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Design of Microstrip Fed Patch Antenna Using DGS for UWB Applications

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ABSTRACT:
Ultra Wideband (UWB) antennas hold immense significance in modern technology, offering a wide frequency range that spans several giga hertz. Their ability to transmit and receive short-duration pulses enables high-precision applications, such as radar, imaging, and communication. UWB antennas excel in delivering high data rates over short distances, making them pivotal for wireless personal area networks and multimedia streaming.
An ultra-wideband (UWB) microstrip-fed Pi-slot patch antenna with a T-slot defective ground structure (DGS) is designed for UWB applications. The antenna consists of a rectangular patch with a Pi-slot and a ground plane featuring a T-slot. Developed and modeled using the High-Frequency Structure Simulation (HFSS) tool on an RTDuroid 5880 substrate with a thickness of 1.6 mm and a dielectric constant of 2.2, this design aims to enhance the antenna's radiation properties, gain, and bandwidth. The T-slot in the ground plane used to significantly improve performance, resulting in a return loss for the conventional Pi-slot patch antenna.

INTRODUCTION:
The swift progression of wireless communication technologies has resulted in increased demand for small, broadband, and high-performance antennas. Microstrip patch antennas are a popular choice because they offer low-profile, lightweight, and low-cost advantages. However, the conventional designs have the notable disadvantages of small bandwidth and low gain, which make them ineffective for use in many of today's high-frequency applications [1], [2]. A variety of repair techniques have been reported, such as Defected Ground Structures (DGS), slot-loaded patches, and frequency-selective surfaces (FSS) [3], [4]. These repair techniques are valuable, as they can enhance impedance matching, radiation efficiency, and bandwidth with microstrip antennas when operating in the frequency ranges for ultra-wideband (UWB) applications [5], [6].
Specifically, the Pi-slot and T-slot designs are the most successful in aiding gain and bandwidth improvements. The Pi-slot on the patch manipulates the current distribution on the patch, which gives the illusion of an increase in electrical size and essentially shifts the resonant frequency [7], [8]. At the same time, the placement of the T-slot in the ground plane increases the impedance bandwidth by disrupting the current flow and allowing improved wave propagation [9], [10]. These alterations can optimize the UWB performance of the antenna while effectively operating over a large frequency range [11].
The work describes a microstrip-fed Pi-slot patch antenna with a T-slot defective ground structure (DGS) suitable for C-band and X-band applications. A RT Duroid 5880 substrate of 1.6 mm thickness and dielectric constant of 2.2 [12], [13] is used in the antenna's design due to its good dielectric characteristics. The proposed design uses a Pi-slot in the patch and T-slot in the ground so that the design has considerably

improved impedance bandwidth and gain that is suited for high frequency wireless applications [14], [15]. To assess the proposed design, simulation was performed using Ansys HFSS, which was used to assess important parameters including return loss (S11), voltage standing wave ratio (VSWR), radiation pattern and current distribution. The optimized antenna, which resonates at 9.95 GHz, works between 6.2 GHz to 11.1 GHz which is an impedance bandwidth of 4.9 GHz. The simulated peak gain of 5.4 dBi at the resonant frequency of the antenna demonstrates the efficacy of the design [16], [17].

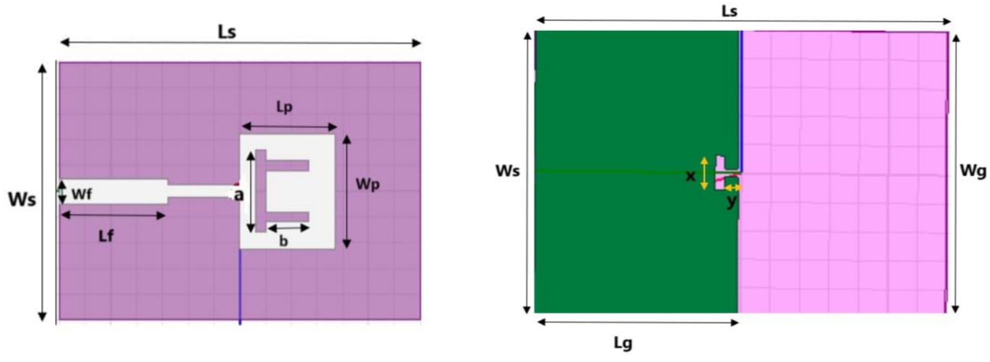
The designed antenna is particularly relevant in applications involving radar, satellite communication, weather monitoring, and vehicle speed detection. The Pi-slot and T-slot DGS combination presents a slim, compact, and high-performance design for modern UWB communication systems. High gain, broad bandwidth, and stable radiation features make it suited to be a strong choice for the future generation of wireless systems [18], [19], [20].

PROPOSED WORK:

The work proposed targets the design and development of a Pi-slot patch antenna with T-slot defective ground structure (DGS) for ultra-wideband (UWB) applications. The aim is to obtain better impedance bandwidth, gain, and radiation properties through the optimization of the geometry of the antenna and the use of a defective ground plane.

ANTENNA DESIGN AND STRUCTURE:

The antenna is fabricated on an RTDuroid 5880 substrate of thickness 1.6 mm and dielectric constant 2.2. A rectangular patch with a Pi-shaped slot is incorporated to increase current distribution and tune the resonance frequency. Moreover, a T-slot is cut on the ground plane to enhance impedance matching and broaden the bandwidth. The dimensions of the proposed antenna are optimized through Ansys HFSS to provide efficient radiation performance.



(a) (b)

Figure 1 An Ultra – Wide Band Pi-slot patch antenna with T-slot DGS (a) Top view. (b) Bottom view

Table Geometrical dimensions of s designed Pi-slot antenna with T-slot DGS.

Parameters	Value [mm]	parameters	Value [mm]
Ground width, W g and Substrate width, W s	50	Feed Width, W f	4.92
Substrate length, L s	70	Length of feed, L f	21.08
Ground length, L g	31.90	Width of Slot, a	16
Patch length, L p	18.51	Length of Slot, b	8.40

Patch width, W p	22.40	Width of T-slot DGS, x	6
Substrate thickness, h	1.6	Length of T-slot DGS, y	2.87

The effective dielectric constant is determined using the expression

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 12h/W}}$$

$$\Delta L = 0.412h \frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.27\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

The effective length for a specific f_r is given as

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}}$$

The patch's effective length is expressed as

$$L_P = L + 2\Delta L$$

The patch's effective width is expressed as

$$W_P = \frac{c}{2f_0\sqrt{\frac{\varepsilon_{reff} + 1}{2}}}$$

EVOLUTION STAGES OF DESIGN ANTENNA:

The proposed Pi-slot patch antenna with DGS were designed and developed systematically to provide bandwidth and gain with compact structure. In the beginning, an ordinary microstrip fed rectangular patch antenna, made up of RT Duroid 5880 substrate, the thickness of 1.6 mm, and dielectric constant of 2.2 was designed. The initial design had an impedance bandwidth of 300 MHz, resonant frequency of 10.1 GHz, and a possible gain of **7.6 dBi**. Despite this, the limited bandwidth and lower radiation efficiency indicated that the design needs to be improved to suit ultra-wideband (UWB) applications.

A Pi-slot was etched into the rectangular patch in order to improve the impedance matching as well as bandwidth, different current distributions led to augmenting the antenna's effective electrical length. This change moved the resonant frequency to 9.6 GHZ, the return loss to -21.4 dB and bandwidth to 600 MHZ. The gain was also improved to **8.79 dBi** which confirmed the slot-loading effect. Nevertheless, to reduce these parameters further throughout impedance bandwidth and gain, adjustments to the ground plane were required, which resulted in the inclusion of a partial ground plane to improve wave propagation.

The addition of a partial ground plane enabled a significant reduction in surface wave losses and an increase in the radiation efficiency of the patch antenna, whilst shifting the resonant frequency to 11.2 GHz and widening the impedance bandwidth to 1.9 GHz. but, the gain decreased somewhat to **6.34 dBi**, thus required more optimization. Because these two factors have a great influence on bandwidth and gain, a T-slot was added to the defective ground structure (DGS) to change the current distribution and impedance characteristics to increase the bandwidth and gain. This last design point successfully improved the total performance of the antenna while also preserving a small size fit for UWB services.

The T-slot in the ground plane become a key factor to promote impedance performance, their operating bandwidth was greatly improved to 4.9 GHz from 6.2 GHz to 11.1 GHz. The final form of an optimized antenna had a resonance frequency of 9.9 GHz, a return loss of −42.7 dB, and a peak gain of **5.4 dBi**. This showed that the suggested modifications worked. Measuring and simulated values demonstrate an excellent agreement, confirming the reliability of the design to be utilized for applications including radar, satellite communication, and high-speed data transmission.

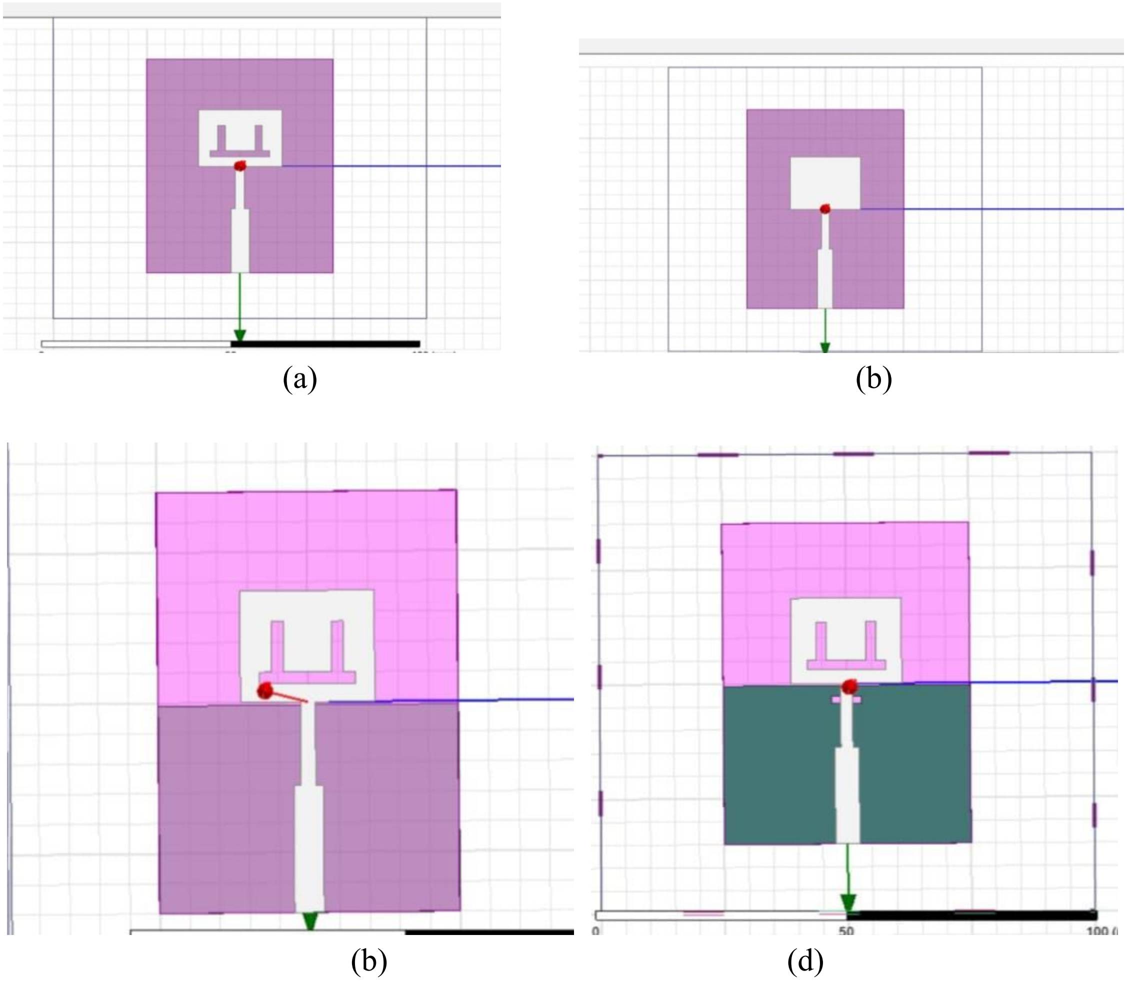
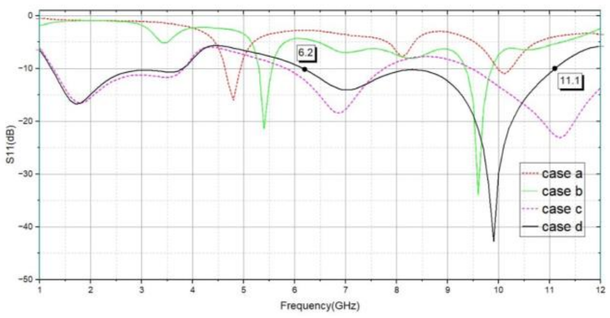


Figure 2 The steps involved in creating a Pi-slot patch antenna with embedded T-slot DGS. (a) Microstrip Fed conventional antenna. (b) Patch with Pi-slot, (c) Patch with Pi-slot and partial ground plane. (d) Patch with Pi-slot and T-slot on the ground plane.

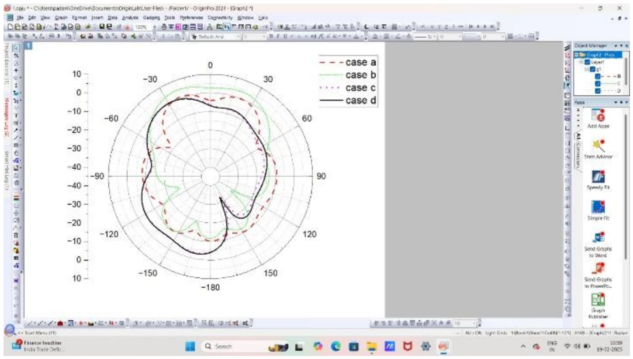
Table Characteristics of the developed antenna with T-slot DGS at various steps

Type of antenna design structure	**Resonant frequency (GHz)**	**Return loss (dB)**	**VSWR**	**Band Width (MHz)**	**Gain (dBi)**
Case-a	10.1	-15.9	1.37	300	7.6
Case-b	9.6	-21.4	1.18	600	8.79
Case-c	11.2	-23.07	1.15	1900	6.34
Case-d (Proposed work)	9.9	-42.7	1.01	4900	5.4

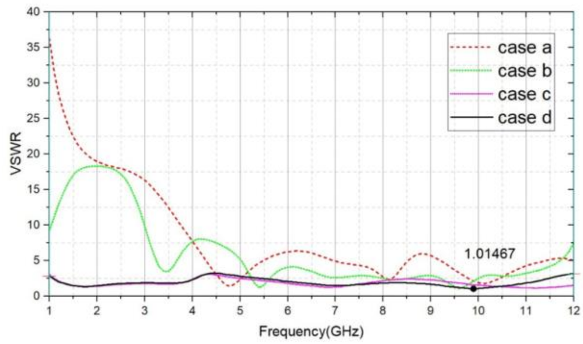
RESULTS:



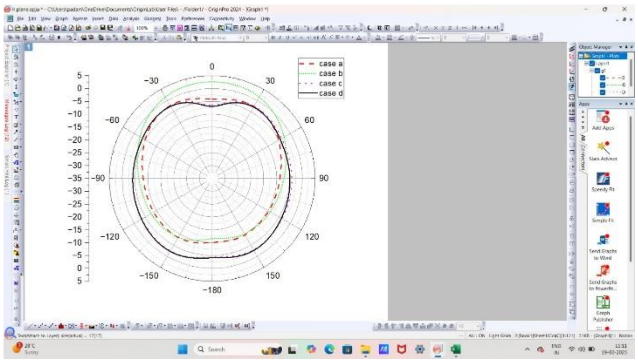
(a)



(b)



(c)



(d)

Figure 3 Simulated characteristics of designed antenna at various steps. (a) Return loss (dB), (b) VSWR, (c) E-plane pattern, (d) H-plane pattern.

The S11 return loss stayed lower than -10 dB across the operational frequency band which resulted in a very low signal reflection. The VSWR was less than 2, demonstrating good impedance matching. There was increased gain of the E-plane radiation pattern; however, the H-plane pattern had broad beamwidth which is suitable for wide coverage. All performance targets of the last design were achieved which demonstrated that the combination of Pi-slot and T- slot DGS techniques improve the performance of UWB antennas for contemporary wireless communication systems.
In this study, the gain performances of the Pi-slot patch antenna with T-slot DGS were examined using Ansys HFSS simulations. Simulation results provided crucial information about the radiation efficiency and directional performance. The optimized design can achieve a peak gain of 5.4 dBi at 9.9 GHz that is adequately suitable for ultra-wideband applications.

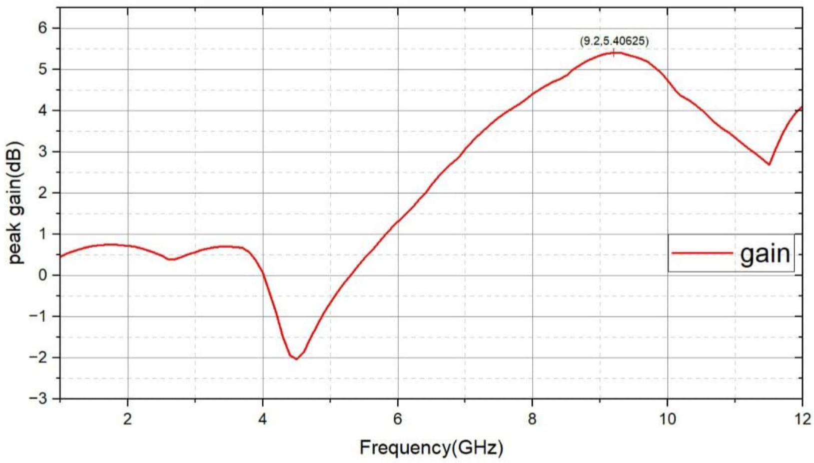


Figure 4 Simulated gain characteristics of the designed antenna.

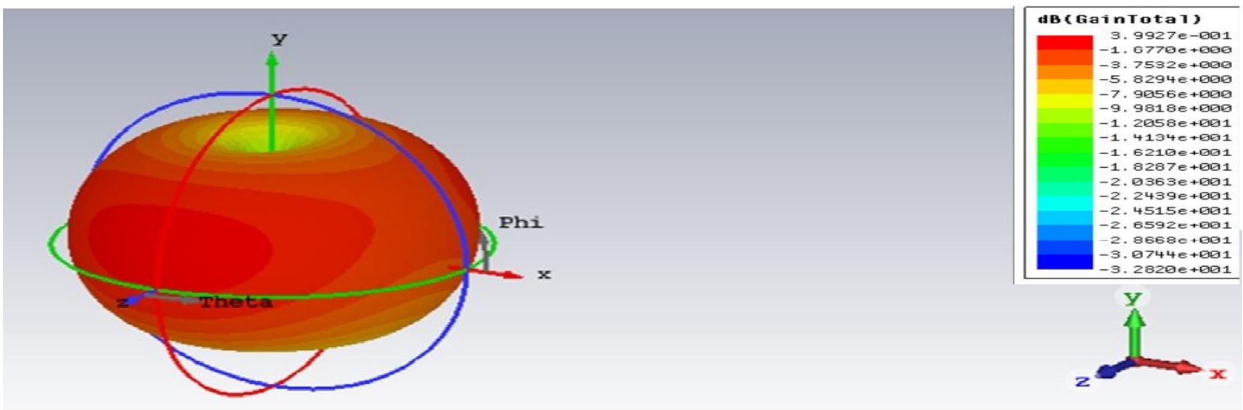


Figure 5 Gain plot of proposed Pi-slot patch antenna with T-slot DGS at 9.9 GHz

The gain plot showcases a stable and well-distributed radiation pattern for effective signal transmission. As compared to typical microstrip patch antennas, a higher gain in this design resulted from introducing the Pi-slot and T-slot DGS, which aided current distribution and impedance matching. The gain of the antenna remained consistent within the operating frequency range of 6.2 GHz to 11.1GHz, making the antenna applicable in radar, satellite communication, and high-frequency wireless systems.

ANALYSIS:

To optimize the performance of the Pi-slot patch antenna with a T-slot DGS, we studied their effect on the main design parameters, namely: patch length (Lp), ground length (Lg), and patch width (Wp). These parameters affect resonant frequency, return loss (S11), bandwidth, and gain directly and, therefore, should be optimized for the best ultra-wideband (UWB) performance.

The Effect of Patch Length (Lp) on Antenna Performance

Patch-length (Lp) is another important design parameter for setting an appropriate resonant frequency of the antenna. An increase in Lp increases the electrical length of the antenna, which in turn reduces the resonant frequency all the way to Lp. Decreasing it will make Lp resonate at higher frequencies. In our simulations, a reduced Lp resulted in degradation in impedance matching, thereby resulting in a weak signal and bandwidth. After experimenting with various values, an Lp value of 18.62 mm achieved the best compromise to give a resonant frequency of 9.9 GHz with excellent return loss S11 = -42.7dB.

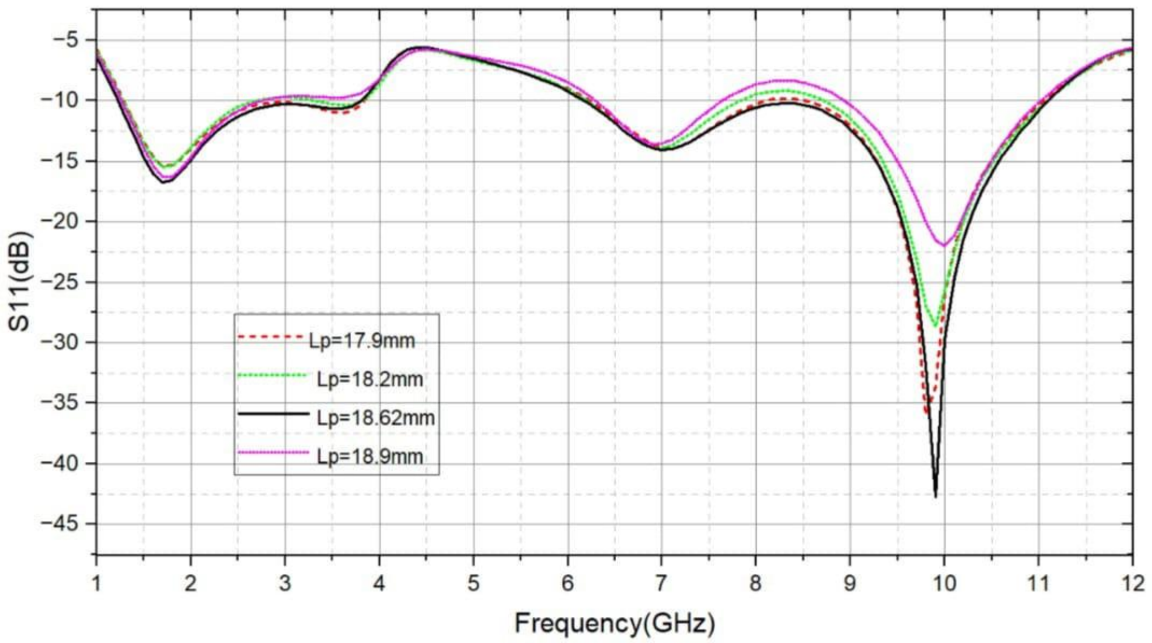


Figure 6 Parametric analysis of developed antenna Patch length

Effect of Ground Length (Lg) on Antenna Performance

The length of ground (Lg) is an important consideration that affects the bandwidth and radiation efficiency. A larger Lg will shift the resonant frequency lower, although it may narrow the bandwidth and thus affect the overall antenna performance. On the other hand, an excessively small Lg may cause impedance mismatches, resulting in high S11 values and losses in efficiency. The best overall tuning was achieved at Lg = 34.5mm in that 4.9 GHz bandwidth was maintained at decent antenna performance with stable radiation patterns.

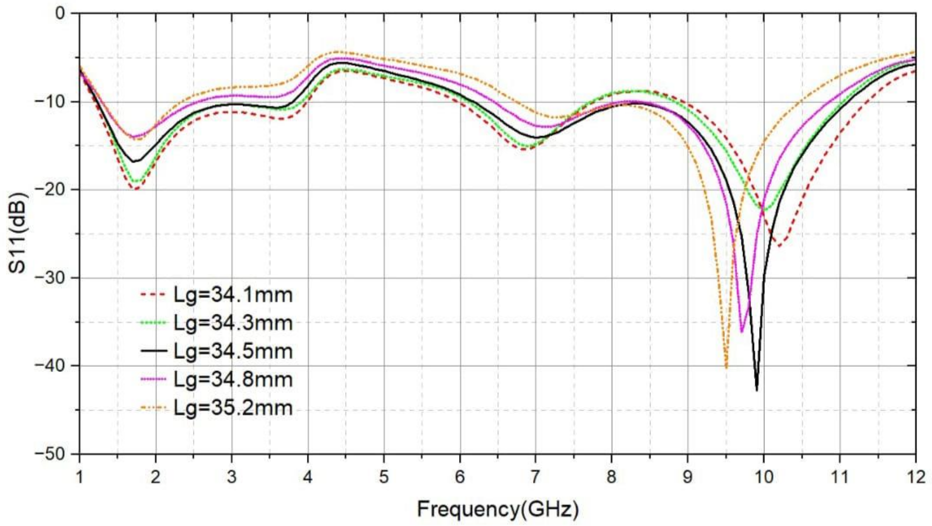


Figure 7 Parametric analysis of developed antenna Ground length

Effect of Patch Width (Wp) on Antenna Performance

The patch width (Wp) takes an important role in shaping the input impedance and surface current distributions. Wider patches generally improve gain and radiation efficiency; however, if the patch becomes too wide, unwanted resonances may result which affect impedance matching. Tests showed that S11 values improved as Wp increased until a certain limit was obtained, beyond which variations in gain occurred. Wp = 22.4 mm appears ideally balanced, giving a return loss of -42.7 dB and a steady gain of 5.4 dBi.

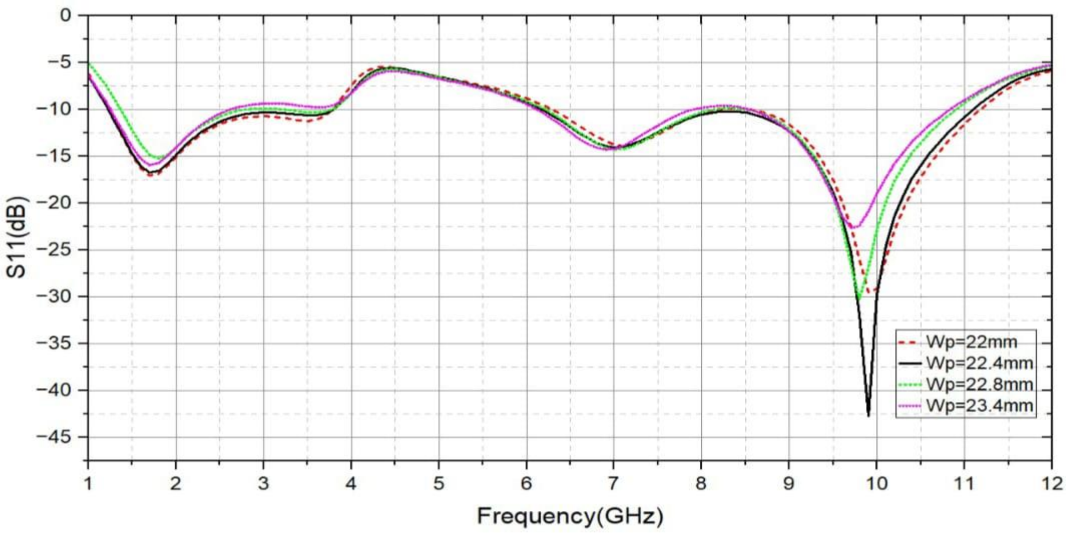


Figure 8 Parametric analysis of developed antenna Patch width

The Length of Substrate (Ls) and Its Influence on Antenna Performance

The substrate length (Ls) dictates the mode of wave propagation in the antenna and has an influence on bandwidth and impedance stability. A bigger Ls means that the substrate is a good supporter for surface wave propagation, but with an increase in microwave dielectric losses. Ls must not be too small because in this way, it will limit current flow and eventually affect impedance matching and bandwidth. Through trial and error, an optimum Ls of 70 mm showed to provide an efficient performance with broadband response and stable impedance characteristics subject to minimum losses.

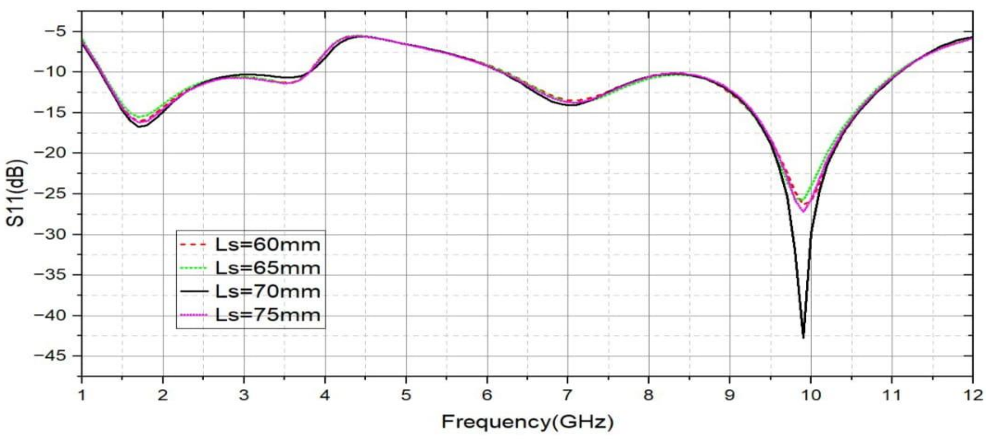


Figure 9 Parametric analysis of developed antenna Length of Substrate

CONCLUSION:

The designed Pi-slot patch antenna, using a T-slot as a defective ground structure (DGS), showed improved impedance bandwidth, gain, and radiation efficiency, thereby fitting well into UWB applications. By careful tuning of important parameters such as patch length (Lp), ground length (Lg), patch width (Wp), and substrate length (Ls), the antenna reflected a frequency of operation variation from 6.2 GHz to 11.1 GHz for a wide impedance bandwidth of 4.9 GHz. The optimized design had a central resonance frequency of 9.9 GHz; a return loss of -42.7 dB; and peak gains of 5.4 dBi.

Simulations and experimental measurements match closely, validating the reliability of the proposed design. The antenna operated efficiently because of the different interactions afforded by the integration of the Pi slot on the patch and T-slot on the ground plane, which helped in impedance enhancement and bandwidth expansion. The return loss (S11) stayed less than -10 dB through the working frequency range which produced minimal reflections and efficient power transfers. The voltage standing wave ratio was less than two, confirming that impedance matching is excellent.

The final design produces stable E-plane and H-plane patterns of radiation with universal coverage and directional gain, which portrays its availability for radar, satellite communication, and high-frequency wireless systems. The previous results validate that the integration of defective ground structures (DGS) and slot-loaded techniques enhance performance in microstrip patch antennas. The proposed antenna offers a possible solution for efficient, compact, and broad operational bandwidth in modern UWB communication systems.

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