simulated data, confirming that the antenna maintains a return loss below -10 dB across a multiple wide band, with minor variation attributed to fabrication tolerances and measurement setup limitations.

4. Result and Discussion

4.1 Return Loss

The different configurations of the proposed antenna, shown in Figure 2, were simulated using CST Studio Suite. The frequency responses for all the four design stages, labeled as Ant 1 through Ant 4, are analyzed and presented in the S_{11} plot in Table 2 and Figure 4. The electrical length of the antenna is tuned by adjusting the width of the C-shaped slot on the radiating patch. As illustrated in Figure 5, the S_{11} plot

demonstrates that the antenna exhibits optimal performance when the gap parameters g_1 and g_2 are set to 1 mm and 1.5 mm, respectively, compared to other configurations.

The effect of truncated DGS on the antenna performance is also observed, and it is concluded that antenna frequency response improves in the presence of DGS, as shown in Figure 6. Further parametric study was carried out to test the effect of the ground-plane length L_g on the S_{11} response of the proposed antenna shown in Figure 7. The value of L_g was varied from 12 to 16 mm, while all other antenna parameters were kept constant. The simulated S_{11} curves show that changing L_g affects the impedance matching and the resonant frequencies, particularly at higher frequencies. Among the investigated values, $L_g=14$ mm provides a suitable impedance response over the desired operating range and was selected for the final antenna design. A second parametric study was carried out to investigate the effect of the circular DGS radius r_1 on the response shown in Figure 8. The value of r_1 was varied while keeping $L_g = 14$ mm and all other antenna parameters constant. The results show that changing affects the impedance matching at both lower and higher frequencies. Among the tested values, $r_1 = 3$ mm provides a suitable S_{11} response over the desired operating regions and was selected for the final antenna design.

4.2 Proposed Antenna Gain & Efficiency

The antenna gain across the band is simulated and shown in Figure 9, showing considerable variation, with a gain of approximately 2 dBi around 3 GHz. The gain shows a small reduction to about 1.4 dBi at 5.6 GHz.

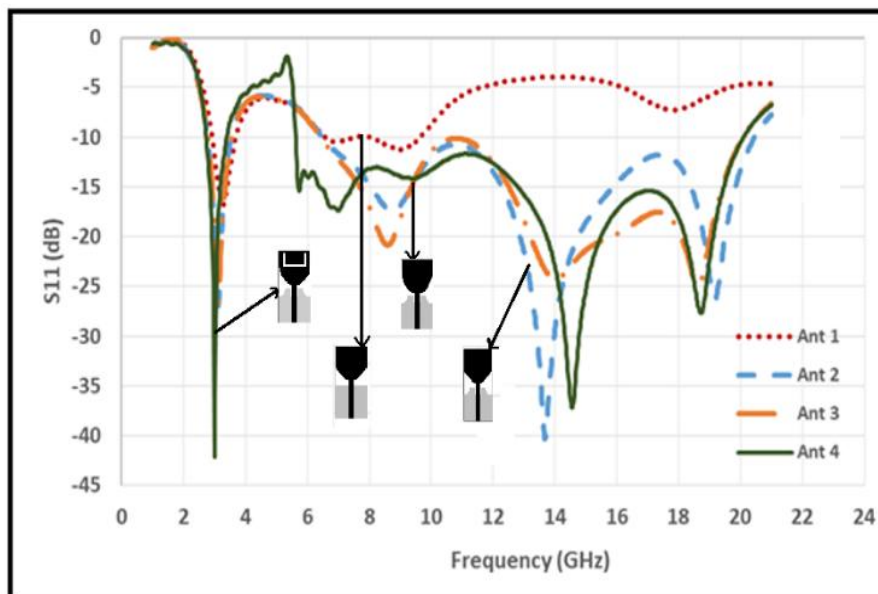


Figure 4. Return loss of all four steps

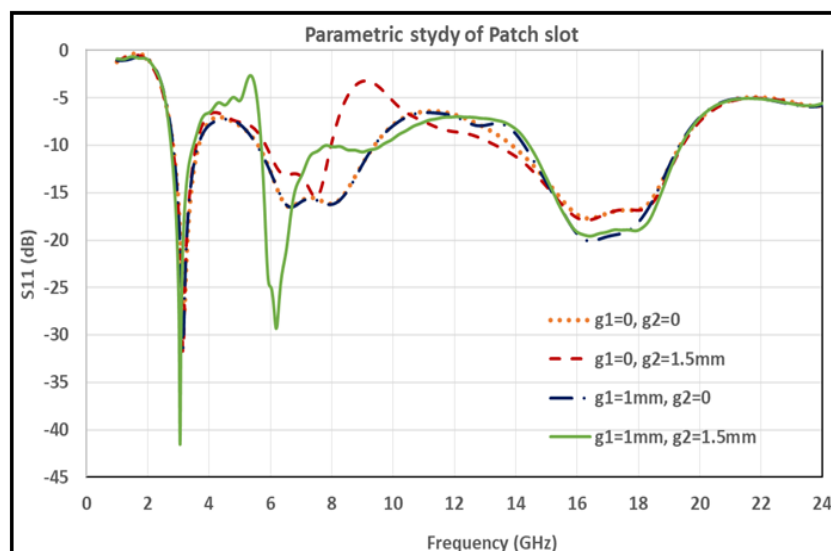


Figure 5. Parametric study of slot width on S11.

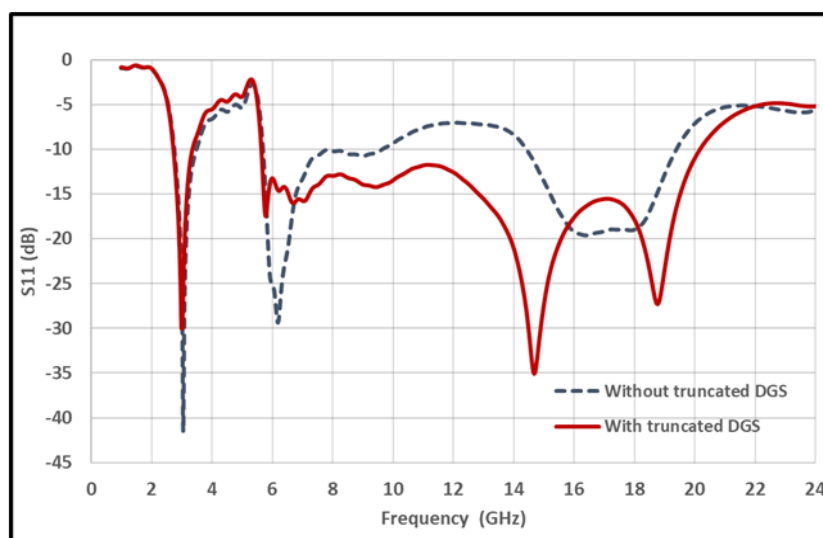


Figure 6. Effect of truncated DGS on S11.

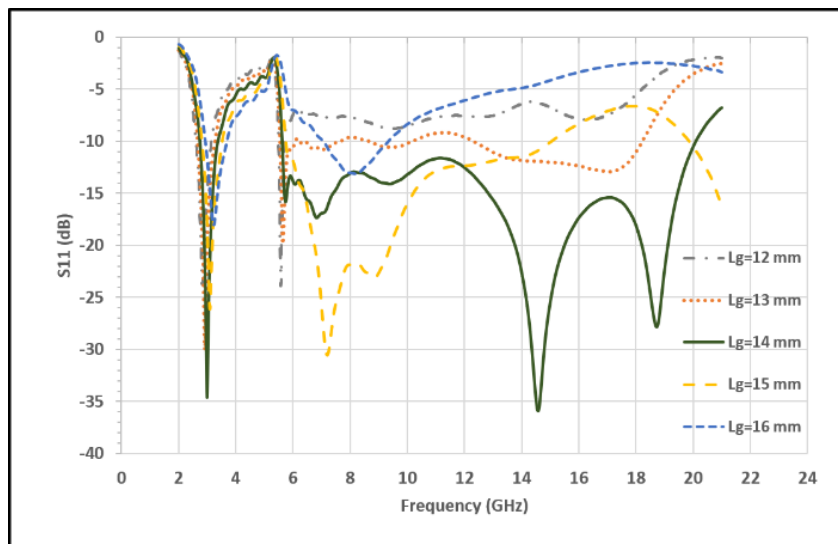


Figure 7. Parametric analysis of on L_g -simulated response.

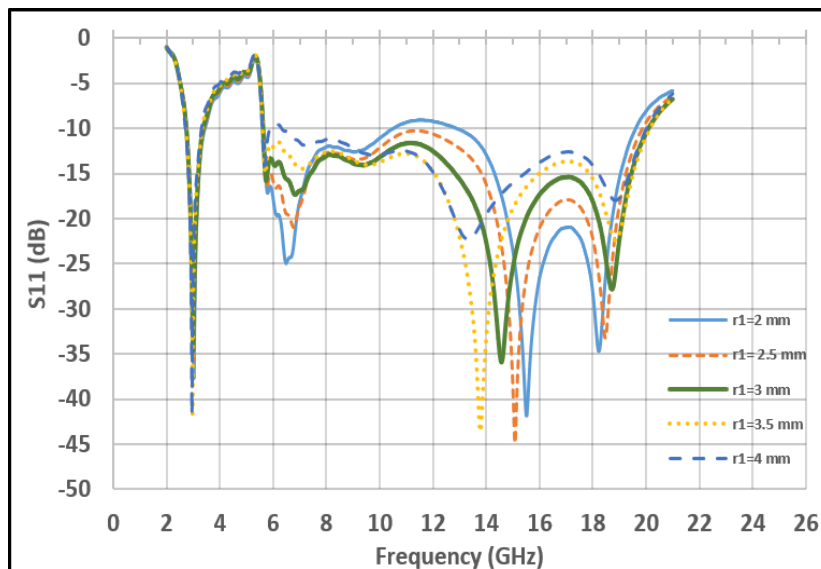


Figure 8. Parametric analysis of on r_1 -simulated response.

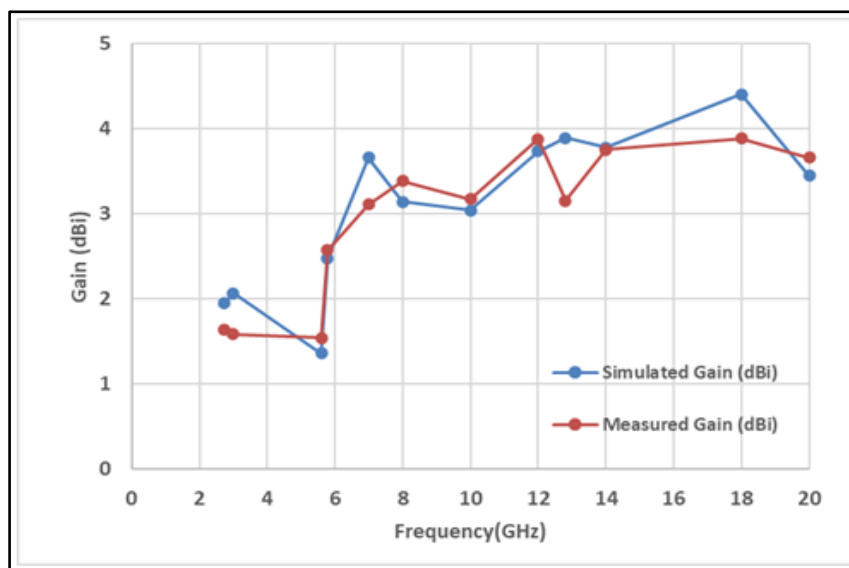


Figure 9. Simulated and measured Gain(dBi).

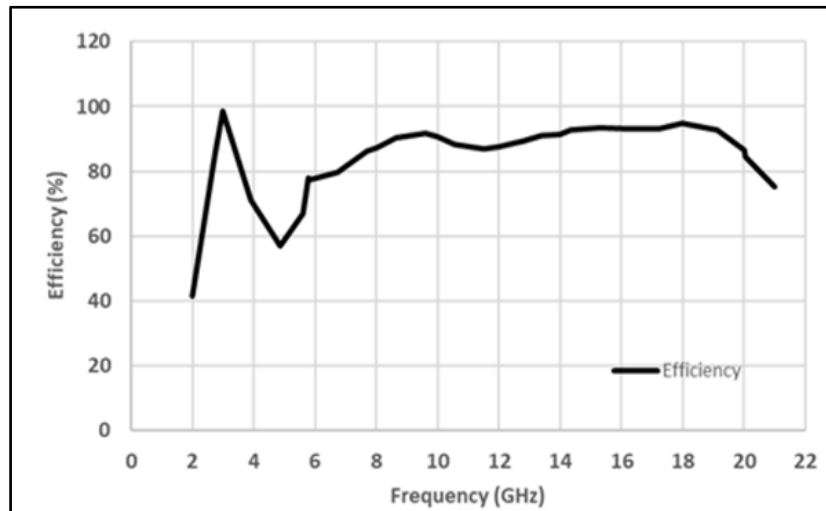


Figure 10. Simulated Total Efficiency.

It then rises to approximately 3.7 dBi at 6.5 GHz and reaches a maximum of 4.4 dBi near 18 GHz. The higher gain obtained at these frequencies suggests improved radiation characteristics of the proposed antenna. At 20 GHz, the gain is still about 3.5 dBi, indicating that the antenna maintains reasonable radiation performance toward the upper end of the operating range. Hence, the antenna provides better gain performance above 6 GHz, which can be useful for UWB-based wireless systems, including 5G and radar applications.

Figure 10 shows the simulated total efficiency of the proposed antenna obtained from CST Studio Suite. The efficiency changes with frequency over the considered operating range. A maximum efficiency of nearly 98% is obtained around 3 GHz. At other frequencies, the efficiency varies because of changes in substrate and conductor losses as well as the electromagnetic response of the antenna structure. In the lower operating band of 2.74–3.37 GHz, the simulated total efficiency varies significantly, reaching approximately 98% near 3 GHz. In the higher operating band of 5.62–20.07 GHz, the efficiency remains generally above 75% and reaches approximately 95% near 18 GHz. These results demonstrate that the proposed antenna maintains satisfactory total efficiency across its two operating bands.

4.3 Antenna Factor

Antenna factor (AF) is a measure of electric or magnetic field strength of an electromagnetic wave to the voltage measured at the antenna's terminals. It measures how effectively the antenna converts the incident electromagnetic field into a voltage. The antenna factor helps to describe the antennas used in the electromagnetic compatibility (EMC) measurements and other similar applications where field strength needs to be determined from the voltage measurement. In this work, the antenna factor is calculated from the simulated

antenna gain using the antenna-factor relationship given in Eq. (8).

$$AF = \frac{E_{incident}}{V_{received}} = \frac{9.73}{\lambda\sqrt{G}} \quad (8)$$

where λ is the free-space wavelength and G is the linear antenna gain.

AF is a parameter which directly affects the sensitivity and accuracy of signal reception in wideband and multi-band situations. In military and defense applications such as tactical communication, radar warning receivers, electronic surveillance, and secure UWB links, a lower antenna factor is generally desirable for improved field-strength sensitivity. The proposed compact semi-circular UWB microstrip antenna exhibits a frequency-dependent antenna factor over the targeted frequency range. As shown in Figure 11, the calculated AF varies from approximately 37 to 38.80 dB/m within the lower operating band of 2.73–3.37 GHz, corresponding to a variation of about 1.81 dB/m. In the higher operating band of 5.62–20.07 GHz, the AF varies from approximately 42.98 dB/m at 5.78 GHz to 52.73 dB/m at 20.07 GHz, corresponding to a variation of about 9.75 dB/m. A small decrease in AF is observed near 5.78 GHz, followed by an overall increasing trend with frequency. The increase in AF at higher frequencies indicates frequency-dependent field-to-voltage sensitivity of the antenna. Therefore, the antenna factor is not considered uniform across the entire investigated frequency range, but instead exhibits relatively small variation in the lower operating band and more pronounced frequency dependence in the higher operating band.

To validate the proposed approach, a prototype of an antenna is fabricated & shown in Figure 12. The antenna is fabricated on a FR-4 substrate of 0.8 mm in thickness, and fed by an SMA connector (50 ohm, high frequency). An Anritsu Vector Network Analyzer with a frequency range up to 43.5 GHz was used to measure the return loss of the fabricated antenna

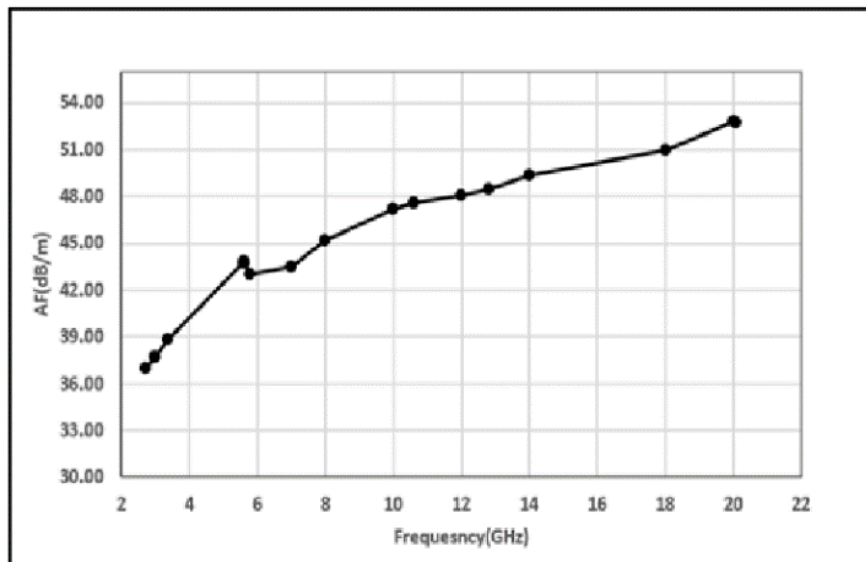


Figure 11. Simulated antenna factor of the proposed antenna.

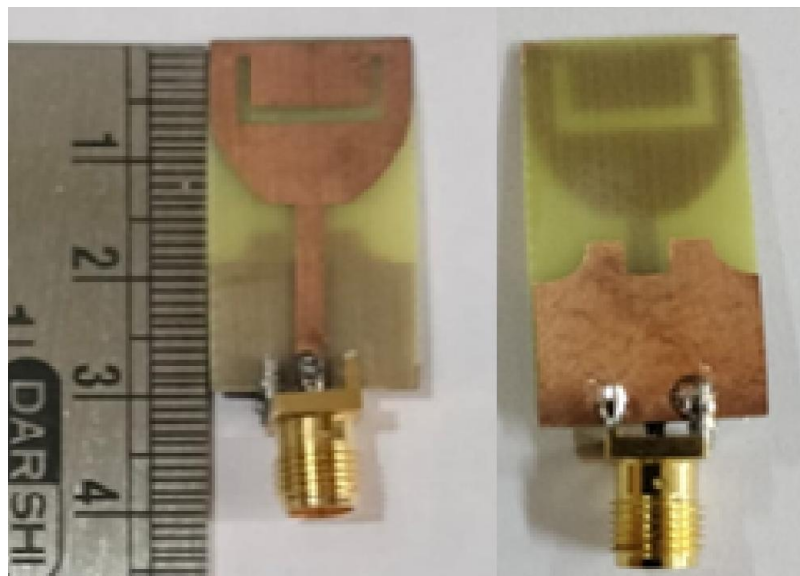


Figure 12. Fabricated antenna Front and back view.

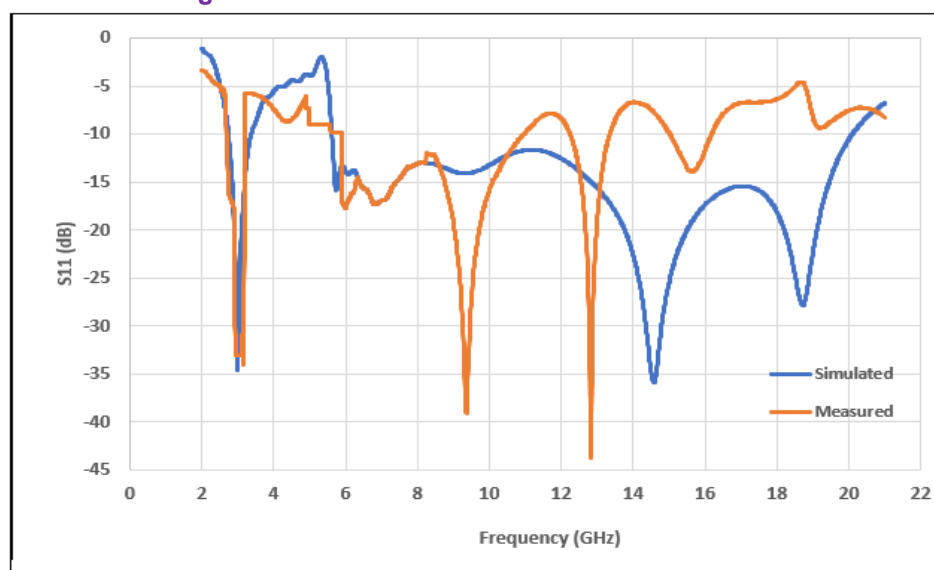


Figure 13. Simulated and measured Return loss (S11).

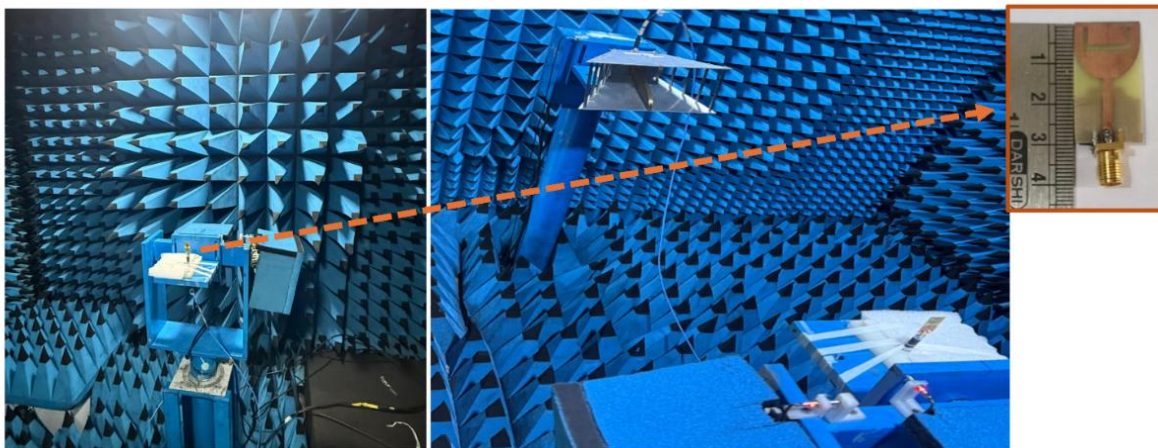


Figure 14. Measurement and Testing setup.

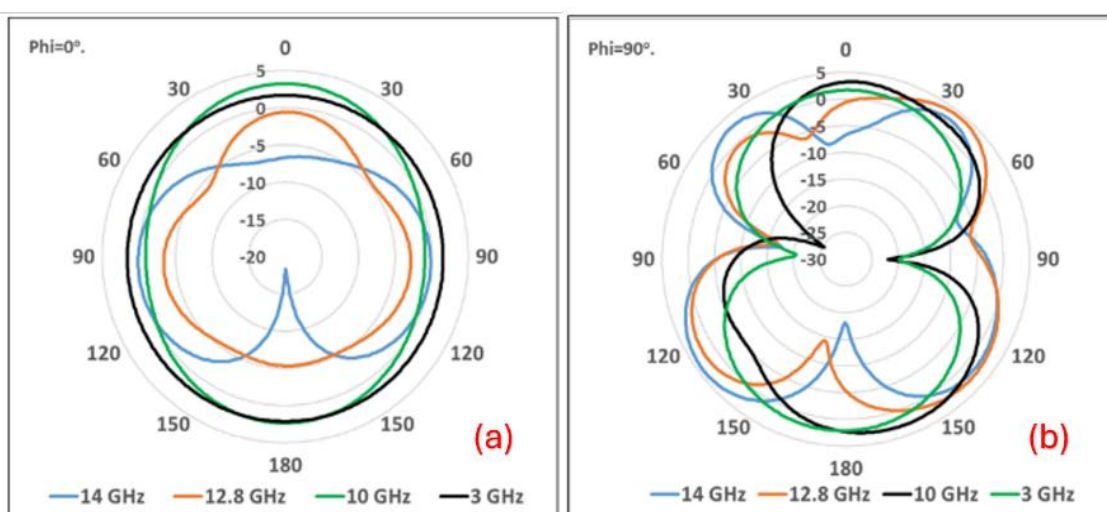
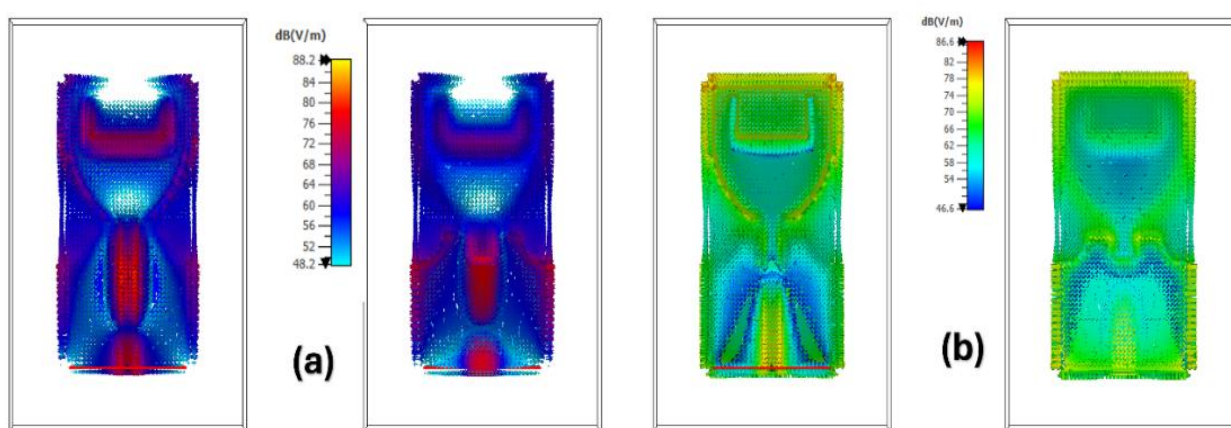
Figure 15. Simulated radiation patterns: (a) H-plane ($\phi = 0^\circ$, x-z plane) and (b) E-plane ($\phi = 90^\circ$, y-z plane)

Figure 16. Surface Current distribution.

The measured return-loss plot is shown in Figure 13, and the measurement setup is depicted in Figure 14. The proposed antenna was fabricated on an FR-4 substrate ($\epsilon_r = 4.4$, and $\tan \delta = 0.024$), primarily because of its low cost, easy availability, and suitability for rapid prototyping. It is acknowledged that FR-4 exhibits higher dielectric loss and reduced dielectric

stability at higher microwave frequencies compared with high-performance substrates such as Rogers or Taconic laminates. These characteristics may lead to reduced efficiency and discrepancies between the simulated and measured results, particularly at higher frequencies. Nevertheless, FR-4 is widely used in practical and low-cost RF systems. For high-end defense or space-grade

applications, the proposed design can be adapted to low-loss substrates, which is expected to further improve its performance.

The radiation characteristics of the fabricated antenna were measured in an anechoic chamber using a wideband horn antenna as the reference/source antenna. The radiation response was measured through the transmission coefficient at different angular positions, with an angular step of 3.6° . An Anritsu MS46524B vector network analyzer was used, with 12-term RF correction and an IF bandwidth of 1 kHz. The measured gain values were obtained from the gain output displayed by the measurement system during the chamber measurement. The measured radiation and gain data were recorded at the required frequencies for comparison with the simulated results.

The measured and simulated responses of the fabricated antenna are compared in Figure 13, simulated response exhibits two operating bands of approximately 2.74–3.37 GHz and 5.62–20.07 GHz, whereas the measured response is 2.68–3.19 GHz, 5.88–10.94 GHz, 12.25–13.35 GHz, and 15.03–16.18 GHz. Thus, although the measured response confirms the impedance-matching behavior of the fabricated antenna, noticeable differences in the bandwidth distribution and resonance locations are observed compared with the simulation, particularly at higher frequencies. The principal low-frequency resonance shifts from approximately 2.998 GHz in simulation to 3.150 GHz in measurement, corresponding to a shift of about 0.152 GHz (5.1%). The differences in the measured and simulated responses can be attributed to FR-4 dielectric-property and thickness tolerances, fabrication dimensional variations, SMA connector and feed-transition effects, and measurement-system uncertainties. These factors become more significant at higher frequencies and may cause changes in resonance frequency.

Figure 15 (a-b) presents the simulated radiation patterns in the H-plane ($\phi = 0^\circ$, x - z plane) and E-plane ($\phi = 90^\circ$, y - z plane) at 3, 10, 12.8, and 14 GHz. The antenna has a quasi-omnidirectional radiation pattern that is relatively stable throughout the operating band. At the selected frequencies of 3, 10, 12.8, and 14 GHz, the main radiation direction remains generally stable without a significant shift in the dominant radiation region. The beam shape remains broadly distributed, although some changes in beamwidth and pattern shape are observed with increasing frequency. Minor side-lobe variations also appear at the higher frequencies, which are attributed to the excitation of higher-order modes. Overall, these variations do not significantly alter the quasi-omnidirectional radiation behavior of the proposed antenna. Comparative analysis of various UWB planar patch antennas is discussed in Table 3 below, and it is found that the proposed antenna approach is compact and provides a wider bandwidth with high efficiency

compared to the discussed antennas. As seen from Table 3, a comparative study with existing antenna designs shows that most reported antennas have been developed for specific applications such as WiMAX, WLAN, radar, biomedical sensing, and wireless communication, while the application of UWB antennas for EMI/EMC purposes has received comparatively limited attention. The proposed antenna addresses this research gap by providing two distinct operating bands of 2.74–3.37 GHz and 5.62–20.07 GHz, corresponding to fractional bandwidths of 20.62% and 112.5%, respectively, with a peak gain of 4.4 dB. Compared to earlier works, the design combines compact size with broad coverage, making it highly suitable UAVs, and advanced radar systems.

At 3 GHz, as shown in Figure 16(a), the surface current is mainly distributed around the feed transition and the central part of the radiator. A higher current is also seen along the edges of the C-shaped slot. This shows the effect of the slot on the current path and the lower-frequency resonance. The current also reaches the outer edge of the radiator, resulting in a longer effective current path at this frequency. The current near the feed region also shows that the input energy is coupled to the radiator. At 14 GHz, Figure 16(b) shows a different current distribution. The current is mainly concentrated around the C-shaped slot, the radiator edges, and the modified ground section. The truncated ground and circular defect change the ground-current path and introduce additional paths for current flow. At this frequency, the current is confined to smaller regions around the slot and other discontinuities. This behavior is related to the higher-frequency resonance and shorter effective current paths. The current distributions at 3 and 14 GHz therefore show the contribution of the C-shaped slot, feed transition, truncated ground, circular defect, and radiator edges to the two-band response.

The antenna coordinate system is defined with the y -axis along the feed and polarization direction, while the x - and z -axes represent the transverse directions. The y - z plane ($\phi = 90^\circ$) is taken as the E-plane and the x - z plane ($\phi = 0^\circ$) as the H-plane. Figure 17 presents the radiation patterns for the two angular cuts. At $\theta = 0^\circ$, the pattern is nearly omnidirectional, with a main lobe magnitude of 3.23 dBi. At $\theta = 90^\circ$, the pattern is more directional, with a main lobe magnitude of 2.04 dBi at 138° . The corresponding 3 dB beamwidth is 65.7° , with side lobes also visible in this cut.

Figure 18 shows the simulated 3D radiation pattern of the proposed antenna at 12 GHz. The peak directivity obtained at this frequency is approximately 4.07 dBi. The radiation lobe has a nearly omnidirectional shape, although a small amount of directional behavior can be observed.

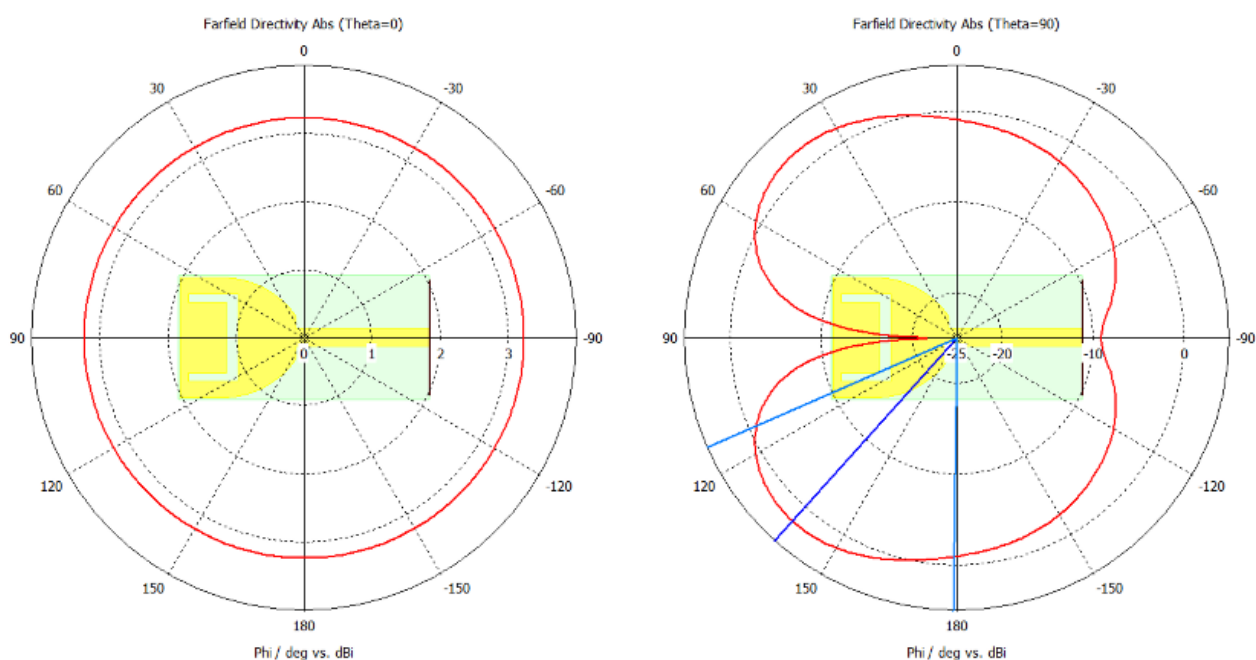


Figure 17. Simulated radiation patterns of the proposed antenna for (a) $\theta = 0^\circ$ and (b) $\theta = 90^\circ$ cuts.

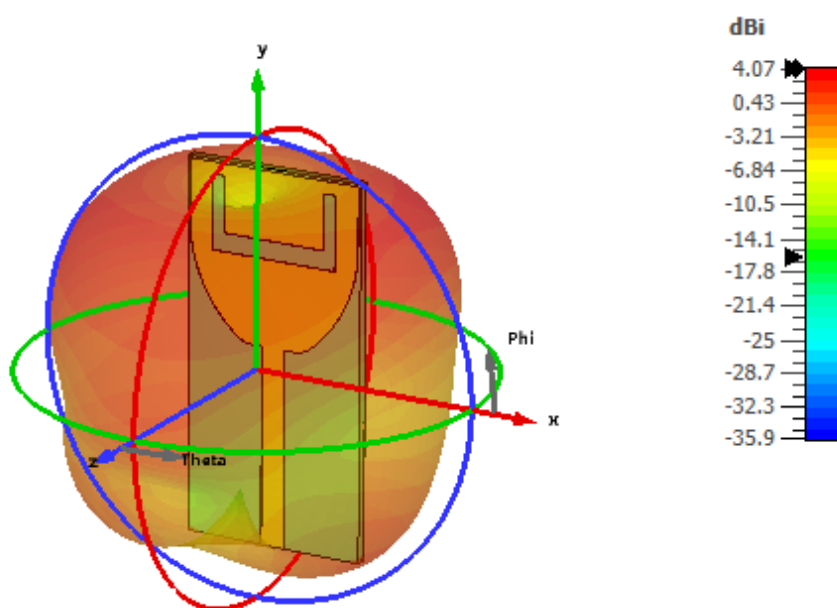


Figure 18. 3D radiation lobe and directivity of the proposed antenna at 12 GHz.

The red and orange portions of the plot correspond to the regions of higher radiation intensity, whereas the green and blue regions represent lower levels. Unlike the gain shown in Figure 9, the directivity represents the concentration of the radiated power without including the radiation losses. The pattern at 12 GHz therefore indicates that the antenna can maintain broad spatial coverage while providing a moderate concentration of radiation in the direction of maximum intensity.

Table 3 compares the proposed antenna with selected UWB antennas reported in the literature. Several of the reported designs are developed for particular applications, including imaging and wireless communication, and generally provide narrower operating ranges. The proposed antenna occupies only $30 \times 15 \times 0.8 \text{ mm}^3$. At the lowest operating frequency of 2.74 GHz, its dimensions correspond to $0.274\lambda_0 \times 0.137\lambda_0$.

Table 3. Comparison of the Proposed Antenna with Existing UWB Designs

Ref.	Application	Antenna Size (mm ³)	Substrate	Operating Frequency (GHz)	Normalized Size ($\lambda_0 \times \lambda_0$)	Bandwidth (GHz)	Gain (dBi)	Maximum Efficiency (%)	Efficiency Type
[10]	UWB Communication	25×20 ×1.6	FR-4	3.1–10.6	0.259 × 0.207	7.5	3.8	88	Simulated & measured
[8]	Microwave Imaging	28×25 × 1.6	FR-4	2.9–12.4	0.271 × 0.242	9.5	4.5	91	Not reported
[9]	UWB Detection	45 × 40 × 1.6	Rogers 5880	3–12	0.450 × 0.400	9	6.1	90	Simulated
[11]	High-Gain UWB	30 × 40 × 0.8	Rogers 5880	4–20	0.400 × 0.534	16	7.2	93	Not reported
[14]	V2X and UWB	18 × 20 × 1.2	FR-4	3–12	0.180 × 0.200	9	4.9	94	Not reported
[17]	UWB	20 × 20 × 1.6	FR-4	3–11	0.200 × 0.200	8	5.6	92	Simulated
[18]	Wearable Health Monitoring	25 × 28 × 0.8	RT-Duroid	3.1–10.6	0.259 × 0.290	7.5	3.2	86	Simulated and Measured
[19]	UWB MIMO System	35 × 35 × 1.6	FR-4	3–12	0.350 × 0.350	9	5.3	90	Not reported
Proposed	Defense and Radar Communication	30 × 15 × 0.8	FR-4	2.68–3.30 & 5.59–20	0.274 λ_0 × 0.137 λ_0	15.03	4.4	98	Simulated

The antenna covers two frequency ranges, from 2.74–3.37 GHz and 5.62–20.07 GHz, thereby extending its operation across the S, C, X, and Ku bands. The corresponding fractional bandwidths are 20.62% and 112.5%. A maximum simulated gain of 4.4 dBi and a total efficiency of nearly 98% are obtained. The combination of small size, wide frequency coverage, and acceptable radiation characteristics makes the design a suitable candidate for compact radar, surveillance, and other defense-oriented wireless applications.

5. Conclusion

A compact semi-circular UWB microstrip antenna with a DGS was developed and investigated for multi-band defense communication. The antenna uses an FR-4 substrate and occupies an area of 30 × 15 × 0.8 mm³. From the simulated S11 response, two operating regions were obtained: 2.74–3.37 GHz and 5.62–20.07 GHz. The second band is particularly wide and extends up to 20.07 GHz. Together, the two bands include parts of the S, C, X, and Ku-bands. The antenna geometry was modified using a C-shaped slot, a truncated ground plane, and a circular defect in the ground plane. These changes affect the current path between the radiator and ground and help obtain the required impedance

response. The calculated fractional bandwidths are 20.62% and 112.5%. A maximum simulated gain of 4.4 dBi was obtained, while the highest total efficiency was close to 98%.

A prototype was fabricated and measured to check the simulated response. The measured impedance characteristics follow the general trend of the simulation, but the two curves do not coincide at all frequencies. The difference becomes more noticeable toward the higher-frequency region. In practice, the result can be affected by the actual FR-4 properties, small dimensional differences in the fabricated PCB, the SMA connector, and the positioning of the antenna during measurement. These factors are difficult to reproduce exactly in the simulation. The current-distribution plots were examined at the resonant frequencies to understand the operation of the antenna. High current density appears around the C-shaped slot and along the outer portion of the radiator. The feed transition and the truncated ground also show strong current concentrations. At other resonant frequencies, the circular defect in the ground plane contributes to the change in the current distribution. The radiation patterns obtained from simulation are close to omnidirectional at the frequencies considered. With increasing frequency, some changes in the shape of the pattern and side-lobe

levels can be seen. The antenna-factor results also change with frequency over both operating regions.

The results indicate that the proposed antenna can provide wide frequency coverage while maintaining a small physical size. Its measured impedance response, simulated gain and efficiency, together with the radiation characteristics, make the design relevant to compact UWB communication and sensing systems. The wide upper band also makes it suitable for consideration in radar and surveillance applications.

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Authors Contribution Statement

Sonal Dubal: Conceptualization, Methodology, Software, Investigation, Data curation, Formal analysis, Visualization, Writing – Original Draft, Writing – Review & Editing. Hetal Pathak: Supervision, Validation, Writing – Review & Editing. Vikas Gupta: Supervision, Validation, Writing – Review & Editing. All authors have read and agreed to the published version of the manuscript.

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Competing Interests

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Data Availability

The data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

Has this article screened for similarity?

Yes

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