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A Novel Compact CPW-fed Octagonal-Shaped Slotted Antenna for UWB Applications

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ABSTRACT

A size-reduced CPW-fed Ultra-Wideband (UWB) octagonal-shaped patch antenna with a combination of multiple slots designed for UWB applications is proposed here. The proposed low-profile antenna includes three equal-sized slots in an octagonal radiating patch. Moreover, better matching is provided by the feedline's U-shaped slots. A new combination of CPW configuration with a slotted octagonal patch increases bandwidth and reduces antenna size. The fabricated prototype of this octagonal-shaped antenna is situated on a basic FR4 substrate with a relative permittivity of ε_r = 4.3. The suggested antenna's substrate size measures 15 x 21 x 1.6 mm^3 and has an 8.8 GHz overall bandwidth, which includes the frequency range of 3 GHz to 11.8 GHz. Variations in gain range from 1.3 to 3.2 dB, with an average overall efficiency above 81 %. This antenna has been fabricated and successfully validated with simulated results. Other features include its compactness, directivity, realized gain, and stable radiation properties across the entire operating band, proving its effectiveness.

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1. INTRODUCTION

The most fundamental requirement for an Ultra-Wideband (UWB) system is an antenna that can take in all signal elements spread over the whole UWB employed band without signal distortion in the phase of these received components. The radiation patterns and matching features should be consistent over the UWB spectrum. The design of printed monopole UWB antenna is popular for wireless communication due to their low cost and small size, making it possible for simple integration with other equipment. UWB technology has features such as deficient power levels for communication over short distances and high information distributed over a broad spectrum [1]. It is challenging to make antennas with appealing features such as better size reduction, consistent radiations, improved impedance matching, and inexpensive. Patch antennas are excellent choices for UWB applications because of their tiny, flat de-sign and simplicity of integration with different types of electrical components [2].

Unfortunately, because of various intrinsic limitations for electrically tiny antennas, developing a smaller UWB antenna is extremely difficult in practice [3-7]. Particularly, decreasing the size of the structure results in the current channel to shorten, which in turn causes the impedance matching at lower frequencies to become less effective. In the last few years serval designs have been proposed to improve the characteristics of UWB antenna as well as its radiation efficiency [8]. It has been demonstrated that by progressively integrating multiple pairs of rectangular notches between the two ends of the radiation patch, the H-plane pattern becomes more stable. The key to achieving smaller dimensions is meticulous planning that reduces space while maintaining adequate electrical performance [9]. It has been observed that the impedance bandwidth of circularly and elliptically planar monopole an-tennas can be increased by introducing stages to the lower boundary of the patch [10].

Different feed methods, etching slots, multiple resonators, reactive loads, metamaterials, etc., can all be used to create multiband antennas [11]. Metamaterials have attracted a lot of interest lately for use in multiband antenna design. The most frequent shapes for tiny UWB antennas include circular, tri-angle, stepped rectangle, square, ring, ellipse, pentagon, and hexagon. Numerous methods, including the low permittivity substrates, multiple feeding concepts, multiple slots and slits geometry, lumped element loading, shorting posts, and fractal geometry, have been reported in the literature as ways to boost the bandwidth of UWB antennas. It is possible to mix different UWB approaches to create a hybrid structure that operates efficiently. Nowadays, a combination of structures is employed in the development of the majority of UWB antennas [12].

In CPW configuration, low dispersion and regulated impedance matching are guaranteed by a core signal strip encircled by two ground planes with a tiny space between them. Slots are incorporated into the radiating patch or ground plane to enhance impedance matching, boost bandwidth, and optimize radiation characteristics. The antenna's wideband performance and consistent omnidirectional radiation patterns are provided by the excitement of many resonant modes through these slots [13]. Because the CPW feed topology is easy to integrate with active circuits, fabrication losses and complexity are reduced. The antenna's compact size, excellent radiation efficiency, and improved impedance bandwidth can be achieved by carefully changing the feed location and slot shape. Because of this, it is perfect for UWB applications including radar, imaging systems, and short-range wireless communication.

The impedance bandwidth is improved by an extra L-shaped stub and a rectangular slit in the modified ground plane, approximately spanning from 3 to 12 GHz. Its electri-cal efficiency is good, and its size is quite little [14]. The antenna is composed of several circular radiators with trun-cated segments, a microstrip line for feeding, and a partially ground plane. This structure offers WLAN and UWB bands an operational bandwidth of 2.13–12.4 GHz. A U-shaped slot with the patch is designed using the centre notch frequency of 3.7 GHz [15]. Two miniature UWB antennas with partial ground plane and band-notches on microstrip feeding have been demonstrated in another work. The patch has been de-signed as a semi-circle using different stages that improve impedance bandwidth, particularly on the upper-frequency end ranging in the (3.1–10.6 GHz) UWB range. To remove the noise level from the lower WLAN (5.1–5.3 GHz) band, two U-shaped inverted resonators, each having a half-wavelength electrical length, are inserted around the feedline. This prevents interference from the upper WLAN (5.7–5.8 GHz) band [16].

It is possible to get a good matching throughout a broad frequency band by applying a wideband approach to the antenna and feeding that matches with impedance. The tapered ground plane of a rectangular patch monopole antenna is provided better miniaturization [17]. Research indicates the use of monopole antennas, which provide enhanced bandwidth and an almost omnidirectional pattern. An ultrawide bandwidth is generated by combining three separate stimulated modes. The ground plane operates as a scattered matching network and tapering it off reduces the capacitance between it and the radiator. The small size, cheap manufacturing cost, simple fabrication, thin profile, and exceptionally small ground plane of the monopole antenna make it suitable for integration with compact UWB systems [18].

A UWB antenna is one such application where fractal patterns are mixed with additional DGS (Defected Ground Surface), slots, and various feeding methods. The design and implementation of multiband and ultra-wideband antennas have made great use of it [19]. This investigation shows a novel CPW-fed slotted octagonal shaped patch antenna with multiple slots loaded. The proposed antenna has a total volume of approximately 29 x 31 x 1.6 mm^3. This antenna is suitable for incorporation with compact-sized UWB systems because of its small size, simple fabrication, low cost, low profile, and one-sided radiating material. The antenna underwent significant parametric analysis. The proposed antenna's performance is outlined in following section by its scattering parameters, impedance bandwidth, and radiation behavior.

2. DESIGN METHODOLOGY

The proposed octagonal patch antenna's evolution is illustrated in detail in Figure 1. The top layers of this proposed UWB antenna are made of copper material and have been changed to provide an appropriate slot-inspired circular patch which is connected to a CPW feed on same side to transmit/receive signals. Underneath the octagonal patch exists an FR-4 dielectric substrate with a permittivity value of 4.4 and a thickness of 1.6 mm. The complete antenna is 15 x 21 mm² in size. Coplanar Waveguide feeding, with a 2 mm width, feeds the suggested antenna with an impedance of 50 Ω.

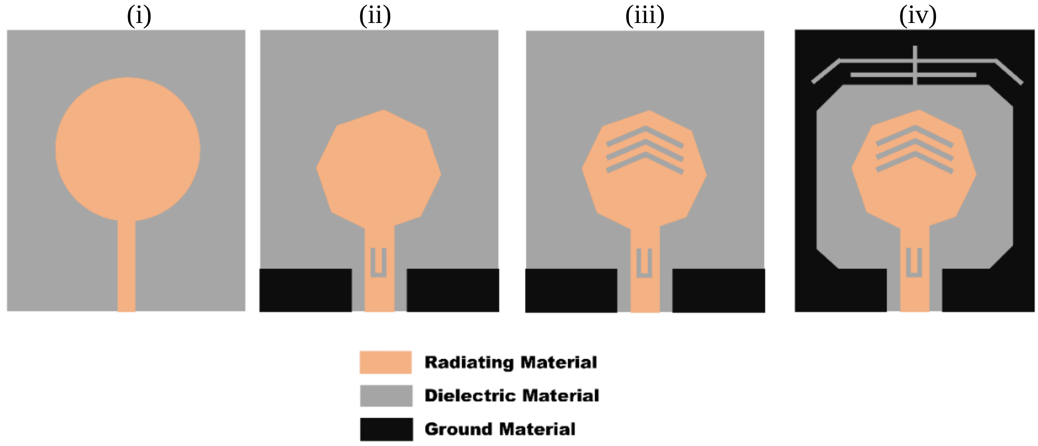


Figure 1. Parametric iterations. (i) Antenna 1, (ii) Antenna 2, (iii) Antenna 3, (iv) Antenna 4.

Figure 2 depicts the proposed antenna's development process. This proposed antenna, which used a simple circular patch as the base model. The original form of the antenna is computed using a full ground plane and the basic layout calculation for a circular microstrip patch antenna [20].

$$f_r = \frac{c}{4\pi D\sqrt{\varepsilon_{eff}}}$$

'c' denotes the velocity of light, 'ε_{eff}' is the corresponding dielectric constant, and 'D' is the outer circumference of the circular patch. Stage 1 covers a very narrow spectrum at 3.1 GHz. Based on current distribution, base antenna structure modified by slits and slots are added to it. On Stage 2, that stage is made by removing ground plane and create CPW feeding on top side. Etching a U-shaped slot in the feedline, the lower frequency of the UWB band is resonated. At the next step of this antenna design includes the three equal shaped slots are etched in maximum current flowing in octagonal patch. This is implemented in Stage 3. To achieve the whole wideband and achieve a minimum possible size reduction, whole outer areas are made of slotted ground plane. That final design is shown in Antenna 4. The physical dimensions are 21 mm in length, 15 mm in breadth, and 1.6 mm in height. This UWB microstrip antenna operates in the frequency range of 3 GHz to 11.8 GHz. In essentially, this antenna produces an 8.8 GHz bandwidth. Table 1 lists every required dimension for the proposed antenna.

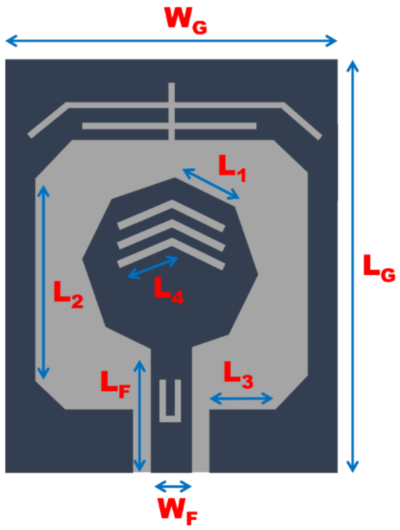


Figure 2. Total geometry and configuration of the proposed antenna.

Table 1. Parameter of the Proposed Antenna

Parameter	W_G	L_G	W_F	L_F	L_1	L_2	L_3	L_4
Size (mm)	15	21	2	6.4	3.1	9.8	3.2	2.8

3. RESULTS AND DISCUSSION

Using an Agilent Vector Network Analyzer (VNA), the performance of the manufactured design is assessed, including bandwidth and normalized gain. Radiation findings are measured in the anechoic chamber. Figure 3 shows a picture of the measuring setup and the manufactured prototype. The results of the simulation and the measurements agree well, with the major causes of the minor differences between the two being cable loss and manufacturing tolerance. Assessing the antenna's functionality and effectiveness involves determining the peak gain, radiation pattern, and reflection coefficients. The amount of the incident energy that returns back because of an impedance mismatch across the transmission network and an antenna is measured by the reflection coefficient (S_{11}). Superior matching of impedance is indicated by a lower reflection coefficient, which maximizes power transmission with minimal signal loss. It is essential for optimizing antenna bandwidth and performance and monitoring using a VNA. The suggested antenna's reflection coefficient is examined and simulated over the complete UWB band using CST Microwave Studio. Since the proposed antenna is properly matched with a 50-Ω impedance, better impedance matching has been achieved, and the maximum reflection coefficient is -48.5 dB obtained at the band of 8.7 GHz with an increased gain.

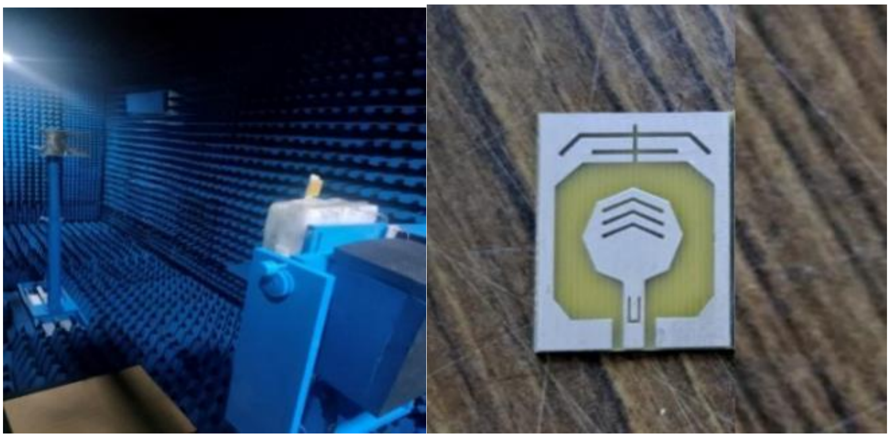


Figure 3. Measurement setup and fabricated prototype of this antenna.

Figure 4 shows the compact circular UWB antenna's combined measured and simulated reflection coefficients. The antenna's (S_{11}) parameter matching is made abundantly evident by the graph. This antenna radiates at the level $S_{11} < -10$ dB in the simulation, with a wideband of 8.8 GHz from 3 GHz to 11.8 GHz. The measured observed impedance bandwidth is approximately 9.2 GHz, and the prototype resonates band 3.2 GHz and 12.6 GHz. The findings of the simulation and the fabrication agree fairly well. There could be a fabrication and measurement tolerance causing the little fluctuation in the reflection coefficient seen in the resonant band.

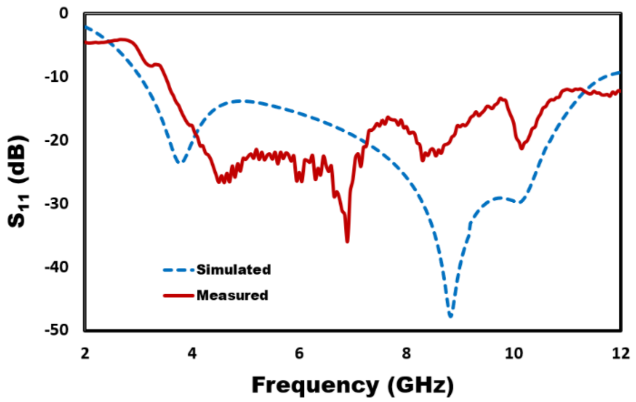
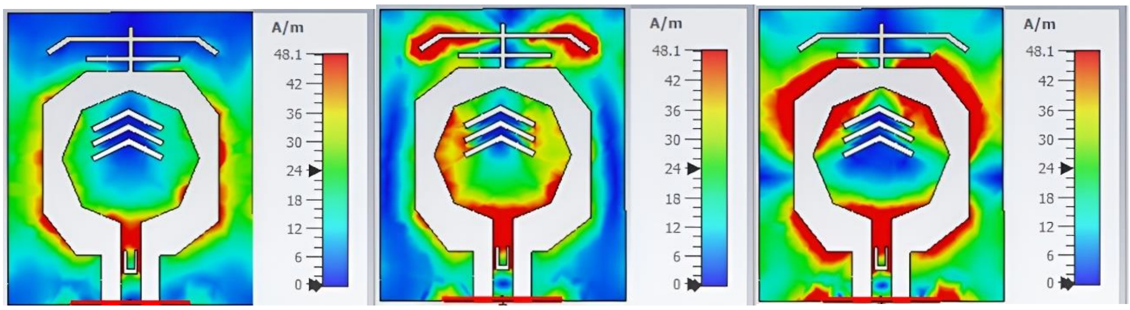


Figure 4. Combined reflection coefficients of the proposed antenna.

Figure 5 depicts the distribution of current density for each frequency to help with the antenna's performance analysis. As it can display the distribution of surface current at 3.5, 7.5, and 10.5 GHz, respectively. The greater gain concerning the increased electrical length of the slots is because of strong distributions over the outer edges of the flower-shaped slots and feedline, which acquire more resonances. This is believed to be the cause of the UWB characteristics. Figure 5(i) makes it clear that currents are mostly flowing through the feed of the patch at lower frequencies. Figures 5(ii) & 5(iii) show the greatest distribution along the boundaries of the inner and outer octagonal patch, which is reason for the wider bandwidth at middle and upper frequencies. The surface current distributions show that the feed line and patch's outside regions are where most of the current is concentrated.

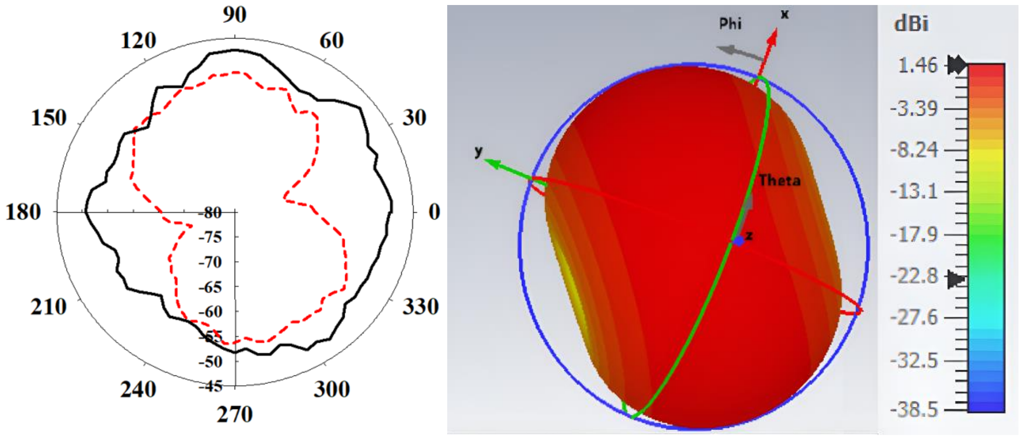


(i) (ii) (iii)

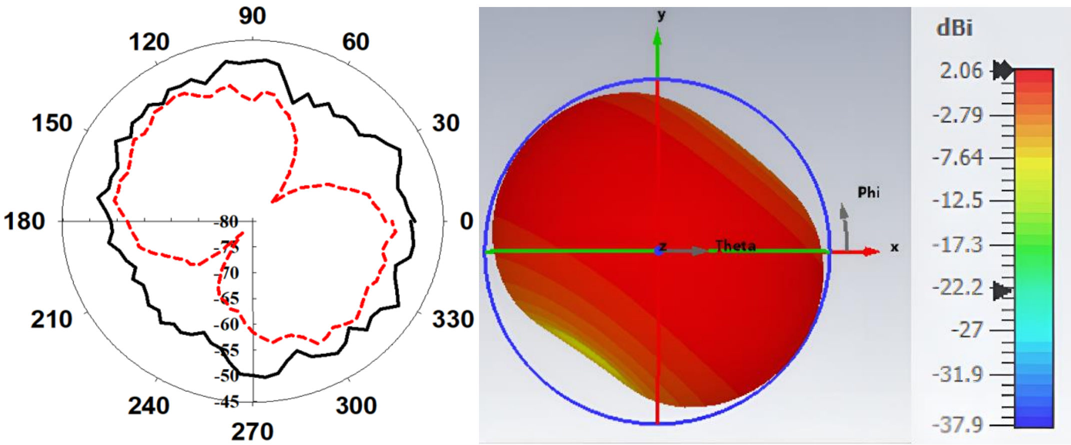
Figure 5. The simulated current distribution of the proposed circular patch antenna. (i) 3.5 GHz (ii) 7.5 GHz and (iii) 10.5 GHz.

A carefully thought-out radiation pattern minimizes interference and undesired lobes while guaranteeing that the antenna efficiently sends or receives messages in the intended directions. Over the whole achievable UWB band, the obtained radiation parameters of this antenna are analyzed. Plotting of the selected resonant frequencies for 3.5 GHz, 7.5 GHz, and 10.5 GHz in the E- and H-planes is shown in Figure 6. The results are shown by displaying the antenna's H and E planes together. E-plane and H-plane radiation patterns, which are roughly bidirectional and omnidirectional, allow the antenna to span the whole frequency range.

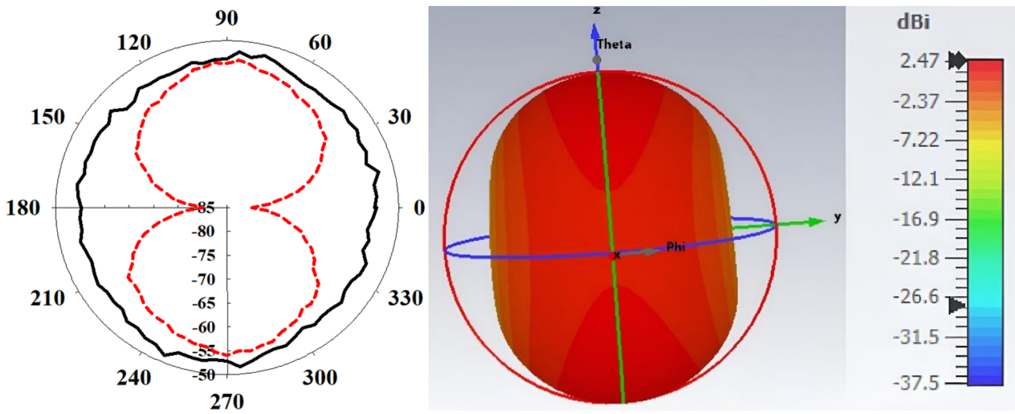
(a) (b)



(i)



(ii)



(iii)

Figure 6. Measured radiation patterns of the antenna. (a) 2D pattern and (b) 3D pattern. (i) 3.5 GHz (ii) 7.5 GHz and (iii) 10.5 GHz.

Assessing the antenna's oscillating activity in response to an input voltage or stimulation is a crucial part of time domain assessment. By evaluating the antenna's dependability, settling time, and overall efficiency during first signal transmission, the study assists personnel in understanding how well the antenna operates during startup. An examination of the voltage applied at 0.4 nS as a time measure for the sent and received pulses is presented in Figure 8.

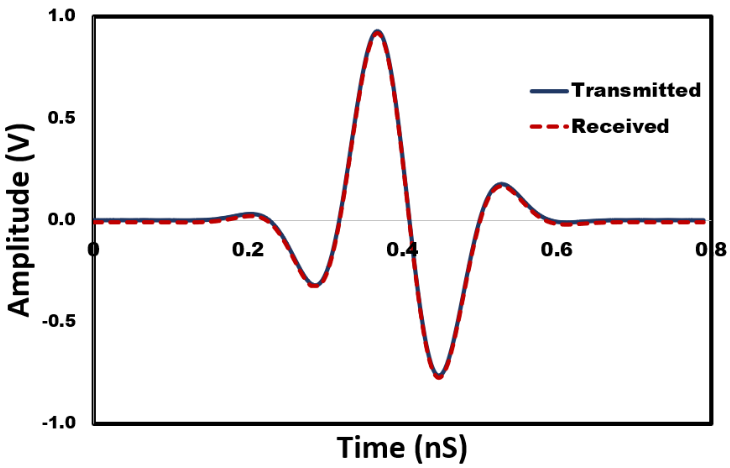


Figure 8. The amplitude value of the proposed work.

Table 2 compares the suggested antenna design with existing small UWB antennas are documented in the brief literature according to antenna size, the substrate, fractional bandwidth, and peak gain. Furthermore, compared to previous studies, the following table shows that the proposed antenna obtains a good reduction in size and gain for whole bands.

Table 2. Comparison with previously published UWB antennas

Reference no.	Antenna size (mm)	Substrate used	Operating frequencies (GHz)	Fractional Bandwidth (%)	Peak Gain (dB)
This Work	**15×21×1.6**	**FR-4**	**3.1 – 13.6**	**125.8**	**3.2**
[21]	21×23.52×1.6	FR-4	3.14 – 13.5	124.5	~2.5
[22]	28×18×1.6	FR-4	3.1 – 13.4	124.85	~ 1.1 - 5.5
[23]	16×25×1.52	TLY 5A	3.1 – 12.5	120.5	4.5
[24]	17.6×16×0.12	Flexible PET	2.9 – 10.61	114	5.5
[25]	21.6×20.8×1.6	FR-4	2.2 – 16.5	153	3.45
[26]	300×143×1.6	FR-4	0.5 – 6	169.23	11.9
[27]	50×42×1.57	FR-4	2 – 12	142.86	5.2

Figure 7 displays the designed antenna's radiation efficiency and achieved peak gain. The designed antenna achieved an optimal radiation efficiency of 81% and an average gain of 3.2 dB at an operating frequency of 10.2 GHz. For UWB-notch applications, the proposed antenna's small dimensions, improved gain, better radiation efficiency, and simple construction make it a suitable device.

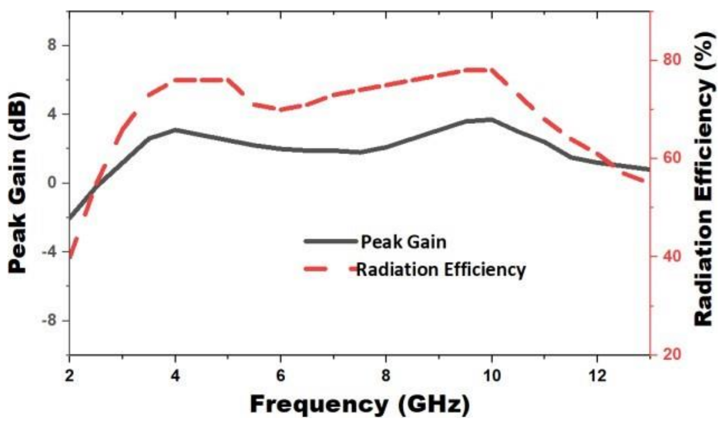


Figure 7. Gain and radiation efficiency analysis at entire resonated UWB band.

4. CONCLUSION

A small, octagonal, CPW-fed UWB antenna with numerous slot configurations is described in this investigation. FR4-Lossy material has been used for substrate in the antenna's design. Examined as UWB characteristics are a slotted octag-onal patch, a ground plane in the patch's outer region, and a U-shaped slotted in the CPW feedline. A new combination of CPW configuration with a slotted octagonal patch allows for both bandwidth increase and antenna reductions. The suggested antenna's substrate is 15 x 21 x 1.6 mm3, and under measurement conditions, its 10.5 GHz bandwidth includes the frequency range between 3.1 GHz to 13.6 GHz. Based on its performance, this antenna may be a more cost-effective choice for UWB applications.

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