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Design of a Novel Capsule-Shaped Compact UWB Antenna for 5G Wireless Applications

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In this paper, a simple and novel Ultra-wideband (UWB) micro strip patch antenna is developed with a compact dimension (15 × 12 × 0.8) mm^3 and low complexity. This design improves a number of microwave circuit features, including wide bandwidth, and achieved optimum gain, among others. The proposed antenna is intended to operate in the frequency range from 22 to 29.6 GHz, the antenna is mounted on a Rogers RT Duroid 5880 compact dielectric substrate with a thickness of 0.8 mm and a dielectric constant of ($\varepsilon_r = 2.2$). Elliptical slots have been added in the simple capsule shape radiating patch to achieve wideband performance for the proposed antenna structure. The proposed antenna, with a frequency range from 22 to 29.6 GHz, has a wide bandwidth of 7.6 GHz. As a result, the proposed antenna design is small and appropriate for higher frequencies. The results of the simulation confirm that the antenna model is appropriate. In comparison to conventional patch, performance parameters like reflection coefficient, gain, and VSWR has improved. The EM simulator Ansoft HFSS v.15.0 performs all essential simulations, and a thorough comparative analysis based on the current antennas is performed. The suggested antenna has good impedance matching at $|S_{11}| < -10$ dB, VSWR is less than 2 and peak gain is 6.08 dBi at 24 GHz. Since the suggested antenna resonates at millimeter wave frequencies, it can be used for 5G applications. These excellent results in terms of tiny size, UWB operating band, high gain, good impedance matching, desired radiation features suggest that the proposed antenna would be a decent choice for 5G mm-wave applications.

Keywords: Capsule-shaped patch, Microstrip antenna, Millimeter waves, Ultra-Wide Band (UWB), 5G wireless communication systems.

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1. INTRODUCTION

5G stands for fifth generation and it is a wireless technology used in digital cellular networks. 5G technology frequency spectrum is divided into three major bands: Millimeter waves and its frequency range from 24 GHz to 40 GHz, it has fastest speed but smaller coverage area. Mid-band and its frequency varies from 1 GHz to 6 GHz, it is also called sub-6 GHz band. Low-band (less than 1 GHz), it is more extensive but slower speeds [1]. Antennas for 5G will play major role, specifically the performance of the 5G UWB microstrip patch antenna would enhance the performance of wireless communication systems of the next generation. Greater transmission speeds, extremely high data rates, increased dependability, lower latency, improved spectral efficiency, and the ability to connect a larger number of wireless devices to the networks are the main benefits of 5G technology. One of the most anticipated 5G innovations is the UWB microstrip patch antenna, which increases spectral efficiency by 50 times while boosting capacity compared to a traditional antenna [2].

The Microstrip patch antennas can meet the majority of the specified requirements nowadays. Even though microstrip patch antennas are small and have a low profile, they have several disadvantages like low return loss, limited bandwidth, and poor strength [3]. The most likely technology to be employed in short-range, high-speed indoor data transmission is ultra-wideband (UWB).

UWB antennas should typically be tiny and affordable while still providing appropriate wideband performance for a variety of industrial applications. Thus, obtaining better bandwidth, efficiency, and low profile within allotted reduced dimensions is one of the key problems of building UWB antennas. By altering the radiating patch's shape, the UWB antenna's properties can be enhanced. The basic patch can be round, elliptical, heart-shaped, rectangular, or any other shape.

Additionally, many antennas have large sizes and intricate designs that are inappropriate for portable wireless terminals with limited space. A 28 mm × 29 mm patch is printed with an *I*-shaped monopole antenna [4]. A 60 mm × 60 mm multiband antenna with an *H*-shaped slot is reported in ref. [5]. A wideband dual-polarized antenna with strong isolation and minimal cross-polarization is provided here by the author. The two linear polarizations are produced using a reflector ground plane and a pair of orthogonal planar printed dipoles. To increase isolation and cross-polarization, slots are carved out at the corners of the dipoles and brief connections are made between the

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orthogonal dipoles. The author of ref. [6] proposed a printed elliptical patch antenna with a band-notch frequency band at 5 GHz and a UWB operational bandwidth. This design yields a generally flat gain over the UWB frequency range, an impedance bandwidth from 2.97 to 15.09 GHz, band rejection of 4.90 to 5.86 for – 10 dB return loss, and an acceptable radiation pattern with the exception of the band rejection. The article in ref. [7] proposed a UWB Vivaldi antenna that is antipodal and has good impedance matching and gain. Two symmetrical sets of rectangular slits are implanted around the tapered slot to increase impedance matching at the low-frequency band, while the slot itself has an elliptical-shaped director placed in it to maximize gain at the high-frequency band. In ref. [8], authors proposed an extremely small dual-band antenna with a special patch inspired by the Fibonacci sequence and a rectangular ground plane slot. The ellipse's bandwidth is increased by connecting circular sectors and an *L*-shaped strip to the rectangular slot to create a UWB antenna. The ground plane also has a strip to control the circularly polarized behavior of the antenna. In [9], a low-cost UWB elliptic antenna is introduced by the author. The antenna is mounted on FR4 dielectric material, which has a compact size of (21 × 27 × 1.6) mm^3. It has a maximum Gain of 6 dBi and a 16.26 GHz impedance bandwidth. In [10], the author has provided an elliptic monopole antenna with a small size of (15 × 25 × 1.6) mm^3. A simple FR4 dielectric material is utilized in the antenna design. The frequency range between 3.1 GHz and 10.6 GHz, where the reflection coefficient is less than – 10 dB, is where the antenna operates most effectively. Additionally, the antenna's minimum and maximum gain values in the UWB range are 2.5 dBi and 9 dBi, respectively. In this article [11], the author presents a small (17 × 14 × 1.6) mm^3 elliptical antenna constructed of FR-4 material and suitable for mobile applications. The suggested antenna has a gain of 6.8 dBi and operates at a bandwidth of 24 GHz. In this article [12], the author describes a small (18.3 × 23 × 1.6) mm^3 elliptical antenna for ultra-wideband (UWB) using CPW that was constructed out of FR-4 material and operational frequency band of 3.6 GHz to 11.2 GHz. The unique feature of this antenna is its modest size and uni-planar form, which makes fabrication simple and inexpensive.

From the above literature survey, we find the research gap to minimize the antenna overall size while maintaining its essential characteristics.

2. PROPOSED ANTENNA DESIGN AND METHODOLOGY

A capsule-shaped microstrip line-fed tiny patch antenna for UWB and 5G applications is introduced in this paper. The primary goal of the work is to create results that can be used in higher-level 5G applications that operate in the 22-29.6 GHz frequency spectrum. A capsule-shaped patch, a portion of a ground plane, and a microstrip feed line make up the proposed design. The results from the simulation are presented for the antenna's reflection coefficient (< – 10 dB), VSWR (< 2), gain, and radiation pattern etc. In this article, we suggest a UWB antenna that is much tiny in size and has a very wide bandwidth that extends more than 7000 MHz. Additionally, it offers improved gain performance and stable desired radiation pattern characteristics that is advantageous for 5G wireless applications.

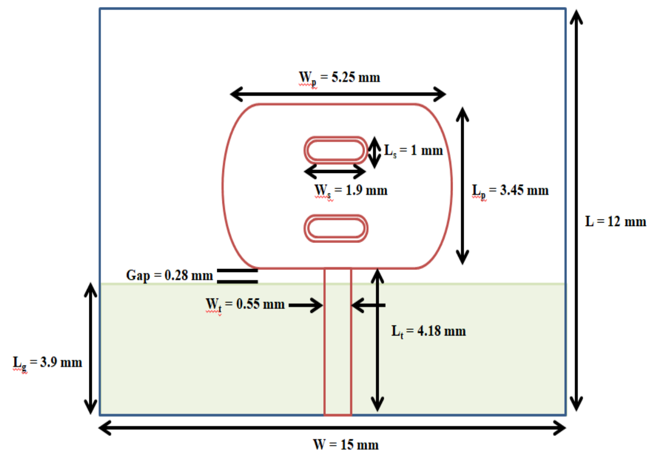


Fig. 1 – Proposed Antenna design with dimensions

Fig. 1 depicts the schematic for the UWB antenna. The initial engraving has been done on a partial ground (3.9 × 15 mm^2) Roger RT Duroid 5880 laminate with depth (t = 0.8 mm), permittivity (ε_r = 2.2), and tangent loss (tanδ = 0.0009). A capsule-shaped patch of radius 1.725 mm is coupled with a feed transmission line of 4.18 mm. Two elliptical slots are created by cutting two holes or slots from the radiating (capsule) patch in order to achieve a broader bandwidth. The slot-loading approach is identical to this technique. The proposed antenna structure has been designed and simulated using the High-Frequency Structure Simulator (HFSS).

Table 1 – Dimensions of the suggested capsule shaped UWB antenna

Parameters	Dimensions (mm)
Dielectric Substrate	Roger RT Duroid 5880
Thickness of Substrate (h)	0.8mm
Dielectric constant (ε_r)	2.2
Length of Substrate (L)	12
Width of Substrate (W)	15
Transmission line length (L_t)	4.18
Transmission line Width (W_t)	0.55
Ground Length (Lg)	3.9
Ground Width (Wg)	15
Capsule patch length (L_p)	3.45
Capsule patch width (W_p)	5.25
Elliptical Slots (E_1 and E_2) length (L_S)	1
Elliptical Slots (E_1 and E_2) width (W_p)	1.9

All dimensions pertaining to the antenna design's specifications is listed in Table 1. It is notable to mention that the proposed antenna has a small, miniature architecture that permits its integration into a range of 5G wireless devices. This suggests that the proposed antenna has exceptional performance since it can attain the maximum bandwidth possible while maintaining the smallest possible size.

3. RESULT AND SIMULATIONS

The Ansoft HFSS simulator is used to simulate antenna's performance between 20 GHz to 30 GHz frequency band. Reflection coefficient (S_{11}), bandwidth, voltage standing wave ratio (VSWR), gain, and radiation patterns are analyzed and presented in this section to evaluate performance of the proposed antenna.

Fig. 2 shows the S-parameter (S_{11}) of the antenna. The antenna has a 27.20 GHz resonance. At the resonant point, the reflection coefficient is approximately – 13.66 dB. With a reflection coefficient of (≤ – 10dB), the antenna achieves an ultra-wide bandwidth, which ranges from 22 GHz to 29.6 GHz.

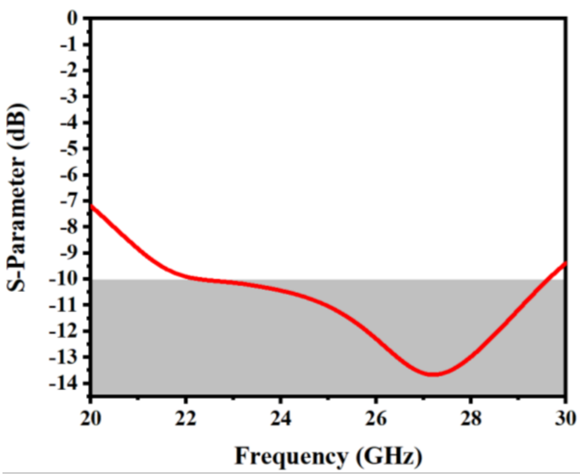


Fig. 2 – Simulated reflection coefficient (S_{11}) performance for Capsule shaped UWB antenna

Fig. 3 displays the VSWR value of the same antenna against frequency. The recommended capsule-shaped patch antenna provides adequate impedance matching at 27.20 GHz, as indicated by the VSWR value of 1.52 (i.e., less than 2). The suggested antenna is smaller than numerous existing antennas for relevant purposes that have recently been published. By adopting the slotted antenna technique, the gain at the center operating frequency is increased and a broader bandwidth is supplied.

Fig. 4 displays the gain of the suggested design in relation to frequency. The recommended antenna has minimum gains of above 3.50 dBi over the entire operating band (22-29.6 GHz). A peak gain of 6.08 dBi is obtained at 24 GHz, which are suitable gains over the operating frequency band.

Fig. 5 shows the proposed UWB antenna's 2D radiation patterns at different frequencies in terms of XZ (E-plane) elevation plane and YZ (H-plane) azimuthal plane which is expected from an ultra-wideband antenna.

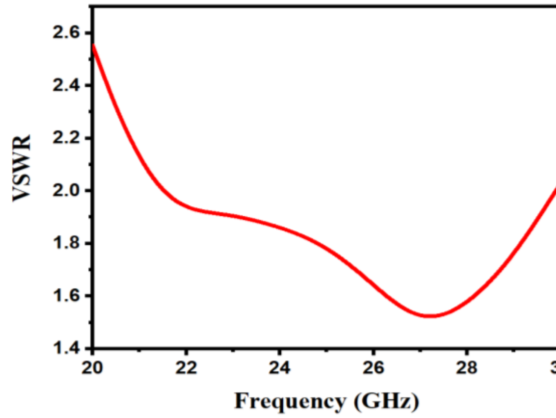


Fig. 3 – VSWR vs. Frequency Plot for Capsule shaped UWB antenna

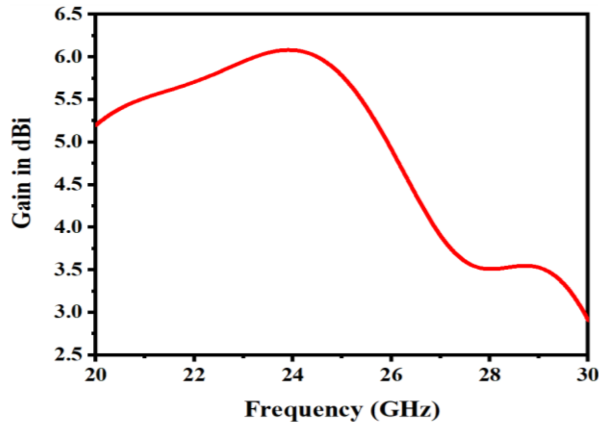
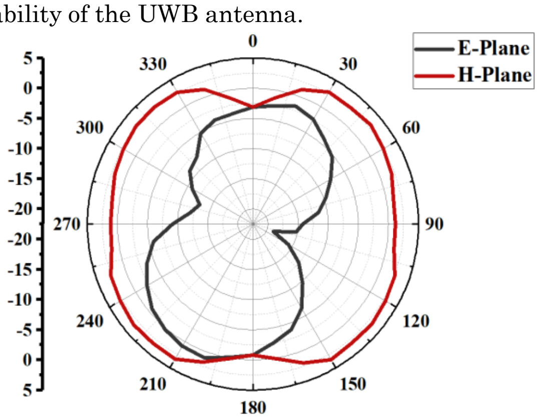
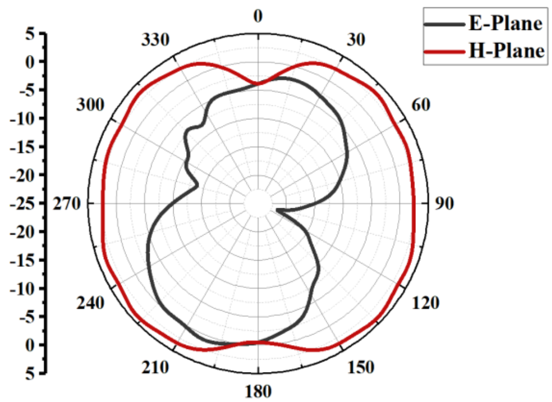


Fig. 4 – Simulated Gain vs. frequency performance of proposed UWB antenna

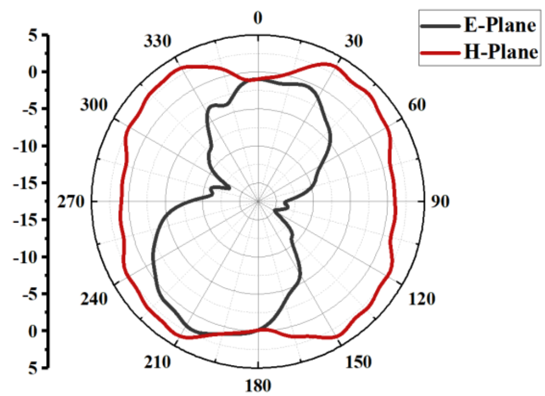
The radiation patterns are shown at different application bands (24, 26, 28 GHz). The radiation patterns clearly show a figure-eight shape pattern in the XZ-plane (phi 0°) and a pattern that is almost omnidirectional in the YZ-plane (phi 90°), respectively. The radiation patterns are almost stable throughout the whole wide coverage of the operating band. These findings demonstrate the suitability of the UWB antenna.



(a) 24 GHz



(b) 26 GHz



(c) 28 GHz

Fig. 5 – 2D *E* and *H*- Plane radiation patterns of the suggested UWB antenna (a) 24 GHz (b) 26 GHz (c) 28 GHz

4. PERFORMANCE COMPARISON WITH PREVIOUS REPORTED DESIGNS

The proposed UWB antenna's performance in terms of size, frequency band, gain, and VSWR has been compared with some previous works [13-18] that have been published in the literature and comparative summary is presented in Table 2. As compared to all previous antenna designs included in the comparison Table 2, the proposed antenna has compactness in size and also fulfills other characteristics parameters requirements like gain, VSWR and return loss etc. The suggested antenna also operates with ultra-wideband resonance and produces superior gain. So, here the proposed design is the appropriate choice for mm-wave high frequencies and 5G wireless communication systems as well as UWB applications.

Table 2 – Performance comparison between the suggested UWB antenna and some earlier works

Ref. No.	Size (mm^3)	Frequency Range (GHz)	Gain (dBi)	VSWR
[13]	20 × 20 × 1.5	3 to 15 (3.3,4.6, 9.2)	2.95, 4.15, 4.30	NP
[14]	38 × 40 × 1	5.15–5.825	NP	NP
[15]	41.95 × 21.2 × 1.27	2.5−10.5	5.2	NP
[16]	18 × 17 × 1.605	24−31	3.53	1.16
[17]	50 × 41 × 1.75	3−11.4	5.27	< 2
[18]	30 × 35 × 0.9	3.1−10.6	NP	< 2
[Proposed]	12 × 15 × 0.8	22−29.6	6.08	1.57

NP = Not Present

CONCLUSION

A simple and novel capsule shaped micro strip patch antenna with slot loading technique has designed and discussed for 5G applications at millimeter wave frequencies. At higher frequencies, the compactness ensures the antenna's incorporation into the constrained space around microwave electronics. In order to improve the antenna design, two elliptical slots are added, and as a result, the operating bandwidth is increased. The proposed antenna's optimal dimensions are (12 × 15 × 0.8) mm^3, which shows that it has compact size and very simple design. The suggested design offers advantages over other UWB micro strip antennas like less radiation loss, less dispersion, a new design, and good gain without the usage of any specific techniques. The antenna has a good VSWR (< 2), a wide bandwidth between 22 and 29.6 GHz, and a maximum gain that is satisfactory (6.08 dBi). One of the key advantages of the suggested design is its miniaturization. The suggested antenna is a good choice for both 5G and UWB applications at millimeter wave frequencies because of its appropriate geometry and its simple structure.

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Дизайн нової компактної UWB антени у формі капсули для бездротових додатків 5G

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У цій статті розроблено просту та нову надширокосмугову (UWB) мікросмужкову антену з компактними розмірами (15 × 12 × 0,8) мм³ і низькою складністю. Ця конструкція покращує низку характеристик мікрохвильової схеми, включаючи широку смугу частот і досягнуте оптимальне посилення, серед іншого. Пропонована антена призначена для роботи в діапазоні частот від 22 до 29,6 ГГц, монтується на компактній діелектричній підкладці Rogers RT Duroid 5880 товщиною 0,8 мм і діелектричною проникністю (ε_r = 2,2). Еліптичні щілини були додані в просту випромінювальну ділянку у формі капсули для досягнення широкосмугових характеристик запропонованої структури антени. Пропонована антена, з діапазоном частот від 22 до 29,6 ГГц, має широку смугу пропускання 7,6 ГГц. Як наслідок, запропонована конструкція антени є невеликою та підходить для високих частот. Результати моделювання підтверджують відповідність моделі антени. У порівнянні зі звичайним патчем покращилися параметри продуктивності, такі як коефіцієнт відбиття, посилення та КСВ. ЕМ-симулятор Ansoft HFSS v.15.0 виконує всі необхідні симуляції, а також виконується ретельний порівняльний аналіз на основі поточних антен. Запропонована антена має гарне узгодження опору на |S11| < – 10 дБ, КСВ менше 2 і пікове посилення становить 6,08 дБі на 24 ГГц. Оскільки запропонована антена резонує на частотах міліметрових хвиль, її можна використовувати для програм 5G. Ці чудові результати з точки зору невеликого розміру, робочого діапазону UWB, високого посилення, хорошого узгодження імпедансу, бажаних характеристик випромінювання свідчать про те, що запропонована антена підійде для додатків 5G мм-хвиль.

Ключові слова: Капсулоподібний патч, Мікросмужкова антена, Міліметрові хвилі, Ультраширокий діапазон (UWB), Системи бездротового зв’язку 5G.