

Design and Analysis of UWB Microstrip Antenna for 5G Communications and Military Applications

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Abstract — This paper presents an ultra-wideband (UWB) microstrip antenna designed for military applications, capitalizing on the inherent advantages of millimeter-wave (mmWave) spectrum, particularly enhanced frequency reuse enabled by limited signal coverage and reduced interference. Fabricated on a compact Rogers RT/duroid 5880 substrate ($8 \times 15 \times 0.4 \text{ mm}^3$), the antenna demonstrates a broad bandwidth, high radiation efficiency, and quasi-stable gain, fulfilling the demands of miniaturized wireless devices. The significant atmospheric attenuation at mmWave frequencies not only facilitates dense frequency reuse for improved network capacity but also enhances communication security through inherent resistance to long-range eavesdropping. These characteristics, combined with the antenna's planar geometry, position it as a robust solution for different applications as: military applications, next-generation 5G infrastructure, secure IoT networks, and high-density urban deployments where spectral efficiency and signal integrity are paramount.

Keywords — Coplanar waveguide (CPW), military applications, millimeter-wave, Patch antenna, UWB, 38 GHz, 5G, IoT.

I. INTRODUCTION

Millimeter-wave (mmWave) technology has emerged as a transformative trend in recent years, driven by its high-frequency operation that enables large bandwidths and supports ultra-high data rates. Operating within the frequency range of 30 GHz to 300 GHz, mmWave technology facilitates the transmission of substantial data volumes over short distances, making it ideal for next-generation communication systems. Its high frequencies also support high-resolution applications while enabling compact device integration—a critical advantage as modern components increasingly prioritize miniaturization. Researchers have leveraged the extensive spectrum available in mmWave bands, to address diverse applications such as dense urban networks, industrial automation, satellite communications, automotive radar systems, security imaging, and military operations.

The 38 GHz band has become a cornerstone for 5G systems [1], reflecting global demand for enhanced mobile communications, low-latency IoT networks, and smart infrastructure [2]. Satellite communications have similarly embraced mmWave technology, with the Ka-band (27–40 GHz) [3] and Q-band (33–50 GHz) [4] proving essential for high-throughput space-to-earth data links. Beyond telecommunications, mmWave's applications extend to automotive radar systems, security imaging scanners, airport surveillance, and short-range, very high-resolution mapping [5]. Its short wavelength enables precise resolution, making it indispensable for applications requiring accuracy and detail.

In military applications, mmWave technology plays a pivotal role due to its unique characteristics. Its short range, dictated by high frequencies based on the Friis equation, provides secure and survivable communication in the presence of enemy threats. Adaptive tuning for varying atmospheric absorption meets military requirements for quickly adjusting covert communication zones, accommodating rapid movements of network nodes, dynamic output power constraints, and changing environmental conditions [6], [7].

The advantages of mmWave in military applications have been extensively discussed in [8], highlighting its ability to enhance communication security and operational resilience.

Passive Millimeter-Wave (PMMW) imagers, known for their exceptional resolution, are widely used in remote sensing, security checking, and target detection [9]. The Brijot PMMW system enhances military security by enabling standoff detection of concealed threats such as explosives, weapons, and non-metallic objects through clothing, thereby reducing risks to personnel during screenings [10]. Its passive operation preserves privacy while integrating seamlessly with layered systems like X-ray and biometrics in high-threat environments such as base gates or containerized ScanPort

units. Applications include safeguarding installations, detecting suicide bombers remotely, and mitigating loss of sensitive materials, ensuring rapid, non-invasive screening without compromising operational efficiency [10].

This multi-domain adoption of mmWave technology stems from its unique combination of spectral efficiency, component miniaturization, and inherent signal directionality. These features address both current bandwidth scarcity challenges and future ultra-reliable connectivity requirements, positioning mmWave as a cornerstone for advancements in telecommunications, defense, and beyond.

II. ANTENNA DESIGN AND CONFIGURATION

A. Antenna's Geometry

The antenna was designed to operate in the Q frequency band of millimeter waves. The proposed design was embedded on the top side of 0.4 mm of Rogers RT/duroid 5880 substrate with a relative permittivity of 2.2 and a very low loss tangent of 0.0009.

The antenna design is based on a coplanar waveguide (CPW), which eliminates the need for a ground plane on the bottom of the substrate, as the ground planes are coplanar with the signal conductor. Fig.1 shows the optimized parameters, respectively, while table.1 listed all the parameters used to design our proposed structure:

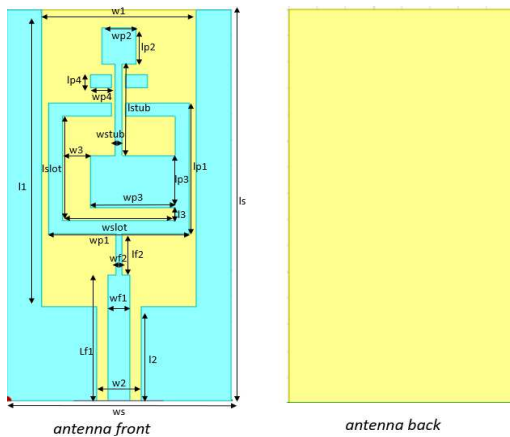


Fig. 1. Geometry of the proposed antenna
Table 1. Dimensions of proposed design

Par.	Dim.(mm)	Par.	Dim.(mm)	Par.	Dim.(mm)	Par.	Dim.(mm)
ws	8	ls	15	wp1	5	lp1	5
w1	5.5	l1	11.4	wp2	1.2	lp2	1.4
w2	1.6	l2	3.6	wp3	3	lp3	2
w3	1	l3	0.5	wp4	0.75	lp4	0.5
wf1	0.8	lf1	4.8	wslot	4	lslot	4
wf2	0.2	lf2	1.6	wstub	0.25	lstub	3.5

B. Design Procedures of the Proposed Antenna

The design process of the proposed ultra wide band antenna is illustrated in Fig.2. The antenna was developed through four incremental steps on its rectangular patch. The proposed antenna has been evaluated in terms of reflection coefficient and gain with different scenarios.

The evolution from the first step to the second causes the antenna to resonate at 38 GHz, as it indicated in Fig.3. Adding

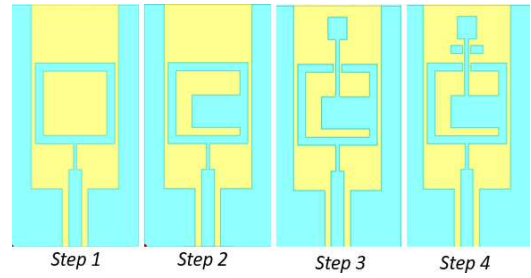


Fig. 2. Step-by-step design process of the proposed antenna.

a small patch on the top, connected to the main patch, as it shown in Fig.2 (step 3), increase the max gain from 6.83 dB to 7.62 dB at 47.6 GHz. The final radiator patch with two parasitic elements, as it depicted in Fig.2 (step 4) helps to achieve a larger bandwidth of the antenna at Q band, by introducing other operation modes, as it shown in Fig.3.

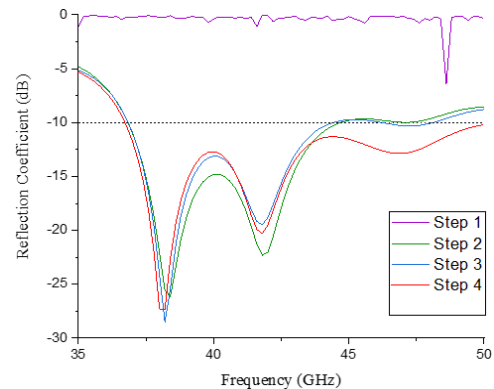


Fig. 3. Reflection coefficient of the four designs.

III. SIMULATION RESULT

A. Return Loss

Fig.3 shows that the proposed antenna is an UWB structure with an impedance bandwidth of 30.63% (36.72 GHz- 50 GHz). The presented structure has two resonant frequencies: the first at 38 GHz with a return loss of -27.28 dB, and the second at 41.8 GHz with a return loss of -20.29 dB.

B. Radiation efficiency and gain

The antenna's radiation performance, as depicted in Fig.4, demonstrates consistently high efficiency exceeding 91% throughout the operational bandwidth. This characteristic indicates optimal power utilization where the majority of input energy is effectively radiated into free space rather than being lost through Ohmic losses or dielectric absorption. Such efficient electromagnetic conversion directly enhances system-level performance by improving signal-to-noise ratios and operational reliability, while simultaneously reducing thermal management requirements in practical deployments. The antenna demonstrated high gain at the operating frequencies. The proposed structure achieved maximum peak gain of 8.46 dB at 47.6 GHz, highlighting its efficacy in transmitting and receiving signals efficiently.

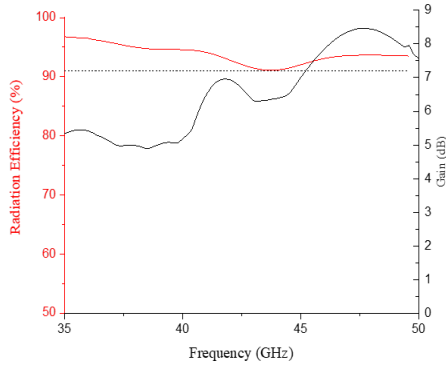


Fig. 4. Radiation efficiency and gain of the antenna design.

C. Radiation Patterns

In Figures 5(a)–5(b)–5(c), the polar plot radiation patterns of this proposed design are shown in the XY -XZ- and YZ-planes for 38 GHz. In Figures 6(a)–6(b)–6(c), the polar plot radiation patterns of this proposed design are shown in the XY -XZ- and YZ-planes for 41.8 GHz.

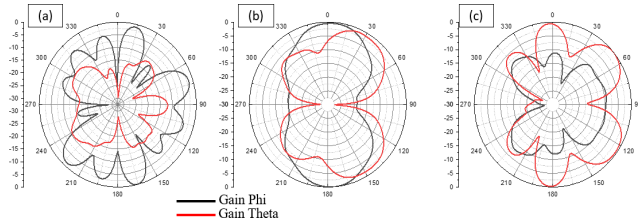


Fig. 5. 2D radiation Patterns at 38 GHz in:(a) XY-Plane, (b) XZ-Plane, (c) YZ Plane.

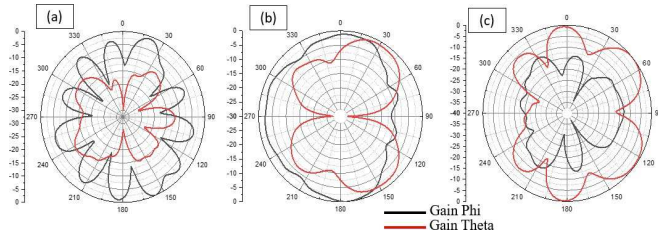


Fig. 6. 2D radiation Patterns at 41.8 GHz in:(a) XY-Plane, (b) XZ-Plane, (c) YZ Plane.

Table 2. Performance comparison of the proposed antenna with recent works on the literature.

References	Frequency (GHz)	Bandwidth (GHz)	Gain (dB)	Radiation efficiency (%)
[11]	38	36.8 – 43	> 7	90
[12]	38	35.83–41.22	4.5 dBi	> 80
[13]	38	-	6.84	> 85
[14]	15	1.34	5.42	80
	37.5	7.5	8.65	> 82
Our work	38	36.72-50	8.46	> 91

IV. CONCLUSION AND FUTURE WORK

This paper introduces an UWB planar antenna of 8 mm × 15 mm × 0.4 mm substrate size. The design used the CPW structure and the parasitic elements to enhance its performances. The proposed antenna exhibits an impedance bandwidth of 30.63%, peak of gain of 8.46 dB, and radiation efficiency upper than 91%, making it a good candidate for military applications.

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