engineering proceedings

Proceeding Paper

Dual-Band UWB Monopole Antenna for IoT Applications †

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† Presented at the 8th International Electrical Engineering Conference, Karachi, Pakistan, 25–26 August 2023.

Abstract: A dual-band UWB coplanar waveguide monopole antenna is presented in this paper. The antenna proposed in this paper consists of an FR4 substrate, two ground planes, and a rectangular patch. The size of the antenna proposed is $24 \times 25 \times 1$ mm^3 with a slit of length and width of 5.7 and 0.5 mm, respectively. We received two operating bands, a C- and Ku-band, with both Bi and Omni-directional radiation patterns. The bandwidth values of the first (3.65–7.49) GHz and second (11.5–13.4) GHz band of the proposed antenna are 3.9 GHz and 1.7 GHz, respectively. The proposed antenna operating at a frequency 5.8 GHz has a maximum bandwidth of 4.5 GHz and minimum bandwidth of 1.6 GHz. The characteristics of this antenna show that the antenna proposed in this paper is suitable for dual-band and UWB communication systems. We achieved a wide bandwidth by improving the ground plane.

Keywords: monopole antenna; dual-band UWB

1. Introduction

Since the Federal Communication Commission (FCC) approved the 3.1–10.6 GHz range of frequency band for commercial UWB applications, the FCC defines the UWB phenomenon as a radio system with a bandwidth >=500 MHz that spans more than 25% of the center frequency [1]. The evolution of the techniques that adapt to ultrawideband has been increasing ever since the use of UWB spectrum was made permissible by the FCC. Nowadays, developers are paying more attention to methods that fulfil the requirements of UWB applications. Because WLANs are becoming more popular daily, many different designs of dual-band antennas operating at 2.4 GHz and 5 GHz have been made [2]. We all know that if any transmitting and receiving antenna's radiation patterns are circularly polarized, they are less sensitive to their respective orientations. Thus, coplanar waveguide antennas are used for many applications, including Wireless local area network (WLAN) and radio frequency identification (RFID) systems. Due to low coupling with neighboring RF components and its simple metal structure, CPW has gained a lot of popularity and attention [3].

Slot antennas and patch antennas are configurations of this existing planar antenna. A 3 dB bandwidth of less than 10% for the antenna is typically allowed. Slot antennas with coplanar characteristics have recently been made to achieve bandwidths and relatively wide impedance. However, these antennas are more extensive, so using them in compact wireless devices is not easy. Small sizes, functional radiation patterns, acceptable S11 parameters, and cost-effectiveness are some of the common properties of UWB antennas, and any UWB antenna design must have these properties [4]. Some benefits of UWB technology include high data rates, reliability, low complexity, minor interference, and cost-effectiveness. The fraction of a millisecond is equal to pulse time, so one of its most important disadvantages is that it requires precise receptor time synchronization. UWB

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Citation: Muzaffar, S.; Turab, D.; Zahid, M.; Amin, Y. Dual-Band UWB Monopole Antenna for IoT Applications. *Eng. Proc.* **2023**, *46*, 29. https://doi.org/10.3390/engproc2023046029

Academic Editors: Abdul Ghani Abro and Saad Ahmed Qazi

Published: 25 September 2023

technology has many applications, including medical imaging, military communications, and radar [5].

UWB with band rejection capabilities has been developed to reduce interference in wireless applications. To achieve these band rejection capabilities, several slits can be made in feed, ground, or patch [6]. Using a slot to boost bandwidth, a reduced antenna size was proposed in [7]. New antenna designs are being proposed to meet the stringent requirements of smart devices and make them compatible with previous wireless communication systems [8,9]. Dual-band antennas provide a reliable and robust wireless connection in often difficult-to-reach situations; these are also considered energy-harvesting antennas. In dual-band antennas, 2.4 GHz and 3.6 GHz are the two most used frequencies. The 3.6 GHz option has a higher frequency and, as a result, a narrower range. Due to its higher frequency, more information can be handled simultaneously in a 3.6 GHz antenna. On the other hand, the frequency of 2.4 GHz is relatively low. Due to this, it can cover greater distances and penetrate more. Depending on the area, we can switch between these two frequencies or use both. The monopole antenna fed by a coplanar waveguide (CPW) has gained so much attention because of its unique features, such as a larger impedance bandwidth, a more straightforward structure, less conductor loss, and improved radiation efficiency.

Compact wideband or multi-band antennas for handheld communication devices are challenging to design because they must meet general bandwidth requirements; offer consistent gain and symmetric radiation patterns; and be compact in size, easy to fabricate, and lightweight. Because of the diverse operating requirements of communication devices, there has been an increase in interest in finding antennas that cover multiple frequency bands, such as S-band (2–4 GHz), WiMAX (3.3–3.8 GHz), 5G mid bands (3.3–3.8 GHz, 4.4–4.9 GHz), C-band (4–8 GHz), WLAN (5.15–5.825 GHz), UWB (3.1–10.6 GHz), and X-band (8–12 GHz). By inserting slits or slots into the patch/ground plane at appropriate locations, a narrow band microstrip patch antenna can be converted into a multi-band antenna. Many band-notched UWB antennas have been reported in recent studies; for example, an arc-slot in the patch was reported in [10], and a slot with an embedded tuning stud was reported in [11,12]. Cutting a π-slot [13], inserting a slit [14], and placing parasitic elements near feed have also been mentioned in the literature [15,16]. The resonances and stopband are influenced by the placement of the slit, as well as its shape and size. Assume the slit length on the patch/ground plane is a quarter or half wavelength. In that case, it can excite the higher modes around the fundamental method, allowing various operating bands to be achieved. The antenna proposed in this paper operates in C-band and Ku-band. The function of any slot antenna depends on the substrate's material, feed type, antenna geometry, and slot position.

2. Literature Review

In 1990, the first CPW-fed antenna was proposed. Alternative designs include tapered slot antennas with coplanar waveguides. The CPW microstrip antenna, which has a rectangular slot, circularly polarized antenna with a CPW-fed circular patch, dual-polarization antenna, and a miniature tapered-slot antenna, can be used for various applications. The radiating elements that have been proposed are challenging to build; the bandwidth achieved is insufficient, and it has very limited applications. Building a CPW-fed antenna with a simpler structure and much higher efficiency, as well as a larger bandwidth, is difficult [17]. The most common feeding strategy is microstrip line feeders. However, CPW feeding is favored because the ground plane resembles radiator components.

The CPW-fed antenna, unlike the microstrip line feeder, has a ground plane on its upper radiation components. As reported in [18], CPW can be combined with CPW-fed monolithic microwave integrated circuits. The use of a minor, dual-notch band and CPW-fed ultrawideband antenna was reported in [19]. In this case, the antenna has notch bands that can be selected between 4 and 5.78 GHz and 6.83 and 8.22 GHz. A low-cost FR-4 substrate-integrated octagonal patch antenna can be built. A new small-size UWB microstrip antenna with a dimension of 1327.2 mm^2 was made on an FR4 substrate using a decreased ground plane and slotted patch resonator. A CST electromagnetic simulator planned antenna was simulated, and it has three resonances of 8.5, 5.2, and 3.1 GHz with S11 values of 22, 21.8, and 20.5, respectively, and 6.23 GHz as the impedance bandwidth. This antenna was made and tested to validate the simulation's input reflection results, and the experimental results and simulated results were consistent [20]. To increase the gain single-layer frequency, a selective surface was used as a metallic plate in a SAPM (strawberry artistic-shaped printed monopole). This improved the antenna's UWB frequency range. The strawberry-shaped radiating element was created using six cylinders. With a bandwidth of 8.85 GHz (3.05–11.9 GHz), this antenna with CPW feeding was projected on an FR4 substrate, covering the acceptable UWB frequency range. An antenna with a FSS reflector yielded a 6.22 dB gain in the upper and lower bands. The antenna measures $61 \times 61 \times 1.6$ mm^3. Because of its directed pattern and balanced far-field, the recommended antenna layout can be used in UWB and ground-penetrating radar (GPR) applications [21]. An antenna based on an FR4-epoxy substrate with antenna dimensions of $23.5 \times 31 \times 1.5$ mm^3 was reported in [22]. The operating frequency range of the proposed antenna is 1.76–11.07 GHz, and the frequency range of 2.42 to 5.37 GHz is rejected. The proposed antenna has significant gain, consistent radiation patterns, and efficiency across the entire working spectrum. Finally, the proposed antenna may be viable for wireless communication. For personal wireless communication, a compact-band notched UWB antenna and UWB applications have been proposed [23]. A lightweight, small UWB antenna with improved efficiency gain was reported in [24]. To create the proposed antenna design and feed a jug-shaped radiator, a CPW was used. This antenna had a gain of 4.1 dBi and a frequency range from 3 to 11 GHz. In [25], a U-shaped aperture with two split ring resonators (CSRR) and two stubs is proposed. The dimensions of the proposed antenna are 24×20 mm^2, and an FR4 substrate is used operating at frequencies ranging from 2.7 to 11.4 GHz. The antenna also had an impedance band of 123.4%. An antenna consisting of four crescent-shaped nested rings operating at a frequency range of 2.63–11.6 GHz is reported in [26]. With a gain of approx. 4 dB, this antenna can be used in UWB applications.

3. Antenna Design

Figure 1 shows the antenna design proposed in this paper. In this antenna, we used substrate FR4; the thickness of the substrate is 1 mm, and 4.4 is the value of the relative dielectric constant. The proposed coplanar antenna is $24 \times 25 \times 1$ mm^3 in size. We used a 50-Ohm SMA connector for excitation. The proposed antenna's numerical simulations, including the SMA connector modeling, were carried out by using the Ansys Electronics student version. The antenna dimensions proposed in this paper are listed in Table 1. The bandwidth of the proposed antenna can be significantly increased by inserting a slit, while the proposed antenna's impedance bandwidth is close to that of the antenna without a slit. We can enhance the bandwidth of the antenna proposed in this paper by simultaneously adding a slit in the ground plane.

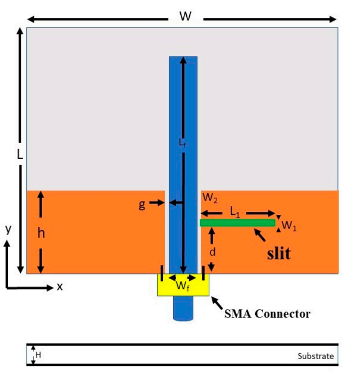


Figure 1. Design of a proposed antenna.

Table 1. Dimensions of a dual-band CPW antenna.

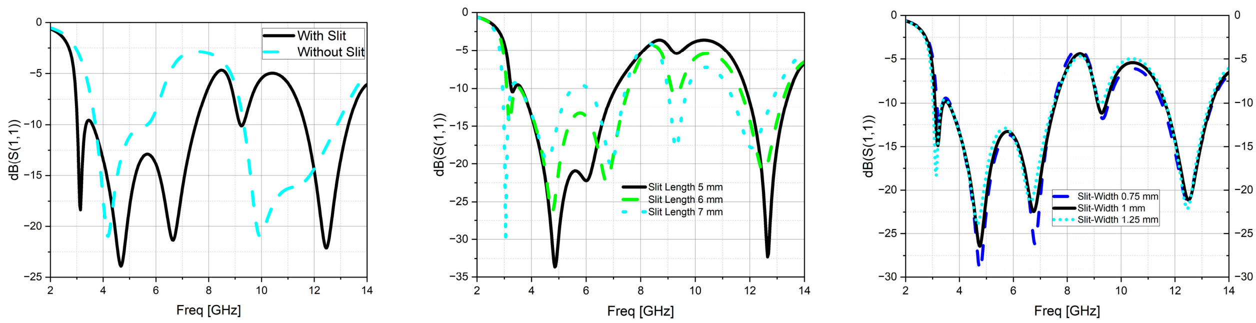
Parameters	Values (mm)	Parameters	Values (mm)	Parameters	Values (mm)
W	24	h	8	l_f	2.2
L	25	g	0.2	d	3.25
H	1	w_1	0.5	l_1	5.7
$\mathbf{W_f}$	2				

In this design, we made a slit l_1 in the ground plane, which affects the impedance bandwidth of the antenna. If we increase the length of that slit graph, the impedance bandwidth is shifted towards the upper frequencies. In the upper frequencies, a coplanar resonant mode is significantly affected by the size of slit l_1. By adjusting the length of the slit, we can obtain the widest bandwidth. We used a slit length l_1 = 5.5 mm in this proposed antenna to obtain the widest bandwidth. The ground plane's effect on antenna performance was also investigated. Return loss for the proposed antenna at various ground-plane heights (h) can be observed as height h grows, and the suggested antenna's first resonant frequency shifts toward a higher frequency. The ground plane h's size has a minor effect on the bandwidth compared to the parameters of l_1 and l_2. An h 8.0 mm was chosen to obtain the most significant 10-dB impedance.

4. Parametric Analysis

An analysis of the antenna was performed by first removing the slit from the design and finding the S-parameter. Then, two further analyses were conducted by including the slit in the design. First, the width of the slit was changed, and then length was changed to find out the S-parameter.

As a result, Figure 2 shows dual bandwidth but not ultrawideband. On the other hand, Figure 2a–c show dual bandwidth with the ultrawideband as the second band, which can eventually be considered better than the one without the slit.

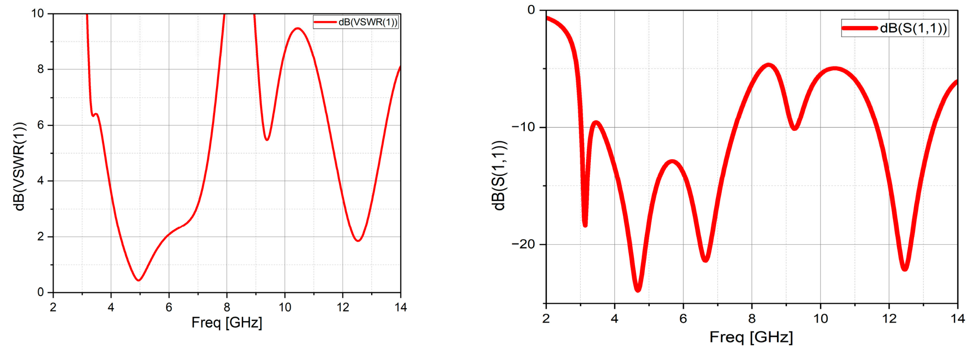


(**a**) (**b**) (**c**)

Figure 2. Scattering parameters of the proposed antenna (**a**) with and without slit; (**b**) variation in slit width; (**c**) variation in slit length.

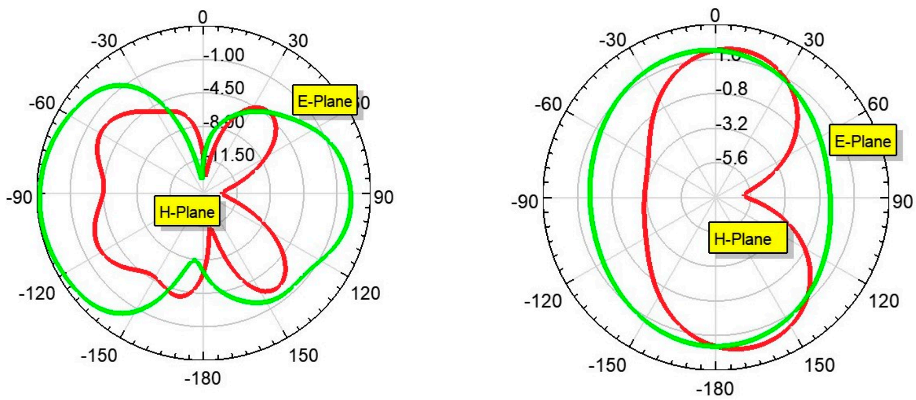
5. Results

All of the simulations of the proposed antenna were performed on the Ansys Electronics desktop student 2022 version. We gathered simulated results from both dual-band and UWB, in which the first band is a 3.65–7.49 GHz band with a frequency of 11.5–13.4 GHz, which lies in the Ku-band with a bandwidth of 3.9 and 1.7 GHz, respectively, which lies in the C-band. The return loss of the proposed antenna is −31 dB at the resonant frequency of 4.94 GHz, which can be seen from Figure 3b. To simulate and plot the radiation pattern results in the x-z and y-z planes presented in Figure 4, we can see that the radiation pattern is both bidirectional and omnidirectional in both E and H planes, respectively.



(**a**) (**b**)

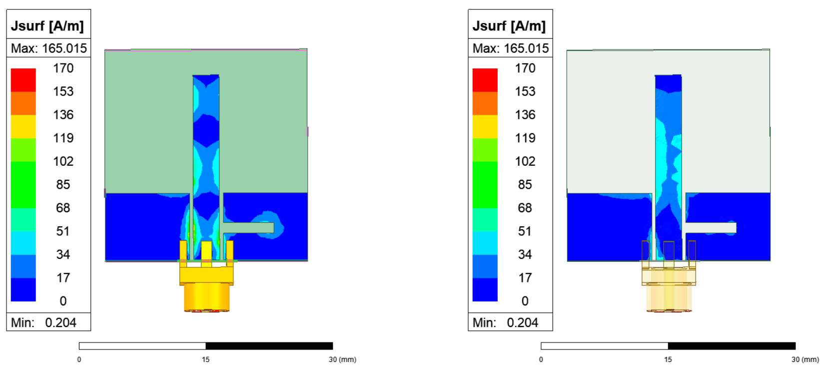
Figure 3. Simulated results of a proposed antenna. (**a**) VSWR; (**b**) S-Parameters.



(**a**) (**b**)

Figure 4. Radiation Pattern of a proposed antenna. (**a**) E and H plane at 4.9 GHz; (**b**) E and H plane at 12.5 GHz.

Because the radiation pattern of this antenna is both omni- and bidirectional, it can be used in any direction for multiple purposes and is highly directive. The minimum gain of the proposed antenna is 2.81 dB, and the maximum gain is 4.68 dB. Due to its radiation pattern in all directions, we can use this antenna in many applications, such as mobile towers, radar systems, and satellite communication system. The surface current distribution of a proposed antenna is shown in Figure 5 for 4.9 GHz and 12.5 GHz. The proposed antenna is compared with the literature work in Table 2.



(**a**) (**b**)

Figure 5. The current distribution of a proposed antenna. (**a**) distribution = 4.9 GHz; (**b**) distribution = 12.5 GHz.

Table 2. Comparison of the proposed antenna with literature.

Ref. #	Band Type	Op. Freq. (GHz)	Antenna Size (mm^3)	Gain (dBi)	Bandwidth (GHz)
[3]	Dual-band	3.54, 5.63	$50 \times 50 \times 1.58$	3.03 and 3.42	3.30 to 3.78, 5.40 to 5.86
[4]	ultrawideband	11	$26 \times 22 \times 1.59$	7.21	2.58 to 20.95
[5]	ultrawideband	7.7	$16 \times 25 \times 1.52$	4.5	3.1–12.5
[6]	ultrawideband	7.5	$72 \times 72 \times 1.2$	6.8	3–12
[7]	ultrawide band	22	28.1×17.1	2.8	4–40
[9]	ultrawideband		$22 \times 18 \times 1.6$	4	4.93–13.54
Prop.	Dual-band and ultrawideband	5.8	$24 \times 25 \times 1$	4.68	3–7.5 and 11.7–13.3

6. Conclusions

A dual-band UWB coplanar waveguide antenna composed of two ground planes and a rectangle patch has been presented in this paper. The ground plane is enhanced by inserting a 5.7 mm $\times$ 0.5 mm slit. The proposed antenna resonates at a frequency of 4.9 GHz and has a return loss of -31 dB. The radiation pattern is both omni- and bidirectional, with a maximum and minimum gain of 4.68 dB and 2.81, respectively. The antenna's impedance bandwidths are improved by correctly cutting a horizontal slit. The measured findings reveal that the suggested antenna can attain a large impedance bandwidth.

Author Contributions: Conceptualization, S.M. and M.Z.; methodology, S.M. and M.Z.; software, S.M. and D.T.; validation, S.M., M.Z. and Y.A.; formal analysis, M.Z.; investigation, M.Z.; writing—original draft preparation, D.T. and S.M.; writing—review and editing, Y.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data can be obtained from the corresponding author on request.

Conflicts of Interest: The authors declare no conflict of interest.

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