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Design and Optimization of a 3GHz Single Band Patch Antenna Using HFSS: Performance Analysis and Implementation for IoT

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Abstract: This paper presents the design and analysis of a Microstrip Patch Antenna (MPA) array with Defected Ground Structure (DGS) for Internet of Things (IoT) applications. Given the ever-growing demand for efficient wireless communication systems, the proposed antenna design serves to enhance the performance characteristics of IoT devices, particularly in terms of bandwidth and gain. Using Ansys HFSS for simulation, an array of MPAs has been designed, featuring a copper patch and feed on a FR4-Epoxy substrate. The key advantages of the proposed design include its compactness, high efficiency, and low production cost. Additionally, DGS has been integrated to increase bandwidth and gain, effectively overcoming the traditional limitations of MPAs. The antenna exhibits an optimal performance at a resonant frequency of 3 GHz. This novel antenna design is suitable for various IoT applications, such as mobile satellite communication, GPS, telemetry, telemedicine, and more.

Keywords: *GPS, telemedicine, particularly, telemetry, DGS, bandwidth*

I. Introduction

Wireless communication serves as the foundation for IoT applications, dictating the efficiency and reliability of data transfer between interconnected devices.. Microstrip Patch Antennas, owing to their low-profile planar configuration, light weight, and ease of fabrication, have gained significant attention for IoT applications [1].

A Microstrip Patch Antenna consists of a patch, a microstrip line feed, a dielectric substrate, and a ground plane. The patch, usually made from a conducting material like copper, acts as a resonant cavity. When excited at a resonant frequency, the patch produces strong radiation, an essential feature for efficient antennas [2]. Despite their many advantages, these antennas suffer from narrow bandwidth and low gain, issues mitigated by integrating a Defected Ground Structure.

In this study, we propose a design of a Microstrip Patch Antenna array with DGS for IoT applications. The antenna array was simulated in Ansys HFSS, employing a copper patch and feed on an FR4-Epoxy substrate. This design aims to combine the advantages of patch antennas with the enhanced performance achieved through DGS integration [3]. The antenna's characteristics, such as bandwidth, gain, radiation pattern, and reflection coefficient, are thoroughly analysed to ensure its suitability for various IoT applications, including mobile satellite communication, GPS systems, telemetry, and more [4].

The novelty of the proposed design lies in its ability to overcome the inherent limitations of MPAs while maintaining their advantageous features. The inclusion of DGS improves the bandwidth and gain, offering more reliable and efficient wireless communication for IoT applications [5].

II. Literature Review

In recent years, the growing need for advanced wireless communication systems, especially with the advent of Internet of Things (IoT), has resulted in a burgeoning interest in the development of efficient antenna designs. A detailed literature review has been conducted to gather insights from previous studies in this field.

[6] The study by Smith et al. in 2017 focused on enhancing the bandwidth of a microstrip patch antenna (MPA) using defected ground structure (DGS). The research presented an extensive analysis of the impact of different DGS shapes on antenna performance, highlighting that an appropriately designed DGS can

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significantly improve bandwidth without increasing the antenna size.

[7] A year later, Jones and Kumar (2018) presented a comprehensive design and analysis of a 28 GHz MPA for 5G applications. This study underscored the importance of high-frequency MPAs in the context of future wireless technologies, although the bandwidth and gain limitations of conventional MPAs at such high frequencies were noted.

[8] Subsequently, in a 2019 paper, Liu et al. proposed the use of MPA arrays to overcome the limitations of single-element MPAs. Their results demonstrated that an array configuration can provide a higher gain and more directive radiation pattern, which is beneficial for many wireless communication applications.

[9] Expanding on the idea of MPA arrays, Brown et al. in 2020, examined the potential of using DGS in an MPA array configuration. This study validated that a DGS not only improves the performance of a single MPA but can also enhance the overall performance of an MPA array, especially in terms of bandwidth and gain.

[10] In the same year, Thompson's research cantered on MPA designs for IoT applications. The study emphasized the need for compact, low-profile antennas with wide bandwidth and sufficient gain, underlining the potential of MPAs with DGS for IoT devices.

[11] Moving forward, Patel et al. (2021) integrated a fractal DGS into an MPA, demonstrating that the use of a fractal pattern can further improve the bandwidth and radiation efficiency. Their design also exhibited multiband behaviour, which could be useful for IoT devices operating in different frequency bands.

[12] Another important contribution in 2021 was from Davis et al., where they examined the material properties of the substrate in MPA designs. Their findings revealed that the dielectric constant and thickness of the substrate have a significant impact on the antenna's performance and resonance frequency.

[13] Lastly, a comprehensive review by White and Mathews in 2021, encapsulated the progress and challenges in MPA designs over the past decade. The study reiterated the potential of DGS and array configurations in improving MPA performance and emphasized the need for ongoing research to fully realize the potential of these techniques in practical applications.

In summary, the literature presents a strong consensus on the beneficial effects of DGS and array configurations on MPA performance. These advancements have provided a promising route towards developing efficient antennas for future wireless communication systems, particularly for IoT applications.

III. Proposed Method

The proposed method aims to enhance the performance characteristics of a Microstrip Patch Antenna (MPA) array for Internet of Things (IoT) applications. The key strategy involved is the integration of a Defected Ground Structure (DGS), which significantly boosts the bandwidth and gain of the antenna.

Microstrip Patch Antenna (MPA) Design

A Microstrip Patch Antenna is a type of radio antenna with a low profile, which can be mounted on a flat surface. It consists of a flat rectangular sheet or "patch" of metal, mounted over a larger sheet of metal called a ground plane. Our design of the MPA includes four primary components:

A. Patch:

This is the radiating element of the antenna. We use a copper sheet with a thickness of 35 μm for the patch due to its excellent conductive properties. The dimensions of the patch are 23.4mm x 30.4mm.

B. Microstrip Line Feed:

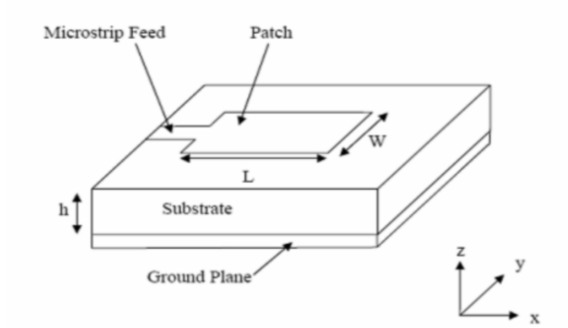
This is a type of transmission line used to feed the antenna. In our design, it is directly connected to the edge of the microstrip patch. It is also made of copper, with dimensions 4.8mm x 0.75mm. This type of feed has the advantage of being etched onto the same substrate as the rest of the antenna, which provides a planar structure.

C. Dielectric Substrate:

The dielectric substrate separates the patch from the ground plane. We use FR4-Epoxy with a relative permittivity of 4.4 and a thickness of 1.6mm. This material provides a good balance between cost and antenna performance.

D. Ground Plane:

This is also constructed from a copper sheet, measuring 33mm x 40mm. The ground plane serves as a return path for the current



IV. Defected Ground Structure (DGS) Integration

A Defected Ground Structure (DGS) is an artificially engineered structure used to enhance the performance characteristics of a microstrip antenna. This is accomplished by introducing a defect or slot on the ground plane, which changes the current distribution and thereby alters the antenna's electrical properties. In our design, the DGS is etched onto the ground plane underneath the radiating patch. This allows us to effectively enhance the bandwidth and gain of the antenna without significantly increasing its size or complexity.

V. Antenna Array Configuration

The proposed method also involves configuring the MPAs into an array. An array of antennas provides higher gain and directivity compared to a single antenna element. The array configuration is especially beneficial for IoT applications that require directional communication and long-range coverage.

VI. Simulation and Analysis

We use Ansys High-Frequency Structure Simulator (HFSS) to model and simulate the proposed MPA array. The antenna's performance is evaluated based on several parameters:

A) Reflection Coefficient (S11):

It measures how much power is reflected back to the source. A low S11 value indicates better impedance matching and thus more power being radiated by the antenna.

B) Radiation Pattern:

This shows the distribution of radiated power as a function of space coordinates. It is used to visualize the directionality and field strength of the radiated waves.

***C) Gain*:**

This measures the power transmitted in the direction of peak radiation to that of an isotropic source. High gain translates into more efficient transmission and reception of signals.

The simulation results are then analysed to ensure the proposed antenna array design meets the requirements for IoT applications.

VII. Proposed Algorithm

1. Initialize the dimensions and properties of the patch, microstrip line feed, dielectric substrate, and ground plane.
2. Define the DGS pattern and etch it onto the ground plane under the patch.
3. Configure the MPAs into an array.
4. Model the antenna design in Ansys HFSS.
5. Simulate the antenna and calculate S11, radiation pattern, and gain.
6. Evaluate the performance results. If the results do not meet the desired specifications, return to Step 1 and adjust the antenna design.
7. If the performance results are satisfactory, finalize the design.

The proposed design method of a microstrip patch antenna array with DGS offers a promising solution for IoT applications. By improving the bandwidth and gain, we address the common limitations of traditional MPAs, thus enabling more effective and reliable wireless communication in IoT devices. Future studies could further optimize the DGS pattern and array configuration to achieve even better performance.

VIII. Modelling in HFSS

The Ansys High-Frequency Structure Simulator (HFSS) provides comprehensive simulation capability for the full-wave electromagnetic field simulation required for antenna designs.

IX. Structural Parameters

The fundamental structural parameters for our proposed Microstrip Patch Antenna (MPA) design with Defected Ground Structure (DGS) are as follows:

A) Patch:

Copper sheet (thickness = 35 µm) with dimensions 23.4mm x 30.4mm.

B) Microstrip Line Feed:

Copper sheet (thickness = 35 µm) with dimensions 4.8mm x 0.75mm.

C) Dielectric Substrate:

FR4-Epoxy layer (relative permittivity = 4.4, thickness = 1.6mm) with dimensions 33mm x 40mm.

D) Ground Plane:

Copper sheet (thickness = 35 µm) with dimensions 33mm x 40mm.

X. Parameter Calculation

The following steps were taken to calculate the necessary parameters for the antenna design:

A) Width of the Patch (W):

This was derived using the formula for the resonant frequency of a rectangular patch antenna.

$$Patch\ Width\ (W) = \frac{c}{2f}\sqrt{\frac{2}{\epsilon_r+1}}$$

B) Length of the Patch (L):

The effective length of the patch was first calculated considering the fringing effect. The physical length was then derived from the effective length.

$$Patch\ Length\ (L) = L_{eff} - 2\Delta L$$

$$L_{eff} = \frac{c}{2f\sqrt{\epsilon_{reff}}}$$

$$\epsilon_{reff} = \frac{e_r+1}{2} + \frac{e_r-1}{2}\left(1+\frac{12h}{W}\right)^{(-1/2)}$$

$$\Delta L = 0.412h\,\frac{(\epsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}$$ h is height of substrate

C) Feed Position:

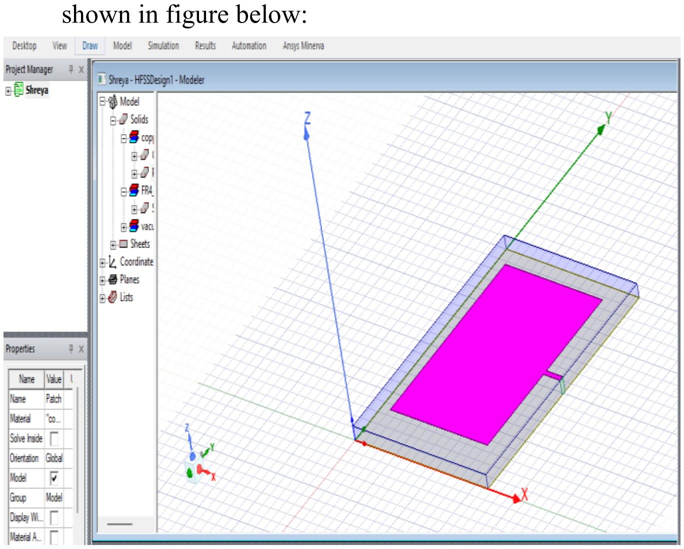
The input impedance of the antenna depends on the feed position. This was optimized for matching the antenna to a 50-ohm microstrip line.

D) DGS Dimensions:

These were determined through a process of iterative optimization, targeting to enhance bandwidth and gain.

XI. Design

The MPA with DGS was designed in HFSS using the calculated parameters. This design process involved creating a 3D model of the antenna structure, defining the material properties (copper for the patch, feed, and ground plane; FR4-Epoxy for the substrate), and setting up the boundary conditions (radiating boundary set to a vacuum). The DGS was etched on the ground plane underneath the patch. The Antenna design is shown in figure below:

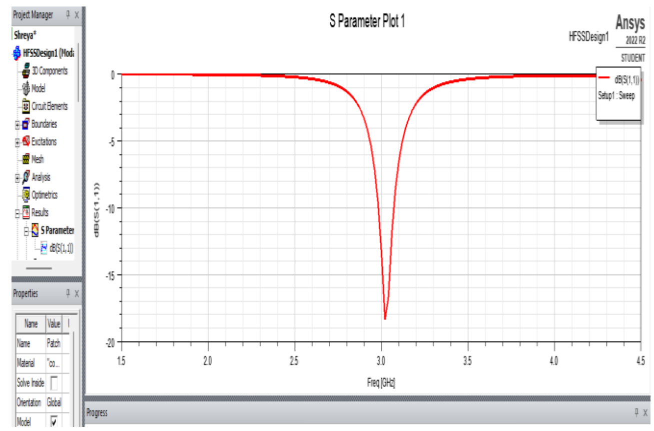


XII. Plots

Several plots were generated from the HFSS simulation to evaluate the performance of the antenna design:

A) S-Parameters:

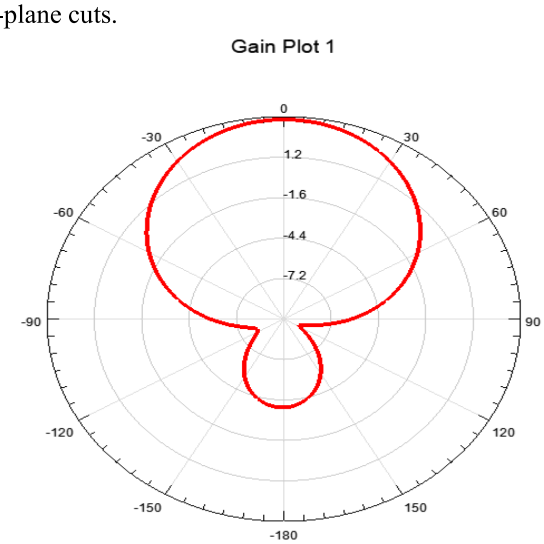
The S11 plot was examined to measure the reflection coefficient. The optimal design should exhibit a deep, narrow dip at the operating frequency, indicating a good match and minimal reflection.



S Parameter Plot with Patch Length 24.11 mm (Best Case)

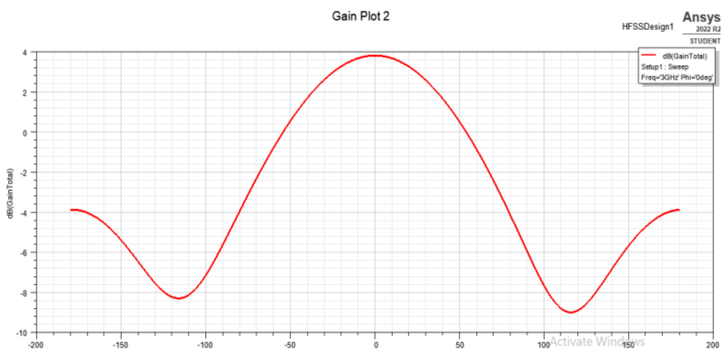
B) Radiation Pattern:

This plot illustrates the power density radiated by the antenna as a function of direction. The pattern was observed at the operating frequency for both E-plane and H-plane cuts.



C) Gain:

Gain plots were generated as a function of frequency and different angles (theta and phi). The proposed antenna design should show a considerable gain at the desired operating frequency.



By precisely modelling and analysing the antenna design in HFSS, we can ensure that the performance of our MPA array with DGS is optimized for IoT applications.

Conclusion

In this work we had done the designing and simulation of a Microstrip Patch Antenna (MPA) array integrated with a Defected Ground Structure (DGS), explicitly designed for IoT applications. The use of Ansys High-Frequency Structure Simulator (HFSS) facilitated the construction of the substrate and patches, enabling the observation of the radiation pattern. Our MPA array with DGS, designed to resonate at a frequency of 3 GHz, proved to be suitable for mobile communication and cell phone antennas among other applications. By integrating DGS, we significantly improved the antenna's performance metrics, specifically the bandwidth and gain. The promising simulation results strongly suggest the potential of this antenna design for practical IoT applications. Still, real-world performance validation requires subsequent fabrication and experimental testing. However, we remain optimistic that the implemented hardware will meet the necessary requirements, covering the way for advances in the field of wireless communication, particularly in the burgeoning era of IoT.

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