

# A Novel Miniature Microstrip Patch Antenna for UWB Applications

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**Abstract:** Microstrip antennas have become integral to modern communication systems, supporting applications such as radar, satellite navigation, telemetry, RFIDs, and transponder tracking. Their popularity stems from features like compact size, ease of fabrication, and planar configuration. However, traditional microstrip antennas are often constrained by narrow bandwidth and limited gain, which restrict their performance in high-demand wireless systems. This research presents an innovative miniaturized microstrip antenna design including a square patch and a defective ground structure (DGS) to overcome these restrictions. The suggested antenna is constructed and simulated with the High-Frequency Structure Simulator (HFSS) at a central frequency of 4 GHz. The concept employs a FR-4 substrate—a economical, readily accessible material—with an average thickness of 1.6 mm. The antenna structure includes a primary rectangular patch of dimensions  $20 \times 7 \text{ mm}^2$  and a dual-ground configuration: a conventional ground plane on the back side with dimensions of  $26.2 \times 6.25 \text{ mm}^2$  and two defected ground sections of  $10.6 \times 8 \text{ mm}^2$  located on either side of the patch plane. Simulation results confirm that the antenna achieves a return loss below -10 dB and a wide bandwidth of approximately 11 GHz, effectively covering the range required for Ultra-Wideband (UWB) applications. The incorporation of the DGS not only enhances bandwidth but also contributes to improved radiation characteristics and gain. These performance benefits position the proposed design as a strong candidate for next-generation compact and high-efficiency wireless communication systems.

**Keywords:** Microstrip Patch Antenna, Ultra-Wideband Antenna, Defected Ground Structure, High-Frequency Structure Simulator, Return Loss.

## 1. Introduction

Ultra-wideband (UWB) communication networks have a significant position in the wireless domain because of their benefits, including high data transmission rates, minimal spectral power density, exceptional accuracy, reduced complexity, and affordability. This expansion started when the Federal Communications Commission (FCC) designated the 3.1GHz to 10.6GHz spectrum as the unregulated band for UWB connectivity [1]. UWB technology is extensively utilized in both short and far-reaching high-speed wireless technologies, including C-band (4–7.5 GHz) satellite

messaging structures, ground-penetrating radars, healthcare imaging structures, WiMAX (3.4–3.69 GHz), extremely rapid wireless local area networks (WLAN) (5.15–5.35 and 5.725–5.825 GHz), and the backbone of X-band satellite messaging systems (7.25–7.75 GHz). The literature discusses several UWB microstrip antenna options with either two or one layers to meet the requirements for diverse applications. One of these prerequisites is to augment the amount of bandwidth [4-7].

Researchers hold on contacting exclusive and improved antenna designs for the use of present-day technologies by simply to use the microstrip antenna designs and call the observed antenna designs so as to achieve applicable overall requirement of the design which is desirable [8]. It used to be in early 1980, when the researchers are working on the suitable and best answer for problem of communication over long-range using microstrip antenna [9]. Recent advancement in applied sciences in each and every field make that, can also associate to communicate additionally over wired or wireless with antennas which are low cost, easy to fabricate and low profile. Through the years, these necessities have been carried out by using microstrip antennas. Even if the band width of the radiating patch is specified, a range of targets should be attained by using it [10]. These microstrip patch antennas are very small and are compatible with many devices, like aero-planes, bullet trains, mobile telephones, navigation and many others that may additionally need exclusive versions and designs of radiating patches [10, 11]. The technical need has focused on the necessity to reduce crosstalk, co-channel disruption, and polarization range, making microstrip antennas indispensable. The patch antennas are significant in terms of geometry, offering various advantages typically unattainable with conventional antenna layouts [12].

Microstrip Patch Antennas (MPA) designed for cellular and various portable devices must be compact to facilitate integration into mobile units and possess broadband characteristics. The bandwidth improvements in tiny antennas have emerged as a significant concern [13]. Academia and industry researchers have been engaged in developing various approaches to create compact broadband antenna structures for different frequency bands. Various techniques have been demonstrated before to achieve ultra-bandwidth, including the utilization of thick substrates, stacked adjustments, shorting pins, active and passive gadgets, specialized feeding configurations, and the implementation of impedance matching networks [14-16]. A MPA consists of a metallic patch situated above a conductive ground plane, separated by a dielectric base. MPA consist of a diminutive radiating patch situated on a substrate above ground planes [17]. It comprises a metallic patch that emits radiation and may take the form of a square, ring, circular, triangle, rectangle, etc., situated on any side of the platform and oriented differently while incorporating a ground plane. Parametric study has indicated that the configuration and size of the finite ground planes and slots in the patch are critical factors in augmenting the bandwidth of any shape [11]. Furthermore, UWB antennas have demonstrated significant advantages in medicinal applications, including imaging with microwaves and lung cancer detection [13-15]. Interference poses a challenge for UWB communication systems [13], as several conventional narrowband systems operate inside the UWB frequency spectrum. Traditional methods for achieving UWB characteristics involve the use of slot antennas, characterized by uniquely shaped big slots in the ground plane [18]. The second strategy involves direct modification of the radiating parts. The third option involves the emergence of defects in the ground plane via CPW/strip line feeding techniques. The fourth strategy emphasizes

altering the feeding line to improve antenna frequency and radiation uniformity [9]. MSPs are extensively utilized in UWB applications due to their benefits, including lightweight design, simplicity of integration, compact dimensions, and tiny footprint. Due to the small bandwidth of microstrip antennas, many strategies have been employed to enhance bandwidth and attain ultra-wideband characteristics. Numerous methods have been documented to minimize the dimensions of microstrip antennas at a designated operating frequency for compactness [19]. Traversing the energized surface current trajectories inside the antenna's radiating patch is an excellent technique for attaining a reduced fundamental resonance rate for the microstrip antenna [20-22]. In the case of a rectangular radiant patch, meandering can be accomplished by including many small slits along the patch's non-radiating edges. The UWB of a tiny microstrip antenna can be augmented by employing a square-ring slot [23] and a bevelled rectangular metal patching [24].

These patch antennas are preferred for their several advantageous characteristics, including lightweight design, low profile, ease of production, cost-effectiveness, and widespread modeling applications. These provide considerable versatility when selected for a distinctive patch configuration concerning polarization, specimens, and resonant frequency. They organize and arrange linear or planar configurations. It can operate across a broad frequency range from around 1 GHz to 30 GHz.

This research seeks to accomplish the primary goal of developing a miniaturized microstrip patch antenna solution that supports ultra-wideband (UWB) spectrum ranges for high-speed modern wireless communication systems. This proposed antenna seeks to meet the market need for inexpensive small high-performance hardware that efficiently receives and transmits signals through long distances. The new antenna design utilizes a square radiating patch and a defected ground structure (DGS) to attain improved bandwidth as well as improved radiation performance. The antenna design utilizes FR-4 substrate material with 1.6 mm thickness since it provides cost-effectiveness as well as standard fabrication compatibility. The compact size of the antenna as well as its improved impedance match as well as increased gain potential forms its application value in future wireless communication systems that require scalability as well as performance improvement. This research has been segregated into sections which include Section 2 for "Related work" and Section 3 for "Problem Formulation" and Section 4 for "Proposed design and framework" and Section 5 for "Simulation and Result" with conclusion and future scope.

## **2. Related Work**

A small UWB antenna utilizing a spanner-shaped microstrip line was presented in [9]. It comprises a simple rectangular patch including a stepped slot on one of the shorter sides, together with a defective ground plane embedded with a reflectively imaged 'P' shaped slot. The antenna's bandwidth was measured at 153.22% (2.94 - 22.2 GHz) with a VSWR of less than or equal to two. It was previously noted to vary from -1.38 to 5.18 dB throughout the whole operational bandwidth. The antenna's radiation patterns have been determined at 3.1, 6.85, 10.6, and 18 GHz, corresponding to the lower, middle, and upper cutoff frequencies of the UWB area. The prototype was manufactured, and dimensions were measured to validate the proposed results.

The broadband E-shaped MSA mentioned right here was once similarly elevated with the aid of reducing a pair of tapered slots which multiplied BW in [10]. The even-mode equal of the E-shaped MSA, which used to be an RMSA with a single slot, gave 50% discount in the patch location with smaller BW. Recently, a broadband layout of E-shape MSA was once accelerated through introducing unequal size slots in it. Unequal slot lengths tune the resonance frequencies that yield huge band response of around five hundred MHz (50%). These extra pair of slots tune the resonance frequency, yielding almost 600 MHz (55%) of BW. The actual bandwidth previously contrasted with the bandwidth obtained by a genuine E-shaped MSA, U-slot reduced RMSA, and several proposed designs of modified E-shaped MSAs with diminished patch dimensions. In [25] delineate the design, modeling, and manufacturing of an innovative microstrip antenna classified as UWB, functioning within the frequency spectrum of 3.8973 GHz to 11.251 GHz. The research findings indicate that the antenna model encompasses the complete UWB frequency range, exhibiting an operational a bandwidth of 7.3536 GHz and an input rejection loss below -10 dB. In contrast to traditional planar devices or MPA, this antenna demonstrates bipolar irradiation patterns.

The E-shaped patch microstrip antenna was utilized by every student during their research activities. Contemporary cellular communication systems often need reduced antenna dimensions to satisfy the miniaturization demands of mobile devices. In the past decade, the E-shaped patch format has been studied under internet connectivity, dual-frequency, dual-polarized, circularly split, and gain-enhanced activities [26].

A broadband design of a probe-fed rectangular patch antenna with two sets of significant slits has been suggested and empirically examined in [27]. The first concept employed an air substrate, and research indicates that precise impedance matching across a broad frequency may be readily achieved by including two large apertures at one of the emitting edges of the symmetrical patch. The proposed antenna, employing air platforms about 8% of the length at the central working frequency, may attain a bandwidth with an impedance of roughly 24%. In the context of impedance internet access, certain radiation characteristics have been observed, with a maximum antenna gain of around 7.2 dB [28].

The bandwidth is similarly enhanced by lowering a pair of tapering slots. A tiny rectangular MPA, loaded with a single slot, is presented by utilizing the even-mode symmetric of an E-shaped MA, with the reduction of a pair of tapering slots, thereby halving the antenna's dimensions. Moreover, its bandwidth is correspondingly diminished. This even-mode equivalent of the E-shaped MSA, which is a resonant microstrip antenna with a single slot, provides a 50% reduction in the patch vicinity, accompanied by diminished bandwidth and gain.

In [29], the author presented a novel geometry with a defective ground for broadband applications. The operational bandwidth of the suggested configuration was 2.04 GHz, which was suitable for contemporary communication systems. Asymmetrical slots had been inscribed into the earth's surface, and a patch of rectangles had been optimized for bandwidth augmentation. The simulated antenna achieved a bandwidth of 71.14% and maintained consistent performance throughout the entire range. An excessive dielectric stable Low Temperature Co-Fired Ceramic (LTCC) substrate was absorbed, and the graph was recreated using the CST graph tool.

An innovative single-patch bandwidth MAP, the E-shaped patch antenna, was developed to improve the standard frequency of microstrip antennas. Two parallel slots were included into a rectangular patch of a microstrip antenna. The wide-band mechanism was investigated by studying the present behavior on the patch. The slot's size and function were optimized to deliver significant bandwidth. The validity of the layout concept was demonstrated by two examples with bandwidths of 21.2% and 32.3%. A thirty percent E-shaped patch antenna was designed, constructed, and evaluated for Wi-Fi transmission frequencies of 1.9 and 2.4 GHz. The radiation intensity and alignment were further supplied.

Presently, scientists work on research concerning UWB-related topics utilizing spanner-shaped feed lines with E-shaped patches and imperfect ground structures (DGS) although they lack simple design, as well as bandwidth and miniaturization performance. Step slots integrated with large slits combined with tapered improvements yield wide bandwidth with excellent radiation due to complicated structures or dielectrics having higher values hence render them incompatible in wireless applications. Introduction of RMSA with single-slot E-shaped counterparts results in both decreased dimensions and bandwidth features along with reduced gain. Though efficient in wideband operation such designs must employ air substrates which must be thick or LTCC fabrication techniques to become economically feasible. Current UWB antenna solutions have skimmed range span or irregular gain behavior over the operating frequency range. Development needs to be concentrated on designing a low-cost miniaturized microstrip antenna which can be readily fabricated while providing complete UWB spectrum coverage and stable radiation patterns along with improved impedance matching through common low-cost materials. The study offers a simple implementation of the DGS square patch antenna which illustrates improved performance along with simple manufacturing along with usability capabilities.

### **3. Problem Formulation**

In the existing scenario, development in science in each field has led to wanting for antennas that are economical, low profile and that can ameliorate dwelling requirements. It might also be associated with conversation that might also be wired or wireless. But interference is a trouble for UWB conversation structures [31], due to the fact there are some different typical slender band structures working in the UWB frequency band, such as international interoperability for microwave get entry to (WiMAX, IEEE 802.16) running at 3.3–3.7 GHz and 5.35–5.65 GHz, wi-fi nearby location community (WLAN, IEEE 802.11) working at 5.15–5.35 GHz and 5.725–5.825 GHz, downlink of X-band satellite tv for pc verbal exchange running at 7.25–7.75 GHz, devoted brief vary conversation working at 5.85–5.925 GHz, etc.

In previous literature, it was noticed that various researchers have presented the antenna designs that are comparable over different parameter like bandwidth, radiation pattern, impedance matching etc. Presently there is huge scope for modification in the design of these antennas. Mostly researchers focus on designing antenna only for a single parameter. Reduction in the size of antenna reduces the bandwidth requirement as stated in literature review. Microstrip antennas should be more compact so that they can further be used for integrating in more than one communication system rather than a single system that can improve the overall portability of a wireless communication system. Many of the researchers have additionally labored for more than one parameter as mentioned in literature

review. It is cited that a versatile microstrip antenna that can be carried out over a huge frequency vary is very difficult to obtain.

Microstrip antenna are antennas with the functionality of enhancing their basic parameter such as bandwidth, radiation pattern, frequency and polarization by surely making changes in the measurement and structure of radiating patch and ground plane. The bandwidth enhancements in compact antennas have turned out to be a very fundamental plan issue. By making practical and required modifications in the substrate cloth the bandwidth of the antenna can be more desirable whilst enhancing impedance matching. For cellular and different transportable devices, the bodily dimension should be stored small so that they can be embedded on a number of gadgets except making it bulky. Academics and industry researchers have been advancing several ways to develop compact wideband antennas designs for diverse frequency bands. Various ways have been demonstrated before to attain extensive bandwidth, including the utilization of thick substrates, layered patches, cutting pins, active and passive devices, particular feeding configurations, and impedance matching networks. Therefore, it would be prudent to implement several Wi-Fi connection systems.

#### 4. Proposed Design and Model

The primary objective of antenna design is to produce a compact yet efficient microstrip patch antenna for Ultra-Wideband (UWB) usage. The antenna serves to provide long-range communication through its large frequency range operation with high performance and easy integration in current wireless high-speed circuits.

Compact microstrip patch antenna will be applied by researcher because it has better fabrication and low-profile features with integration benefit over existing antenna requirement for long speech distance. It works well within a broad frequency range. This work's chief goal is to design compact MPA for future high-speed wireless communication networks. While used in circuits, they offer lower cost as well as minimal material usage together.

##### *Microstrip Antenna Design Equations*

Upon the appropriate selection of the aforementioned three parameters, the subsequent step is to compute the dimensions of the radiating patch, namely its width and length.

**Step 1: Measurement of Width (W):** width of the microstrip patch influences both the input resistance and radiation efficiency. An expanded patch amplifies the fringing field and elevates radiation power, hence enhancing bandwidth. The width equation is obtained from the resolution of Maxwell's equations, based on the premise of a resonant cavity model, which guarantees that the patch accommodates the basic  $TM_{10}$  mode. For an effective radiator, the optimal width that results in high radiation efficiency is:

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r+1}} \quad 4.1$$

where,  $\mu_0$  denotes the free permeability,  $\epsilon_0$  represents the free space permission, and  $\epsilon_r$  signifies the relative permission.

**Step 2: Determination of the Effective Dielectric Coefficient ( $\epsilon_{ref}$ ):** Due to the fringing effect, not all electric fields are confined within the dielectric substrate. Some portion exists in the air,

effectively lowering the permittivity. The effective dielectric constant reflects this combined behavior, lying between the permittivity of air (1) and the substrate material. It affects the guided wavelength and hence, the resonant frequency and the antenna dimensions. The effective dielectric constant is

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[ 1 + 12 \frac{h}{W} \right]^{1/2} \quad 4.2$$

**Step 3: Calculation of Effective Length ( $L_{eff}$ ):** The effective length is longer than the physical length due to fringing fields at the open ends of the patch. This length corresponds to the half-wavelength resonance condition of the  $TM_{10}$  mode. The cavity model approximates the patch as a resonant cavity with magnetic walls, and this step ensures accurate estimation of the antenna's resonant frequency. The effective length is

$$L_{eff} = \frac{C}{2f_0 \sqrt{\epsilon_{reff}}} \quad 4.3$$

**Step 4: Estimation of Length Extensions ( $\Delta L$ ):** Fringing fields result in the antenna exhibiting an effective electrical length greater than its physical dimensions. The extension  $\Delta L$  is calculated empirically based on substrate height and width. This adjustment is critical for accurately modeling the resonance behavior, especially at higher frequencies where fringing is more pronounced.

$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_{reff} + 0.3) \left( \frac{W}{h} + 0.264 \right)}{(\epsilon_{reff} - 0.258) \left( \frac{W}{h} + 0.8 \right)} \quad 4.4$$

**Step 5: Determination of the Actual Length of the Patch ( $L$ ):** The actual physical length of the patch is obtained by subtracting the fringing field extensions from the effective length. This ensures that the patch resonates exactly at the desired center frequency. This step is foundational in achieving the correct operating point for UWB functionality. The precise length of the radiated patch is determined by:

$$L = L_{eff} - 2\Delta L \quad 4.5$$

**Step 6: Calculation of Ground Dimensions ( $L_g$ ,  $W_g$ ):** The transmission line theory applies only to infinite ground planes. However, for practical purposes, it is important to have a limited ground plane. Similar results for limited and infinite ground plans can be obtained if the physical dimensions of the foundation plane are greater than the patch dimensions by approximately six times the layer thickness along the entire periphery, as shown:

$$L_g = 6h + L, \quad W_g = 6h + W \quad 4.6$$

To achieve simulated results, the ground plane is considered an endless ground plane. The input resistance of the patch is determined by basic circuit design

$$Z_{in} = j\omega L_p + \frac{R}{1 + jQ \left( f_R - \frac{1}{f_R} \right)} \quad 4.7$$

The formula for the frequency ratio is  $f_R = f/f_0$ , where  $f_0$  is the patch cavity resonance rate (also known as the RLC circuit resonance frequency). Since the probing inductance is present, this is different from the patch's resistivity resonance frequency ( $f_r$ ), which is the value at which the input response is

zero. At the frequency of cavity resonance  $f_0(f_R = 1)$ , the input resistance of the patch is at its highest, and this is represented by the term  $R$ . Here are the CAD formulae for  $L_p$ ,  $f_0$ ,  $Q$ , and  $R$ : Input resistivity will be marginally less than maximum value  $R$  at resistor resonance rate  $f_r$ , as predicted by the approximation.

$$R_{in} = \frac{R}{1 + \left(\frac{X_p}{R}\right)^2} \quad 4.8$$

The probe reactance, denoted as  $X_p = \omega_0 L_p$ , is defined. The impedance resonance is moved up from the cavity frequency by the quantity  $\Delta f = f_r - f_0$ , which is provided by the approximation formula, due to the probe reactance:

$$\frac{\Delta f}{f_0} = (BW) \left(\frac{1}{\sqrt{2}}\right) \left(\frac{X_p}{R}\right) \quad 4.9$$

where,

$$BW = \frac{1}{\sqrt{2}Q} \quad 4.10$$

BW denotes the antenna's bandwidth (defined as  $SWR < 2$ ), whereas  $Q$  represents the overall quality factor. The input impedance of the tank circuit, including its real and imaginary components, may be expressed in a standardized format as

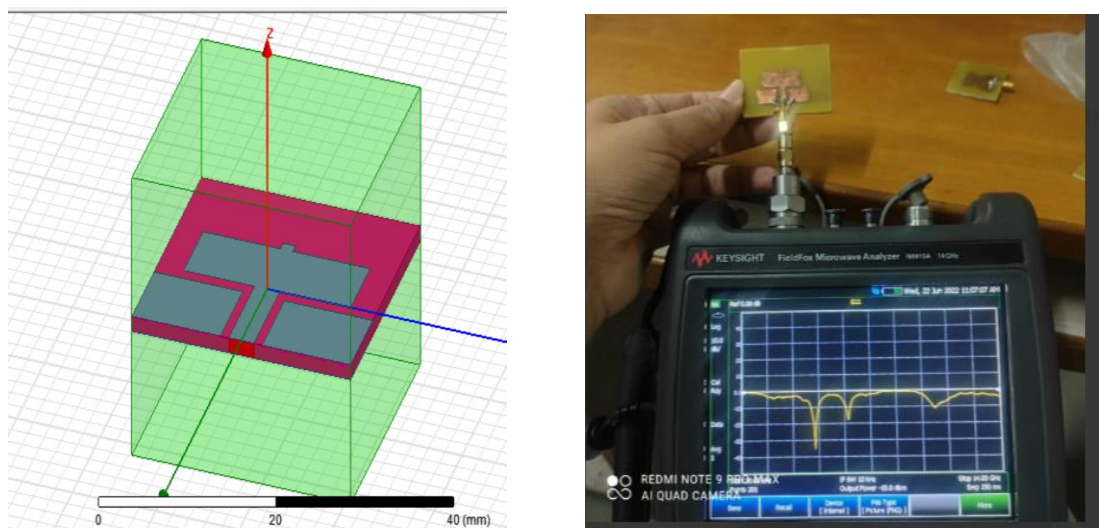
$$Z_{RLC} = \frac{1}{1+jx} R_{RLC} = \frac{1}{1+x^2} X_{RLC} = \frac{-x}{1+x^2} \quad 4.11$$

$$\text{Where,} \quad x = Q\left(f_R - \frac{1}{f_R}\right) \approx 2Q(f_R - 1) \quad 4.12$$

The resistance symbols have been adjusted by dividing them by  $R$ , and the bars over them indicate that the periodic term  $f_r$  has been normalized.

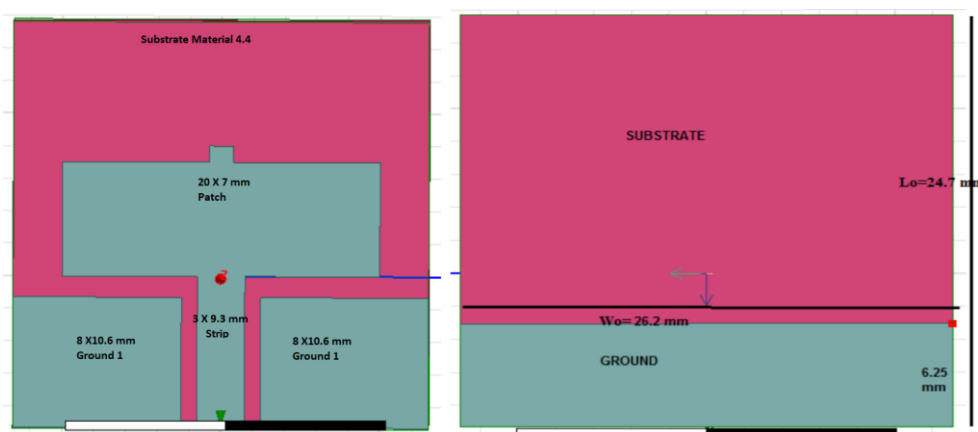
## 5. Simulation and Results

A complete-wave electromagnetic analysis of the designed antenna structure employed industrial-grade software such as CST Microwave Studio and HFSS for verification. The MPA design was simulated within the UWB spectrum range of 3.1 GHz to 10.6 GHz. The simulation parameters included information on the substrate properties along with ground plane dimensions and feed device properties. Return loss (S11) and "Voltage Standing Wave Ratio (VSWR)" coupled with bandwidth analysis and gain and radiation pattern measurement constituted the critical performance parameters tested through simulation. The simulation aimed to establish that the antenna met UWB communication standards by demonstrating stable radiation patterns along with broad impedance bandwidth and small size which enabled its application in modern wireless systems. The subsequent section describes testing of simulated results showing how the miniature antenna preserves the desired wideband behavior along with radiation efficiency and small size suitable for UWB applications.



**Figure 1 Design model a) on HFSS tool b) Antenna design**

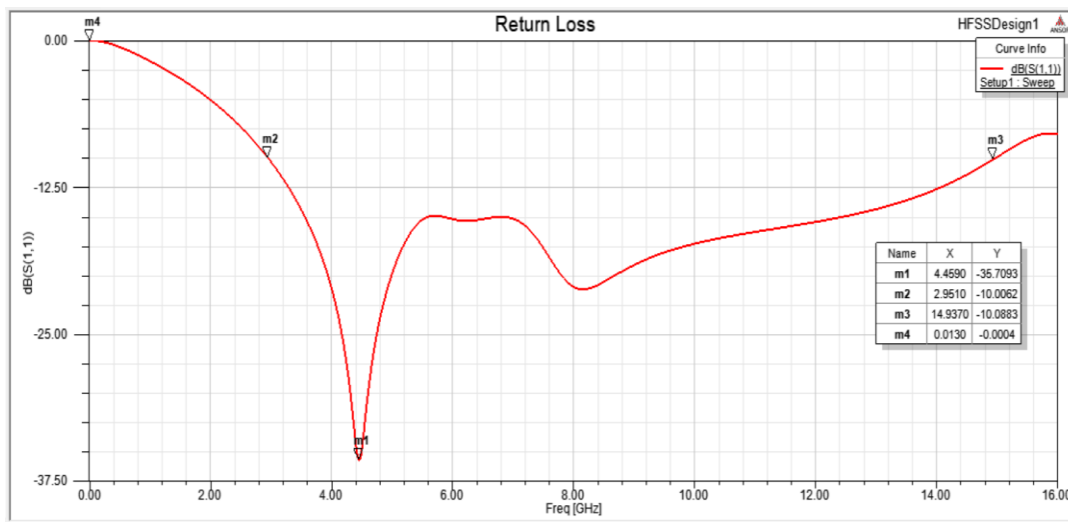
Figure 1 shows the proposed geometry designed and simulated on HFSS tool with the ideal condition by creating the airbox around the patch antenna which is usual technique in designing and testing of any antenna. With the help of design equation, the patch dimensions and overall antenna dimensions are obtained through these equations by taking these values a patch of dimension  $20 \times 7 \text{ mm}$  with stripline on  $3 \times 9.3 \text{ mm}$  is designed waveguide port is connected with the stripline impedance of 50 ohms. The overall dimension of  $24.7 \times 26.2$  of substrate material 4.4 FR 4 is selected with the height of  $1.4 \text{ mm}$ . First ground of dimension  $26.2 \times 6.25 \text{ mm}$  on Back side and second ground consist of a pair on the either side of stripline with dimension of  $8 \times 10.6 \text{ mm}$  is created to achieve optimum results. Figure 2 shows the complete dimensions antenna designed on tool.



**Figure 2: Front and back view of proposed simulated model**

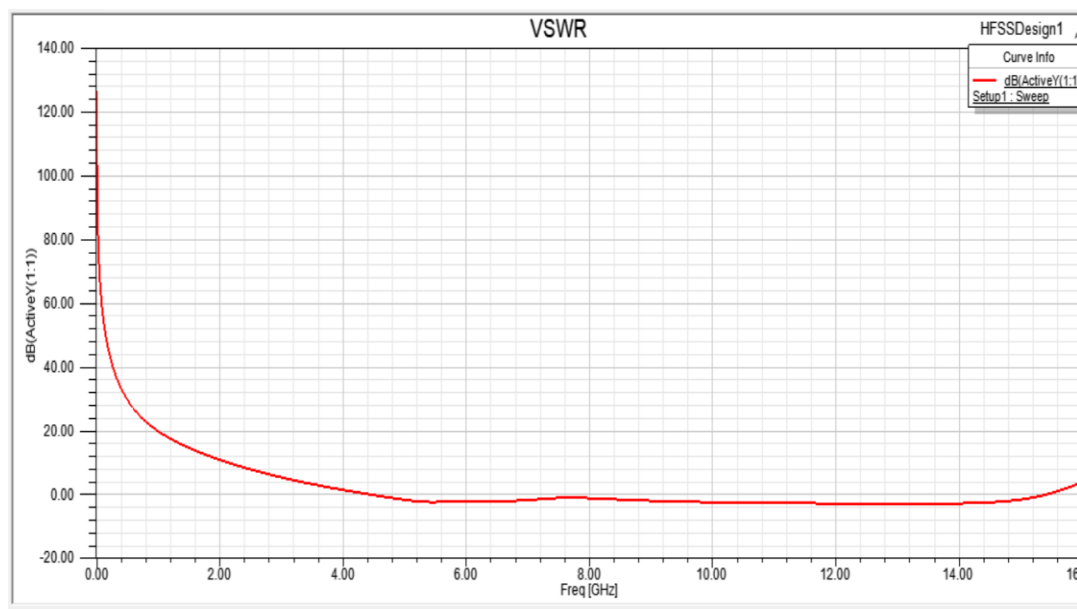
Figure 2 illustrates the front and back views of the proposed miniature microstrip patch antenna designed for UWB applications. The front view shows a centrally placed rectangular radiating patch of dimensions  $20 \times 7 \text{ mm}$ , fed through a microstrip line measuring  $9 \times 3.9 \text{ mm}$ . Two partial ground planes, each measuring  $8 \times 10.6 \text{ mm}$ , are symmetrically positioned on either side beneath the feedline, creating a defected ground structure to enhance bandwidth and impedance matching. The substrate material used has a dielectric constant of 4.4, ensuring a balance between compactness and

performance. The back view displays a complete view of the substrate and ground layer. The total length ( $L_o$ ) and width ( $W_o$ ) of the model are 24.7 mm and 26.2 mm respectively, with the lower part consisting of a 6.25 mm high ground plane. This design structure supports wideband operation while maintaining compact dimensions suitable for UWB device integration.



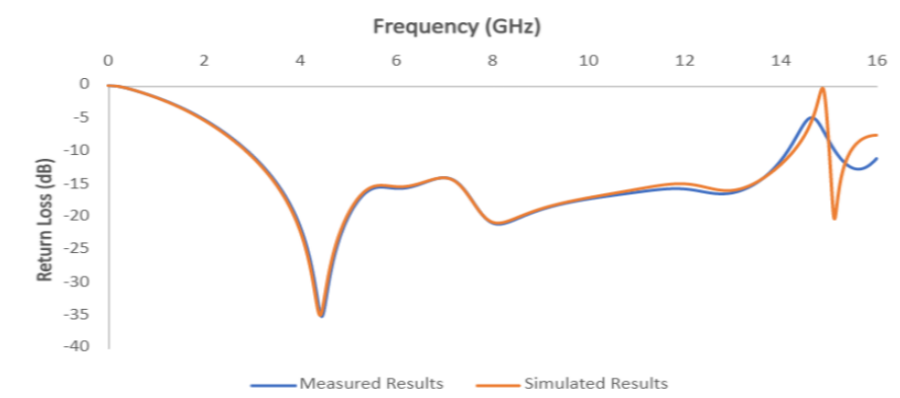
**Figure 3:  $S_{11}$  return characteristics of proposed antenna.**

The  $S_{11}$  parameter illustrates an 11 GHz bandwidth appropriate for UWB applications in Figure 3 of simulated design performance. Via  $S_{11}$  the reflection coefficient values can be assessed to identify the amount of power reflected due to impedance mismatch. An effective radiation acceptable threshold remains at -10 dB, and this implies that little power reflects, and transmission is efficient. Plots results confirm that the designed antenna provides 11 GHz of impedance bandwidth operating from 2.9 GHz to 14.9 GHz with all points under -10 dB. The antenna demonstrates good performance adequacy for UWB applications through its 11 GHz broad operational bandwidth as indicated by the return loss profile presented in Figure 3.



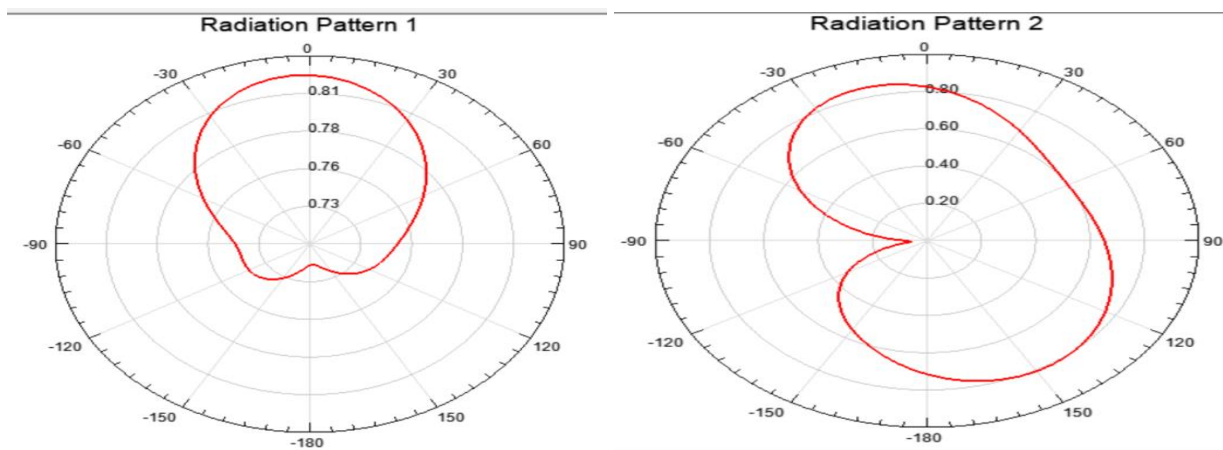
**Figure 4: VSWR properties of the suggested antenna**

Figure 4 presents the VSWR characteristics of the proposed miniature microstrip patch antenna over a wide frequency range extending from 0 to 16 GHz. The plot demonstrates that the antenna maintains a VSWR value below 2 across a significant portion of the UWB range, specifically from approximately 3.1 GHz to 10.6 GHz, confirming good impedance matching throughout the operating band. A VSWR less than 2 is generally considered optimal for efficient power transfer, indicating that the designed antenna minimizes signal reflection and ensures high transmission efficiency. The smooth and continuous nature of the VSWR curve further reflects the antenna's capability to operate effectively across the ultra-wideband spectrum, fulfilling the key performance requirements for UWB wireless communication systems. The sensible cost for VSWR is between one and two however perfect is one which can't be achieved. VSWR is one for ideal matching which is virtually no longer possible.



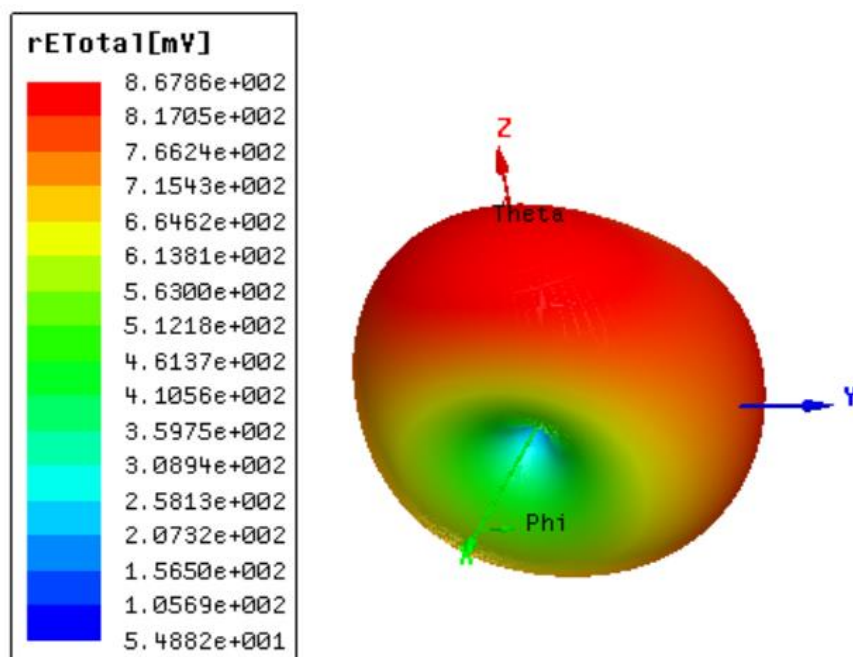
**Figure 5 Measured vs. simulated results**

Figure 5 illustrates the return loss (in dB) versus frequency (in GHz) for both measured and simulated results of an antenna or RF component. The return loss curve helps evaluate how efficiently the antenna radiates or receives energy. The measured results and simulated results show good agreement across the frequency range of 0–16 GHz, with both demonstrating deep notches indicating resonance points. A significant dip around 4.5 GHz suggests strong resonance, followed by smaller dips near 8 GHz and 13–15 GHz. Minor deviations between the two curves are expected due to fabrication tolerances, material inconsistencies, or measurement uncertainties.



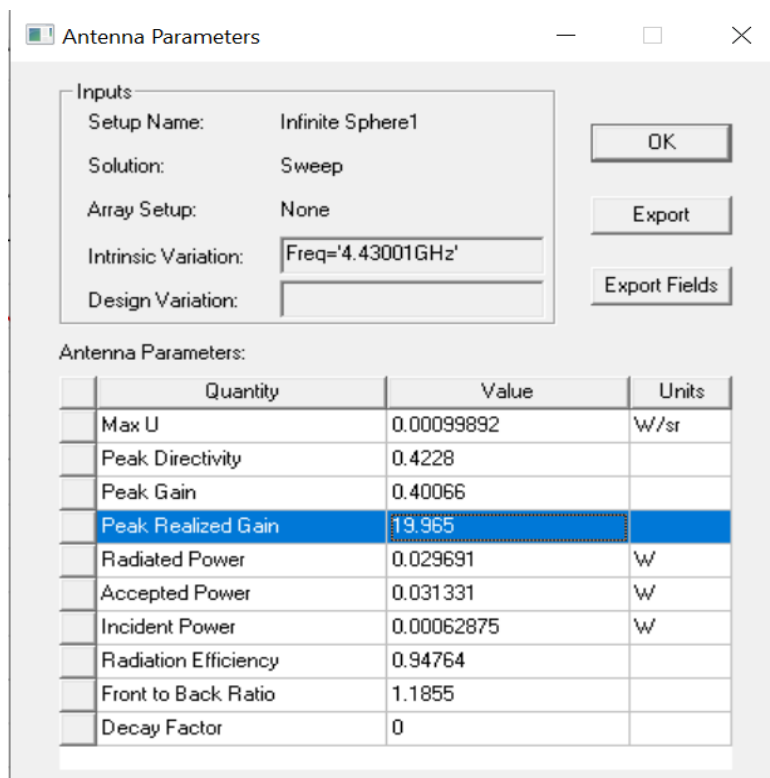
**Figure 5 Radiation patterns in the X-Y and X-Z planes**

Figure 5 presents the simulated patterns of radiation of the suggested in the X-Y and X-Z planes, demonstrating the antenna's directional characteristics. The graphs indicate that the antenna has a nearby-omnidirectional emission sequence, which is very advantageous for UWB system communication to guarantee homogenous radiation in every single direction inside the plane. The measured radiation characteristics indicate a consistent and stable pattern, confirming the antenna's ability to maintain effective coverage and signal transmission regardless of its orientation. The optimum gain observed in the radiation window is approximately 12.2 dB, corresponding to a normalized peak of 0.81 in the X-Y plane and 0.60 in the X-Z plane, validating the antenna's capability to deliver strong signal strength across its operational band. The radiation pattern in XY and XZ plane shows the omni directional pattern and optimum gain in parameter window of 19.9 equivalent to 12.2 dB.



**Figure 6 3-Dimensional radiation pattern of proposed design**

Figure 6 shows the proposed UWB MPA's 3D emission pattern, illuminating the energy's geographic distribution. The color legend represents the relative electric field intensity (rETotal) in millivolts, with red denoting the areas of maximum radiation and blue indicating the regions of minimum field strength. The spherical representation emphasizes the antenna's capability to radiate energy efficiently in multiple directions, essential for consistent signal coverage in UWB applications. The orientation marked by the Theta and Phi axes clarifies the angular behavior of the pattern, where a strong, well-distributed radiation profile can be observed, affirming the antenna's suitability for robust and reliable communication systems.



**Figure 7: Antenna parameters at 4.43 GHz optimum**

Figure 7 presents the simulated antenna performance metrics at the optimal operating frequency of 4.43 GHz. The highlighted parameter, Peak Realized Gain, reaches a notable value of 19.965, indicating high efficiency in converting input power into radiated electromagnetic waves in the intended direction. Other parameters such as Radiation Efficiency (0.94764) and Front to Back Ratio (1.1855) further confirm the antenna’s effective directional performance and minimal backward radiation. With a Peak Gain of 0.40066 and Accepted Power of 0.031331 W, the antenna showcases a well-balanced energy acceptance and radiation behavior. These results validate the suitability of the proposed antenna design for ultra-wideband applications, particularly where reliable gain and directional control are essential.

## 6. Conclusion

In this work, the ultra wideband patch antenna has been designed and simulated which achieved a bandwidth of 11GHz of bandwidth. In this model is run on HFSS software with single antenna rectangular patch of dimension 26.2 mm X 24.7 mm has been designed with FR-4 substrate with dielectric constant 4.4 is used. Proposed design output gain is 12.2 dB covering all UWB Applications. The overall dimension is very small a miniature with good directive gain along with the UWB bandwidth of 11 GHz (2.9-14.9 GHz). In addition, the measured results and simulated results show good agreement across the frequency range of 0–16 GHz, with both demonstrating deep notches indicating resonance points. The proposed design achieved better results than the previously designed antennas and overcome the limitations of bandwidth and gained both suitable for UWB application with Miniature size. Its small size along with high-performance capabilities makes it a suitable candidate for UWB in portable and embedded systems. Further optimization of the antenna

design utilizing future materials or metasurfaces can be considered in future work to increase gain and radiation efficiency. The integration of the antenna with reconfigurable technology like varactor diodes or MEMS can offer tunability across various bands. The design can be also augmented for multi-input multi-output (MIMO) systems in order to increase the channel capacity and reliability in high-speed communications. Lastly, its application in real-life IoT and medical imaging applications can be explored in order to validate performance in real-life environments.

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