Design and Simulation of Microstrip Patch Antenna for GPS Application

تصميم ومحاكاة هوائي رقعة الشريط الدقيق لتطبيقات نظام تحديد المواقع العالمي (GPS)

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ABSTRACT:

This research presents the design and simulation of a dual-band microstrip patch antenna optimized for GPS (L1) and ISM band applications (1.582 GHz and 2.404 GHz). The antenna was designed with compact dimensions of 95 × 82 × 2.1 mm³, making it suitable for integration into modern portable and embedded systems. The substrate material used was FR-4 with a relative permittivity of 4.3. The simulation results obtained from CST Studio Suite showed promising performance metrics, including low return losses of -22.313 dB at 1.582 GHz and -27.229 dB at 2.404 GHz, indicating strong impedance matching at both frequencies. Crucially, the VSWR was consistently maintained below 2, and the resulting radiation patterns exhibited favorable directivity and gain. This work confirms the viability of the proposed low-profile structure for efficient dual-band operation in GPS applications, paving the way for advancements in antenna miniaturization and practical implementation within next-generation wireless systems.

Key Words:
- A microstrip patch antenna
- GPS Applications.
- CST Simulation

الملخص:

يقدم هذا البحث تصميم هوائي رقعة ميكروستريب ثنائي النطاق مُحسَّن ومحاكاته لتطبيقات نظام تحديد المواقع العالمي (L1) (GPS) ونطاق ISM (1.582 جيجاهرتز و2.404 جيجاهرتز). صُمِّم الهوائي بأبعاد صغيرة تبلغ 95 × 82 × 2.1 مم³، مما يجعله مناسبًا للدمج في الأنظمة المحمولة والمدمجة الحديثة. استُخدمت مادة FR-4 كمادة أساسية ذات سماحية نسبية تبلغ 4.3. أظهرت نتائج المحاكاة المُستقاة من برنامج CST Studio Suite مؤشرات أداء واعدة، بما في ذلك خسائر ارتداد منخفضة بلغت -22.313 ديسيبل عند 1.582 جيجاهرتز و-27.229 ديسيبل عند 2.404 جيجاهرتز، مما يشير إلى تطابق قوي

الكلمات المفتاحية:
- هوائي رقعة شريطية دقيقة
- تطبيقات نظام تحديد المواقع العالمي GPS
- محاكاة CST

	للممانعة عند كلا الترَدُّدَيْن. والأهم من ذلك، أنَّه تم الحفاظ على نسبة الموجة الموقوفة (VSWR) باستمرار أقل من 2، وأظهرت أنماط الإشعاع الناتجة توجيهًا وكسبًا مناسبين. يؤكد هذا العمل جدوى الهيكل المنخفض المقترح للتشغيل الفعال ثنائي النطاق في تطبيقات نظام تحديد المواقع العالمي (GPS)، مما يمهد الطريق للتقدم في تصغير الهوائيات والتنفيذ العملي ضمن أنظمة الجيل التالي اللاسلكية.

1. Introduction

Communications are one of the essential elements in the modern era, significantly facilitating the exchange of information and data between individuals and systems. Communication systems vary to include both wired and wireless communications, relying on multiple technologies to transmit information over different distances. Antennas are considered a vital component in communication systems, playing a key role in transmitting and receiving signals. They are used in a wide range of applications, including mobile phones, radar systems, navigation systems, and satellite communication (Jameel et al, 2024).

Telecommunication systems are widely present in our modern smart lives, and one of the most prominent of these systems is the Global Positioning System (GPS). GPS is a satellite-based geographic positioning system used in a variety of navigation systems. These systems have become essential to meet the growing demands for new services and applications across multiple civil and military domains. The GPS is utilized in several areas, such as monitoring systems, intelligent systems, power management, and other applications. Additionally, GPS provides accurate location information in real-time for an unlimited number of users. The satellite navigation system allows users equipped with receivers to determine their locations anywhere on earth by estimating the distance to a minimum number of satellites. When discussing GPS, it is important to systematically consider the equipment used for location determination (Wei et al, 2021). The GPS system consists of three elements known as segments: the space segment, which includes the satellites; the control segment, which contains the control station; and the user segment, which corresponds to the GPS receiver. In user equipment, we find the essential component for transmission, where antennas emit and receive data. These antennas are primarily used in land vehicles, aircraft, and ships to accurately determine their positions. They feature characteristics such as a wide frequency band, security, and high speed, making them a vital element in enhancing the performance of wireless communication systems. Therefore, designing a microstrip patch antenna for GPS applications is considered a crucial task. A microstrip patch antenna is a metallic strip or patch mounted on a dielectric layer (substrate) over a ground plane. It is useful for high performance in extreme applications: aircraft, satellite, missiles, cellphones and electronic devices (Imran et al, 2021).

The research idea revolves around designing a microstrip patch antenna specifically for Global Positioning System (GPS) applications and analyzing its performance. The work includes several key steps, starting with research and study to understand the principles of microstrip antenna design and GPS requirements, particularly focusing on the tow target frequencies (1.582 GHz) and (2.404 GHz) frequencies. This is followed by the design of the antenna and determining the optimal dimensions to achieve these frequencies. Next, the CST simulation software will be used to analyze the performance, evaluate gain, radiation pattern, and return loss. Finally, the design will be modified based on the results to achieve better performance. The expected outcome is an effective antenna that can be used in GPS applications with performance improvements.

2. Related Works

Antennae are essential components in modern communication systems, playing a vital role in transmitting and receiving electromagnetic signals. Antennae are found everywhere, from mobile phones to radar systems and broadcast stations, making an understanding of their properties crucial. An antenna is a device that converts electrical energy into electromagnetic energy, serving as a means of communication between different devices without the need for a physical connection. The performance of an antenna depends on parameters such as gain, input impedance, and radiation pattern, which determine its effectiveness in various usage environments (Aldhaibani et al., 2025). The radiation pattern represents how electromagnetic energy spreads in the surrounding environment, helping to identify effective coverage areas. Meanwhile, radiation resistance measures the antenna's ability to convert electrical energy into radiated energy, where matching radiation resistance with the transmitter's resistance enhances transmission efficiency. Gain is a measure of the antenna's ability to boost the signal in a specific direction, contributing to improved signal quality. The broadband capability allows antennas to handle a wide range of frequencies, enhancing communication flexibility. Polarization refers to the direction of the electromagnetic field's oscillation of the transmitted or received signal, and it must match between the transmitting and receiving antennas to ensure signal quality (Almazok, 2022). By understanding these properties and parameters, the communication experience can be significantly improved, making antennas an integral part of any modern communication system (Topal, 2023).

The design and analysis of a high-efficiency circular antenna created especially for RADAR applications are presented in (ALtalqi, et al. 2024). A circular microstrip patch antenna operating at 32 GHz, which is ideal for a variety of wireless devices, is demonstrated by the simulation results. The RT5880 substrate on which the antenna is developed has a thickness of 0.035 mm. A substrate with a relative permittivity (εr) of 2.2 was used in the design process. Additionally, the substrate's height (H) was 1.575 mm, and its loss tangent ($\tan \delta$) was 0.0009. The antenna is a circular patch with a chosen radius of 8 mm, measuring 22 mm by 20 mm. The antenna has a frequency range of 22 GHz to 40 GHz. The antenna exhibits a return loss of −21.6 dB, an extensive bandwidth of 8.8 GHz, a voltage standing wave ratio (VSWR) of 1.1808, a gain of 7.891 dB, and a directivity of 7.897 dBi. The antenna exhibits an efficiency of 99.999%. Antenna is designed and simulated utilizing CST Studio Suite software for radar applications.

The design, simulation, and performance analysis of a coaxially fed microstrip patch antenna optimized for Global Navigation Satellite System (GNSS) applications in the 1.559–1.591 GHz frequency band (GPS, Galileo, BeiDou) are described in (Topal & Grigorie, 2025). The suggested antenna, intended for portable devices and UAVs, features geometric modification (chamfered corners), an ideal single-point coaxial feed, and the RT Duroid 5880 dielectric substrate to efficiently achieve the desired performance. Through Ansys HFSS simulations, the final configuration revealed a high gain of 6.58 dB and a key Axial Ratio (AR) of roughly 2.83 dB, successfully establishing the requisite circular polarization for reliable satellite signal reception. This design is determined to be a suitable, small candidate for GNSS receivers in aircraft applications, with future study focused on experimental validation.

This article in (Zainab Saadoon, et al., 2024) presents the design and simulation of a new, compact microstrip patch antenna specifically aimed at 5G communication systems, operating at a resonance frequency of 28 GHz. The antenna is built on a Rogers RT/Duroid5880 substrate and features a rectangular patch with three embedded slots fed by a microstrip line. Simulations performed using CST software demonstrated exceptional performance metrics: the antenna achieved a high gain of 6.19 dBi, an extremely low reflection coefficient of -39.534 dB, a near-ideal VSWR of 1.02, and an impedance bandwidth of 1.062 GHz. The authors conclude that these values, combined with the small physical size, make the proposed antenna an excellent candidate for integration into 5G devices with space limitations.

Ayad et al (2022) presents a microstrip patch antenna for use with the Global Positioning System (GPS). It is rectangular in design and has two slots that are notched. The purpose of the notched slots is to enhance the antenna's compatibility with the microstrip line. The antenna was FR-4 material with a relative permittivity of 4.3 and was used as the substrate in the design and simulation by CST. The suggested microstrip antenna is intended to function in the 1.555 GHz to 1.595 GHz GPS range. The suggested antennas' performance has been evaluated in terms of VSWR, gain (dB), and return loss (dB).

3. Proposed System

The proposed research focuses on the development and design of a microstrip patch antenna specifically for Global Positioning System (GPS) applications, with particular attention to the L1 and L2 frequencies. The work involves conducting a comprehensive performance analysis using CST software, aimed at improving metrics such as gain and return loss, while adjusting the design based on simulation results. The work also seeks to compare the performance of the designed antenna with similar models to ensure its suitability for practical applications, thereby contributing to enhanced accuracy in navigation and location determination across various devices. The steps for proposed system is shown in the flowchart below:

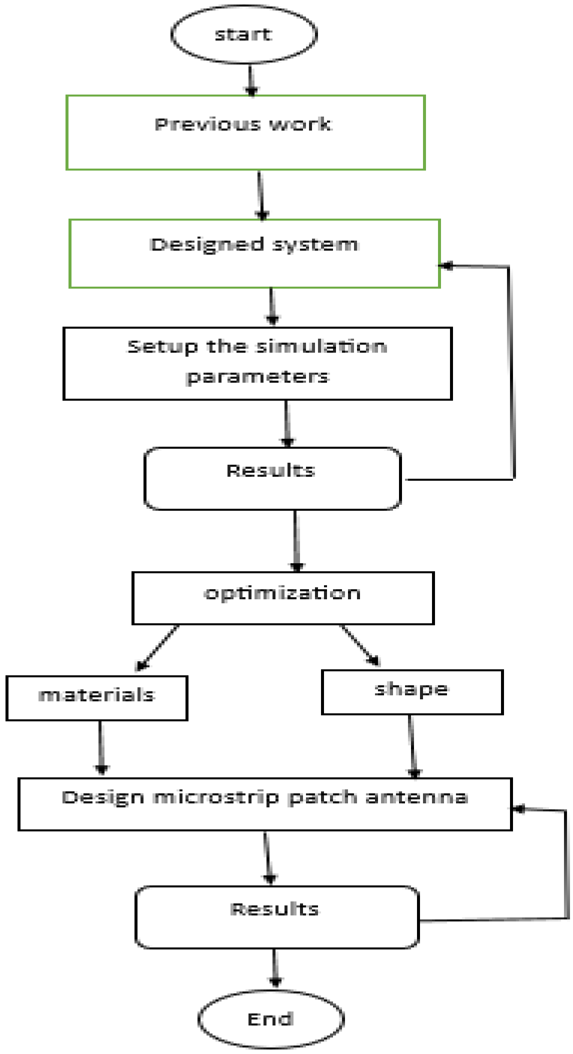


Figure 1: Flowchart of the proposed system

4. System Design

This section will discuss the key parameters that determine the system's performance, along with the radiation pattern that contributes to understanding the system's behavior in various operating conditions. It will also include information about the application of CST (Computer Simulation Technology).

System design is the process of planning and building a system that includes the necessary components and processes to achieve specific goals. This involves analyzing requirements, defining the appropriate architecture, and selecting suitable technology to ensure the system's efficiency and effectiveness in meeting user needs. The parameters design is illustrated in Table 1 below.

The antenna design process began by identifying the fundamental requirements, where the operating frequencies of 1.582 GHz and 2.4 GHz were selected to cover both GPS and wireless communication applications. Subsequently, the FR-4 substrate material was chosen due to its suitable dielectric constant, good efficiency, low cost, and ease of availability.

Table 1. System Design Parameters

Parameter	Dimensions(mm)
Substrate width (ws)	95
Substrate length (ls)	82
Substrate thickness(hs)	2.1
Patch width (wp)	58.5
Patch length (lp)	44.2
Notch thickness (ht)	0.05
Ground plane width (wgr)	95
Ground plane length (lgr)	82
Ground plane thickness (ht)	0.05
Line width (wf)	4.11
Line length (lf)	26.31
Gap length (lg)	8.5
Gap width (wg)	2.07

The 3D model of the antenna was built using CST Studio Suite, with all physical and structural parameters accurately defined. An appropriate feeding technique was also selected to ensure proper impedance matching and enhance radiation efficiency. After completing the model, the simulation settings were configured within CST, including the solver type, frequency range, and the simulation environment. The simulation was then carried out to analyze key parameters such as return loss (S11), radiation pattern, gain, and Voltage Standing Wave Ratio (VSWR). Based on the results, the design was refined by adjusting dimensions and feed location to optimize performance, particularly in terms of gain and minimizing signal losses. Finally, the results were documented by extracting graphs and numerical data Analysis Procedure.

5. Results and Discussion

5.1 S-Parameter

Figure 2 presents the simulation results of the reflection coefficient S_{11}, which is considered one of the most important indicators for evaluating the antenna's performance in terms of radiation efficiency and impedance matching between the antenna and the feed line. The targeted frequencies are 1.582 GHz and 2.4 GHz, both of which represent important bands for wireless communication applications. Based on Figure 2, the S11 value is below -10 dB at these frequencies, which indicates the antenna’s capability to minimize reflection losses, thus ensuring efficient power transfer to and from the antenna. The simulation results also demonstrate the success of the design in covering the desired frequency bands.

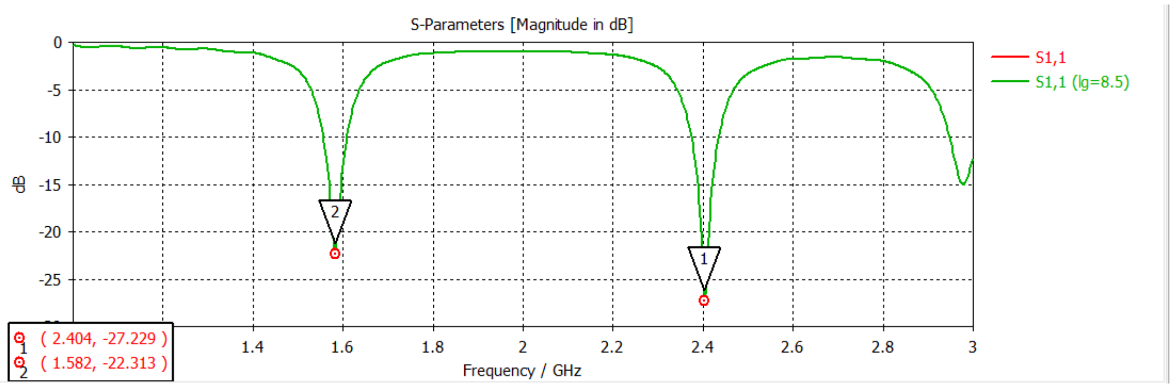


Figure 2. Resonant frequencies

5.2 Voltage Standing Wave Ratio (VSWR)

The Voltage Standing Wave Ratio (VSWR) is another important indicator for evaluating the impedance matching between the antenna and the feed line. The VSWR value reflects the efficiency of power transfer from the source to the antenna, where the values close to 1 indicate ideal matching, while higher values suggest significant power loss due to reflections. In the proposed design, the VSWR was analyzed at the two frequencies, 1.582 GHz and 2.4 GHz, to assess the antenna's compatibility with these bands. The results shown in Figure 3 demonstrate that the antenna achieves a VSWR value of less than 2 at both frequencies, which indicates a good matching that minimizes power loss and enhances transmission and reception efficiency.

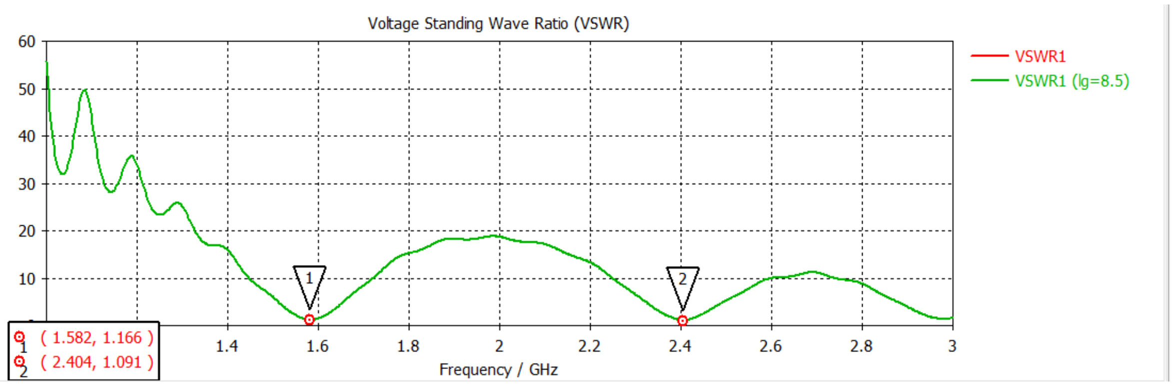


Figure 3. VSWR

5.3 Radiation Pattern

One of the key features that determines how the radiated energy is dispersed in the area surrounding the antenna is a radiation pattern, which is depicted in Figure 4. The coverage areas and the primary direction of radiation are determined by the radiation pattern, which shows the directions in which the antenna effectively radiates energy. Additionally, Figure 4 displays the directivity radiation pattern at 1.582 GHz, with a directivity of 6.492 dBi, a radiation efficiency of 0.426, and a total efficiency of 0.430. Figure 5 displays the directivity radiation pattern at 2.4 GHz, with a directivity of 5.34 dBi, a radiation efficiency of 0.581, and a total efficiency of 0.583.

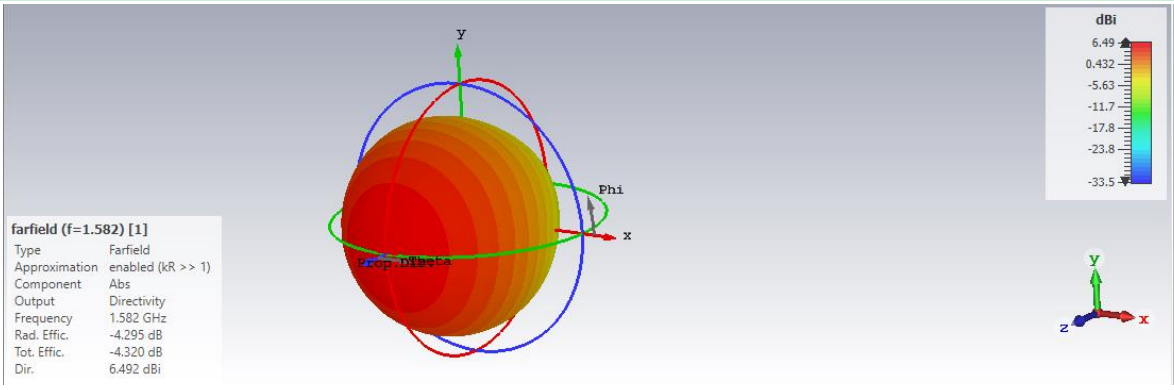


Figure 4. Radiation Pattern at F=1.582

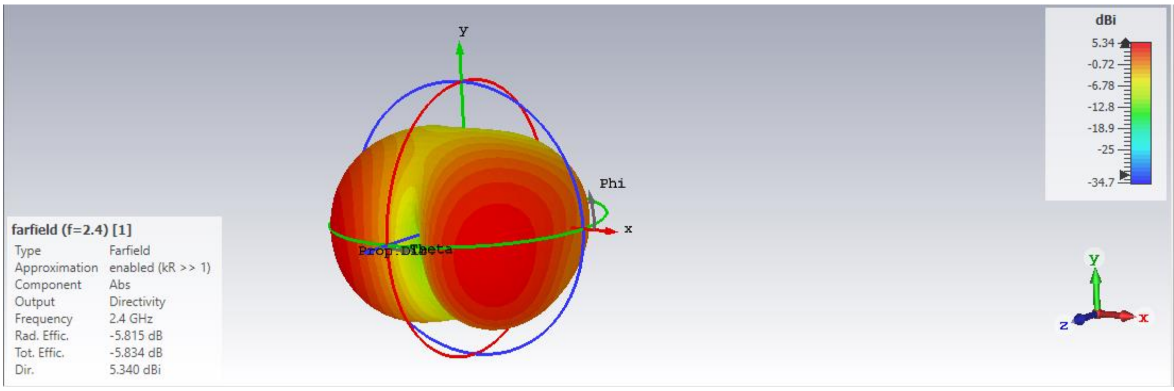
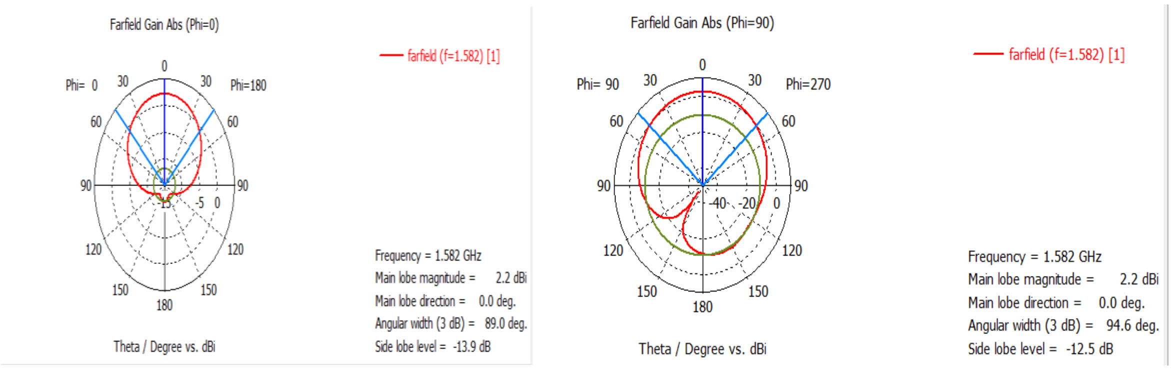


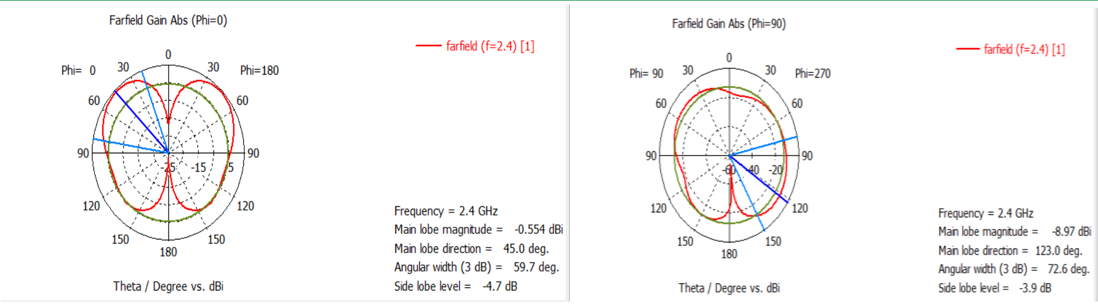
Figure 5. Radiation Pattern at F=2.4 GHz



a. **b.**

Figure 6. Far Field Gain Abs at (a)Phi=0 and (b) Phi=0 and at F = 1.582 GHz

Figure 6 (a) shows the directional gain plot in the longitudinal plane (Phi = 0) at a frequency of 1.582 GHz, with a maximum gain of 2.2 dBi. The main lobe is directed at 0.0 degrees, with a beamwidth of 89.0 degrees, and a side lobe level of -13.9 dB. While Fig. (b) shows the directional gain plot in the transverse plane (Phi = 90) at the same frequency, with a maximum gain of 2.2 dBi. The main lobe is directed at 0.0 degrees, with a beamwidth of 94.6 degrees, and a side lobe level of -12.5 dB.



a. **b.**

Figure 7. Far Field Gain Abs at (a)Phi=90 and (b) Phi=0 at F = 2.404 GHz

Figure 7 (a) shows the directional gain plot in the transverse plane (Phi = 90) at a frequency of 2.4 GHz, with a maximum gain of 8.97 dBi. The main lobe is directed at 123.0 degrees, with a beamwidth of 72.6 degrees, and a side lobe level of -3.9 dB. While Fig. (b) shows the directional gain plot in the longitudinal plane (Phi = 0) at a frequency of 2.4 GHz, with a maximum gain of -0.554 dBi. The main lobe is directed at 45.0 degrees, with a beamwidth of 59.7 degrees, and a side lobe level of -4.7 dB.

5.4 Power Radiated

The simulation results of the radiated power is shown in Figure 8, which is an important parameter for evaluating the antenna's efficiency and performance. Radiated power reflects the amount of input energy that is actually emitted by the antenna into free space. Higher values of radiated power indicate better antenna performance, as more energy is transmitted .rather than lost within the structure or reflected. In this design, the radiated power was analyzed at two key frequencies, 1.582 GHz and 2.4 GHz, to assess the antenna's efficiency across the target bands. The results show that the antenna achieves a maximum radiated power of approximately 0.1849 W at 1.582 GHz, and 0.1305 W at 2.4 GHz, indicating effective radiation at both frequencies. These values confirm that the antenna performs efficiently and is suitable for applications operating in these frequency ranges, contributing to improved signal coverage and overall system performance.

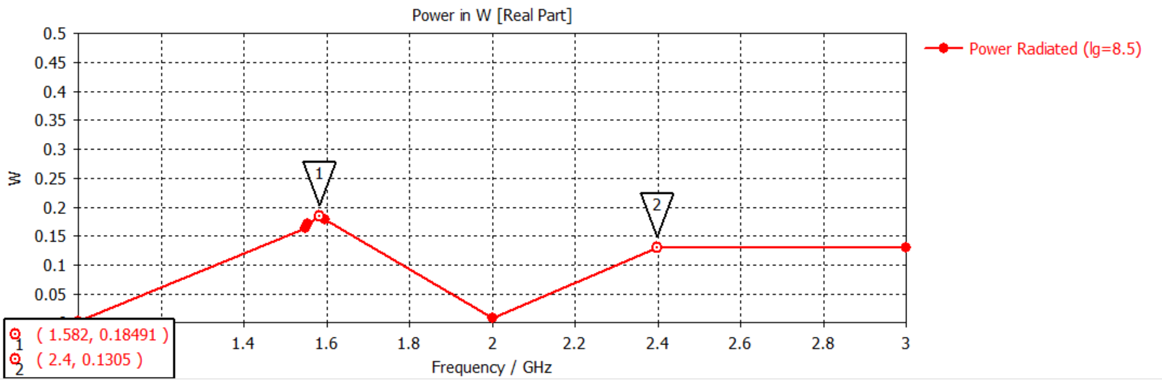


Figure 8. Power Radiated

6. Conclusion

The main goal of this work is to create a microstrip patch antenna especially for GPS applications and evaluate its effectiveness. The research involves a number of crucial processes, beginning with research and study to comprehend the fundamentals of microstrip antenna design and GPS requirements, with a special emphasis on the two target frequencies (1.582 GHz) and (2.404 GHz). The antenna was designed with compact dimensions of 95 × 82 × 2.1 mm³, making it suitable for integration into modern portable and embedded systems. The substrate material used was FR-4 with a relative permittivity of 4.3, chosen for its a balance between cost and performance The simulation results obtained from CST Studio Suite showed promising performance metrics: return losses of -22.313 dB at 1.582 GHz and -27.229 dB at 2.404 GHz, indicating excellent impedance matching. Additionally, the Voltage Standing Wave Ratio (VSWR) remained below 2 across both frequencies, and the radiation patterns exhibited good directivity and gain, confirming efficient signal transmission and reception. Finally, the design will be modified based on the results to achieve better performance. The expected outcome is an effective antenna that can be used in GPS applications with performance improvements.

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