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Design of a Compact Multi-Notched UWB Circular Patch Antenna with Defected Ground Structure for IoT Wireless Devices

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Abstract

Ultra-Wideband (UWB) technology is widely recognised as a key enabler for next-generation Internet of Things (IoT) applications due to its large bandwidth, low power consumption, and high data transmission capability. However, UWB systems coexist with several narrowband wireless services such as WiMAX, WLAN, and X-band satellite communication, which may cause severe electromagnetic interference. To address this issue, this paper presents the design and analysis of a compact multi-notched UWB circular patch antenna incorporating a defected ground structure (DGS). The proposed antenna operates over the UWB frequency range of 3.1–10.6 GHz while introducing multiple band-notched characteristics to suppress interference from coexisting wireless systems. The band-notched behaviour is achieved through slot loading on the circular radiating patch and an optimised DGS on the ground plane. The antenna is designed on a low-cost FR4 substrate and optimised using full-wave electromagnetic simulation software. Simulation results demonstrate wide impedance bandwidth, effective multi-band rejection, stable radiation patterns, and satisfactory gain performance, making the antenna suitable for compact IoT wireless devices.

Keywords: Ultra-Wideband (UWB), Circular Patch Antenna, Defected Ground Structure (DGS), Band-Notch, Internet of Things (IoT).

1. INTRODUCTION

The rapid expansion of the Internet of Things (IoT) has significantly increased the demand for compact, low-power, and high-data-rate wireless communication systems. Among the available wireless technologies, Ultra-Wideband (UWB) has emerged as a promising solution due to its wide operating bandwidth (3.1–10.6 GHz), high time resolution, low spectral density, and robustness against multipath fading. These features make UWB particularly suitable for short-range communication, indoor localization, wearable devices, and sensor-based IoT applications. Despite its advantages, UWB systems operate in a spectrum shared with several narrowband communication standards such as WiMAX (3.3–3.7 GHz), WLAN (5.15–5.825 GHz), and X-band satellite services (7.25–8.4 GHz). The overlap between UWB and these services can lead to significant interference, degrading system performance. Therefore, UWB antennas must incorporate band-notched characteristics to suppress undesired frequency bands while maintaining wideband operation selectively.

Various techniques have been reported to achieve band-notched behaviour, including etched slots, parasitic resonators, split-ring resonators (SRRs), electromagnetic bandgap (EBG) structures, and defected ground structures (DGS). Among these, DGS-based techniques offer advantages such as compact size, ease of fabrication, and effective control over surface current distribution. In addition, circular patch antennas are attractive due to their symmetric radiation patterns, compact geometry, and stable performance across wide bandwidths. Motivated by these considerations, this paper proposes a compact UWB circular patch antenna with integrated multi-band notch characteristics using a defected ground structure, specifically designed for IoT wireless devices operating in interference-prone environments.

2.. LITERATURE REVIEW

Ultra-wideband UWB antenna design has been widely explored in the last decade with respect to the optimization of bandwidth, suppression of interference, miniaturisation, and application in new generations of wireless communication and Internet of Things networks. In the initial stages, researchers mainly aimed at designing UWB antennas with a wide impedance band and consistent radiation characteristics. However, work done by Liao et al. [2] introduced a semi-circle-shaped UWB antenna with triple band-notch characteristics, which utilized a defected ground structure and a complementary split-ring resonator. Even though excellent suppression of interference was attained, designing such an antenna added complexity and hindered miniaturization. Similarly, work carried out by Rajya Lakshmi [3] designed a UWB circular microstrip antenna with a band-notch feature, which accomplished effective suppression of interference. In addition, only a single notched band was suppressed.As a result, new investigations in the area have been carried out on circular and ring-shaped UWB antenna designs because of their miniaturization feature and symmetrical radiation characteristics. Sagar et al. [4] proposed a circular ring UWB antenna with DGS achieving a wide operating bandwidth from 2.4vto 10.4 GHz. While the antenna demonstrated enhance bandwidth and gain, it did not incorporate any band notched features to mitigate interference from coexisting narrowband systems.Elajoumi et. al,[7] further explored novel UWB Microstrip antenna structures with DGS ,emphasizing bandwidth enhancement and radiation improvement rather than interference suppression. Slot based and resonator based notch techniques have also been widely reported.

Bhattacharya et.al. [5] proposed a compact UWB monopole antenna with tunable band-notch characteristics, enabling frequency agility through slot loading. Although tenability was achieved, the design involved increased complexity and focused on a single adjustable notch band.Bong et.al.,[21] presented a dual

Bong et al. [21] presented a dual-band-notched UWB antenna using slit structures to suppress WLAN and 5G interference; however, the antenna lacked multi-band rejection and circular patch geometry. Similarly, Subramanian and Kalva [13] utilised a single parasitic element to achieve dual-band notch characteristics, which was effective for X-band suppression but insufficient for multiple interfering bands encountered in dense IoT environments. Resonator-based approaches using split-ring resonators (SRRs) have also been investigated. Sura et al. [14] designed a dual-band notched UWB antenna loaded with SRRs and L-shaped stubs. Although precise notch control was achieved, the antenna design was limited to dual-band rejection and did not emphasise compact circular patch configurations or IoT-specific integration constraints. Jagadeesh Chandra et al. [8] proposed a circular patch antenna loaded with complementary ring slots (CRS), achieving ultra-wideband performance with enhanced bandwidth, but without explicit multi-band notch implementation.

More advanced techniques, such as reconfigurable and switchable band-notch mechanisms, have also been explored. Yang et al. [22] introduced a stepped-slot UWB antenna with switchable band-notched functions, offering enhanced band-edge selectivity. However, the use of active switching elements increased design complexity and power consumption, which is undesirable for low-power IoT devices. Zhang et al. [10] investigated configurable defected ground structures (CDGS) for low-profile antennas, demonstrating improvements in mutual coupling reduction and polarization control, but without addressing UWB multi-band notch characteristics. Recent studies have focused on MIMO and compact IoT-oriented UWB antennas. Kumar et al. [12] proposed a two- and four-port UWB MIMO antenna with WLAN and X-band notch characteristics using DGS, achieving high isolation and effective interference suppression. However, MIMO configurations increase antenna size and design complexity. Ahmed et al. [18] presented a compact UWB antenna for IoT applications, emphasizing wide bandwidth and device integration, but lacking explicit band-notch mechanisms. Zhao et al. [17] proposed a miniaturized UWB antenna with a single notch band using branch structures, suitable for compact devices but limited in multi-band interference mitigation.

Circular polarization and other notch methods have also been described. Poorna Priya et al. [6] and Verma et al. [20] investigated CPW-fed and EBG notched antennas, respectively, emphasizing polarization diversity and improvement, but not for multi-notched UWB applications. Chen et al. [23] designed a DGS-assisted antenna for IoT applications in LTE bands; however, the antenna was narrowband and not designed for UWB applications. From the above literature survey, it is clear that most of the existing UWB antennas are designed either for bandwidth enhancement or for single/dual band-notch characteristics. Only a few studies have been conducted on compact multi-notched UWB circular patch antennas employing defected ground structures, specifically with a focus on interference mitigation for IoT wireless communication.

Figure 1 shows the distribution of existing research work on Ultra-Wideband (UWB) antennas from the comprehensive literature survey carried out in this research work. It is noted that a substantial amount of existing research work, about 26.9%, is on single or dual-band-notched UWB antennas, for which the interference nulling is restricted to one or two co-existing wireless systems like WLAN or X-band radar. Examples of such research works include slit-UWB, parasitic-UWB, and SRR-UWB notch antennas described in [5], [13], [14], and [21].

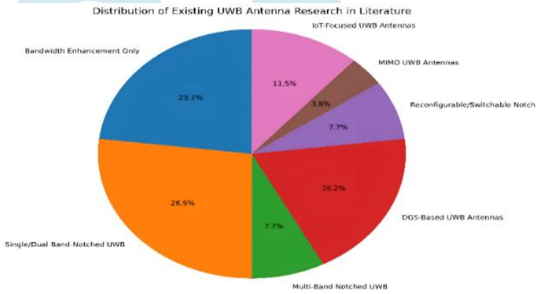

Fig. 1 Distribution of existing UWB antenna research in the literature

Another major share of the literature, accounting for about 23.1%, focuses primarily on bandwidth enhancement without explicitly incorporating band-notch characteristics. These studies emphasise achieving wide impedance bandwidth using modified patch geometries or defected ground structures, but do not address interference suppression from coexisting narrowband systems, as reported in [4], [7], and [11].

Almost 19.2% of the literature uses defected ground structure (DGS) UWB antennas, which proves the efficiency of DGS in enhancing impedance bandwidth, radiation characteristics, and surface current suppression. But most of these designs use DGS only for bandwidth enhancement purposes and not for multiple band-notching properties, as seen in [7], [10], and [11]. The research on IoT-oriented UWB antennas accounts for almost 11.5% of the entire literature. These studies concentrate on miniaturisation, low profile, and easy integration with IoT devices, but do not provide full-proof multi-band interference suppression [17], [18], [23].

Only a small fraction (about 7.7%) of the existing literature discusses multi-band notched UWB antennas. This shows that designs that can suppress more than two interfering bands are quite rare [2], [16]. Similarly, reconfigurable or switchable band-notched antennas make up around 7.7% of reported works. Although these antennas provide frequency flexibility, they often depend on active components, which raises design complexity and power use. This is not ideal for low-power IoT devices [5], [22]. Finally, MIMO-based UWB antennas represent the smallest share at about 3.9%. This reflects the limited number of studies on multi-port UWB systems with built-in band-notch features. While MIMO configurations offer better isolation and diversity, they usually lead to larger antennas and more complex systems [12].

Figure 1 show overall distribution of compact circular patch antennas using defected ground structure, specifically optimised for IoT wireless devices. This observation strongly motivates the proposed work, which aims to address this research gap by introducing a compact UWB circular Patch antenna with DGS enabled multi band notch characteristics and also offering an effective and low cost solution for interference aware IoT communication.

3. ANTENNA DESIGN AND CONFIGURATION

3.1 Antenna Geometry

The proposed antenna is designed on an FR4 substrate with a relative permittivity of 4.4, a thickness of 1.6 mm, and a loss tangent of 0.02. The antenna consists of a circular radiating patch on the top layer and a partial ground plane with a defected ground structure on the bottom layer. A microstrip feed line is used to excite the antenna and ensure proper impedance matching. The overall antenna dimensions are kept compact to facilitate easy integration into IoT devices such as smart sensors, wearable electronics, and portable communication modules. The circular patch geometry is selected to achieve symmetric radiation characteristics and wide impedance bandwidth.

3.2 Band-Notch Mechanism

To reduce interference from nearby narrowband systems, multiple band-notched features are created by combining slot loading on the circular patch with a defected ground structure (DGS) on the ground plane.

1. Patch Slots: Etched slots on the circular patch create resonant paths that form stopbands at certain frequencies. The notch frequency mainly depends on the effective length of the slot, which roughly follows the half-wavelength resonance condition.

2. Defected Ground Structure: The DGS changes the surface current distribution on the ground plane. This improves impedance bandwidth and leads to sharper band rejection.

By carefully adjusting the slot sizes and DGS design, notches are added to reduce WiMAX, WLAN, and X-band interference while maintaining UWB performance.

4. SIMULATION SETUP AND OPTIMIZATION

The antenna is modelled and simulated using a full-wave electromagnetic solver such as HFSS. A parametric analysis is conducted to optimize critical design parameters, including:

1. Radius of the circular patch
2. Dimensions and positions of the slots
3. Shape and size of the defected ground structure
4. Feed line width and length

The optimization objectives include achieving

1. $|S_{11}| \leq -10$ dB across the UWB band
2. Deep and sharp notches at the desired interference frequencies
3. Stable radiation patterns and acceptable gain levels

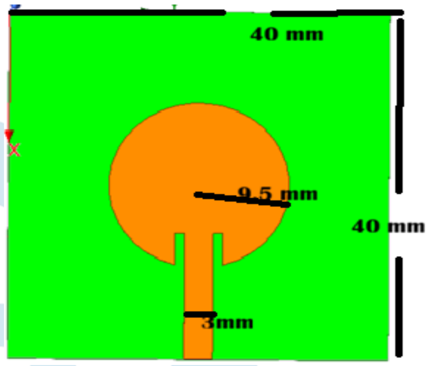

Fig.1.a Front Side

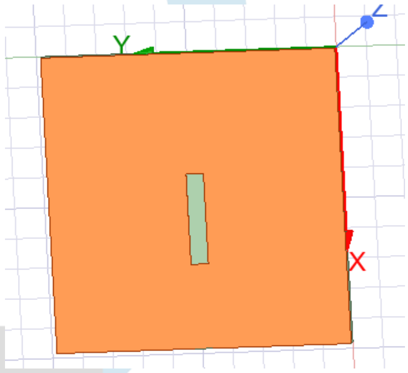

Fig 1.b Back side with DGS Slot

Figure 1 a and 1b shows front side and back side of the antenna. The antenna dimensions are 40 x40 x1.6 mm^3 and rectangular slot DGS at the ground plane.

5. RESULTS AND DISCUSSION

5.1 Reflection Coefficient (S_{11})

The simulated reflection coefficient shows that the proposed antenna is resonant at 3.49, 6.2 and 9.25 GHz.S11 values are -16.76, -34.076 and 11.326dB, respectively for different frequencies are3.49, 6.2 and 9.25 GHz. Different notches are observed at the targeted Distinct notches are observed at the targeted interference bands, confirming effective suppression of WiMAX, WLAN and X Band Signals.

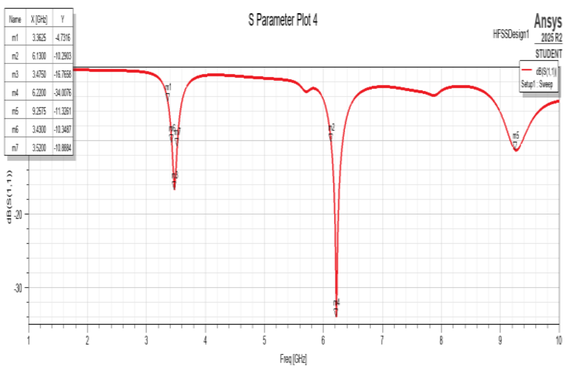

Fig.2 Return Loss

5.2 Voltage Standing Wave Ratio (VSWR)

The VSWR is 1.49 at the UWB operating band, except at the notched frequencies, where it increases sharply. This behaviour validates the effectiveness of the band-notched design.

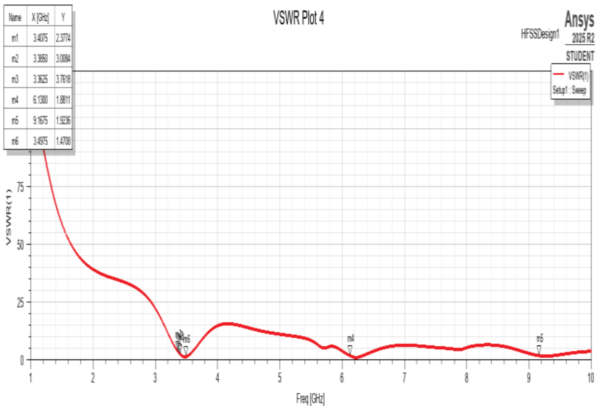

Fig.3 VSWR

5.3 Radiation Characteristics

The antenna exhibits nearly omnidirectional radiation patterns in the H-plane and stable bidirectional patterns in the E-plane across the UWB band. Minimal pattern distortion is observed, which is desirable for IoT communication scenarios involving random device orientations.

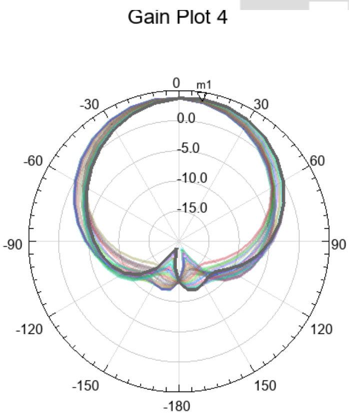

Fig.4 Radiation Pattern

5.4 Gain Performance

The antenna achieves an average realised gain of 3.84 dBi over the UWB band. At the notched frequencies, a significant gain reduction is observed, further confirming successful band rejection.

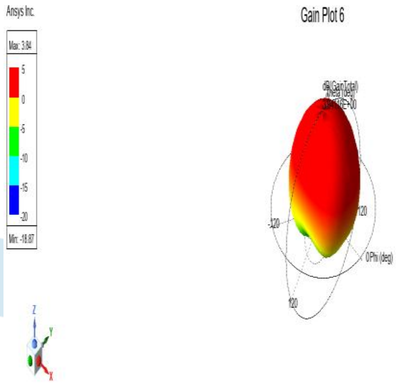

Fig. 5. Gain

5.COMPARISON WITH EXISTING WORKS

From the above result, it is evident that the proposed antenna achieves wide impedance bandwidth and stable radiation behaviour using compact circular patch geometry and Defected ground structure. Compared to conventional antennas, the proposed design offers improved design suppression without increasing design complexity. Low fabrication cost using FR4 substrate.

Table 1 shows the proposed methodology, and it is compared with the references.

Table 1 Comparison with Existing work

REF.	UWB Bandwidth	No. of Notches	Notched Bands	S11	VSWR	Gain (dB)
[2]	3.1 to 10.6	3	WiMAX ,WLAN and x Band	< -15 dB	2	3.2
[4]	2.4 to 10.4	0	-	<-15	<2	3.2
[12]	3.1 to 10.6	2	WLAN and x Band	<-18 [	1.49	4.5
Proposed Method	3.1 to 10.6	3	WiMax, WLAN	-34.07	1.49	3.84

6.**CONCLUSIONS**

This paper presented the design and analysis of a compact multi-notch UWB circular patch antenna with defected ground structure for IOT wireless devices. The antenna achieves a wide impedance bandwidth, effective suppression of multiple interfering bands, stable radiation patterns, and satisfactory gain performance. The simple geometry and low-cost substrate make the proposed antenna a strong candidate for integration into compact IOT systems.

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