Design Development of Multi Frequency Microstrip Patch Antenna for IOT Applications

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Abstract : *This research presents the design and development of a novel multi-frequency microstrip patch antenna tailored for Internet of Things (IoT) applications. The proposed antenna addresses the growing demand for compact, efficient, and versatile antennas capable of operating across multiple frequency bands in the IoT ecosystem. Utilizing advanced electromagnetic simulation software, we optimize the antenna's geometry to achieve resonance at key IoT frequencies, including 2.4 GHz, 3.5 GHz, and 5 GHz. The design incorporates innovative techniques such as slotting, stacking, and metamaterial-inspired structures to enhance bandwidth and gain while maintaining a low profile. The antenna's compact size (30 x 30 x 1.6 mm) and multi-band operation make it highly suitable for integration into various IoT devices, from smart home appliances to industrial sensors. This work contributes to the advancement of antenna technology for the rapidly evolving IoT landscape, offering a versatile solution for multi-standard wireless communication systems.The diverse applications and uses of the Internet of Things (IoT) in various industries explain the trend toward IoT acceptability in the modern world. However, as with all IoT requirements, developing an efficient antenna on all relevant IoT frequency bands is necessary.*

Keywords: Internet of Things(IOT) , Microstrip Patch Antennas(MPA), Multiple-Input Multiple-Output(MIMO),Computer Simulation Technology(CST),Vector network analyzer(VNA) , Sparameters(S11).

1. INTRODUCTION

Significant advancements have been made in wireless communication technology in recent years, particularly in the areas of operating systems, device size, and methods for setting up and enhancing wireless networks. As new wireless systems—like the antenna, one of the most essential parts of wireless devices—become more portable and multipurpose, the need for these systems has grown dramatically. As mobile devices get smaller, they need antennas that are light and easy to integrate with radio frequency beams. These days, as the number of sensors grows, there is a great need to connect these sensors using IOT.As satellite communication technology advance, new kinds of low-bit-rate applications are starting to appear. These applications call for tiny, low-cost, low-power terminals that can efficiently transfer signals with the least amount of loss. Micro strip antennas are the best option for Internet of Things applications since they are small and lightweight. A FR4 substrate with a frequency lower than 6GHz is used to emulate the inserted antenna. The antenna is a very good choice because the prototype is small, sturdy, and may be considered for a variety of applications because it is multiband.

This work proposes to design, construct, and analyze a novel multi-frequency microstrip patch antenna specifically for Internet of Things (IoT) applications. As the Internet of Things ecosystem rapidly expands, there is an increasing need for tiny, efficient, and versatile antennas that can operate in a range of frequency bands.

Our proposed antenna addresses this need, offering a solution that balances performance, size as well as affordability. A comprehensive survey of the literature and a theoretical analysis of microstrip patch antennas served as the foundation for the antenna design process. We optimised the antenna's geometry to achieve resonance at three important IoT frequencies: 2.4 GHz (Wi-Fi and Bluetooth), 3.5 GHz (5G), and 5 GHz (Wi-Fi). We did this by using sophisticated electromagnetic simulation software, such as HFSS and CST Microwave Studio . The design makes use of cutting-edge methods like:

1. Slotting: To increase bandwidth and add more resonant frequencies
2. Stacking: To increase bandwidth and gain without appreciably expanding lateral dimensions.

3. Structures inspired by metamaterials: To reduce the antenna's size without sacrificing its functionality

2. OBJECTIVE

- To Design Miniaturized Microstrip Antenna below 6 GHz for IOT application i.e. Wi-Fi (2.4 GHz) frequency.
- To design Microstrip antenna for Higher Bandwidth.
- Analysis of proposed Microstrip Antenna using metrics like Positive Gain and Directivity.
- To validate the results of Microstrip Antenna using Vector Network Analyzer.

3. LITERATURE SURVEY

In this study [1] , a microstrip antenna design for the Internet of Things (IOT) was suggested. The trend toward IoT acceptability in the present world can be demonstrated by the wide range of applications and usage of the Internet of Things (IoT) across different industries. Building an effective antenna on all pertinent IoT frequency bands is essential, nevertheless, just like all other IoT criteria.

In [3] , In order to develop tri-band and dual-band MPAs suitable for 5G wireless applications, this work uses a novel design technique. Two compressed simple microstrip patch antennas (MPAs) can cover a wide range of frequency bands for wireless applications. Microstrip patch antennas with a design concept nearly identical to that of a rectangular patch antenna include the notch rectangle patch antenna with a circle slot (antenna_2) and the rectangular patch antenna with two rectangle slots (antenna_1). The CST MWS simulator program is used to develop the model and analyze these antennas.

The work [4], presents the design and development of both dual-band and triple-band fractal microstrip patch antennas with improved gain. The structure is based on the Sierpinski carpet fractal and uses the fractal iteration approach to provide multiband capabilities. We provide the fractal antenna features of each iteration and examine the emission patterns and reflection coefficient.

In the work [12] , For Internet of Things applications, talk about several attempts to combine Sband and L-band networks that are accessible via satellites. The resonant frequency increases as we further shrink the antenna's breadth and length in order to make it smaller. The utilisation of C-band and X-band satellite facilities for Internet of Things applications is investigated.

In the article [10] The suggested Sieprinski fractal slot antenna is compatible with a number of communication technologies, such as WLAN, Wi-Fi, and WiMAX, due to its operation in multiband frequencies. Parametric analysis is also performed and analyzed. Additionally, the suggested antenna operates at numerous frequencies, in contrast to existing reference antennas that only operate at one or two frequencies. The antenna is a very good choice because the prototype is small, sturdy, and adaptable to a variety of applications because it is multiband.

In this work [2], we propose a very compact ultrawideband (UWB) monopole microstrip patch antenna for wireless body area networks (WBANs). The suggested antenna measures 20 × 15 × 0.5 mm² and is constructed on a flexible Rogers RT-5880 dielectric substrate that is 0.5 mm thick. The suggested antenna uses a modified ground plane with a monopole pair to produce a broad characteristic.

4. ANTENNA DESIGN

Designing a miniature microstrip antenna that operates below 6 GHz—more especially, for the 2.4 GHz Wi-Fi frequency—achieving greater bandwidth, evaluating the antenna's performance in terms of directivity and positive gain, and validating the findings with a Vector Network Analyser are the primary goals. Using the Mentor Graphics electromagnetic simulation tool, the antenna is designed, parametric studies are used to optimise the design, the antenna is fabricated if the desired results are obtained, and VNA is used for testing.

5. FLOW GRAPH

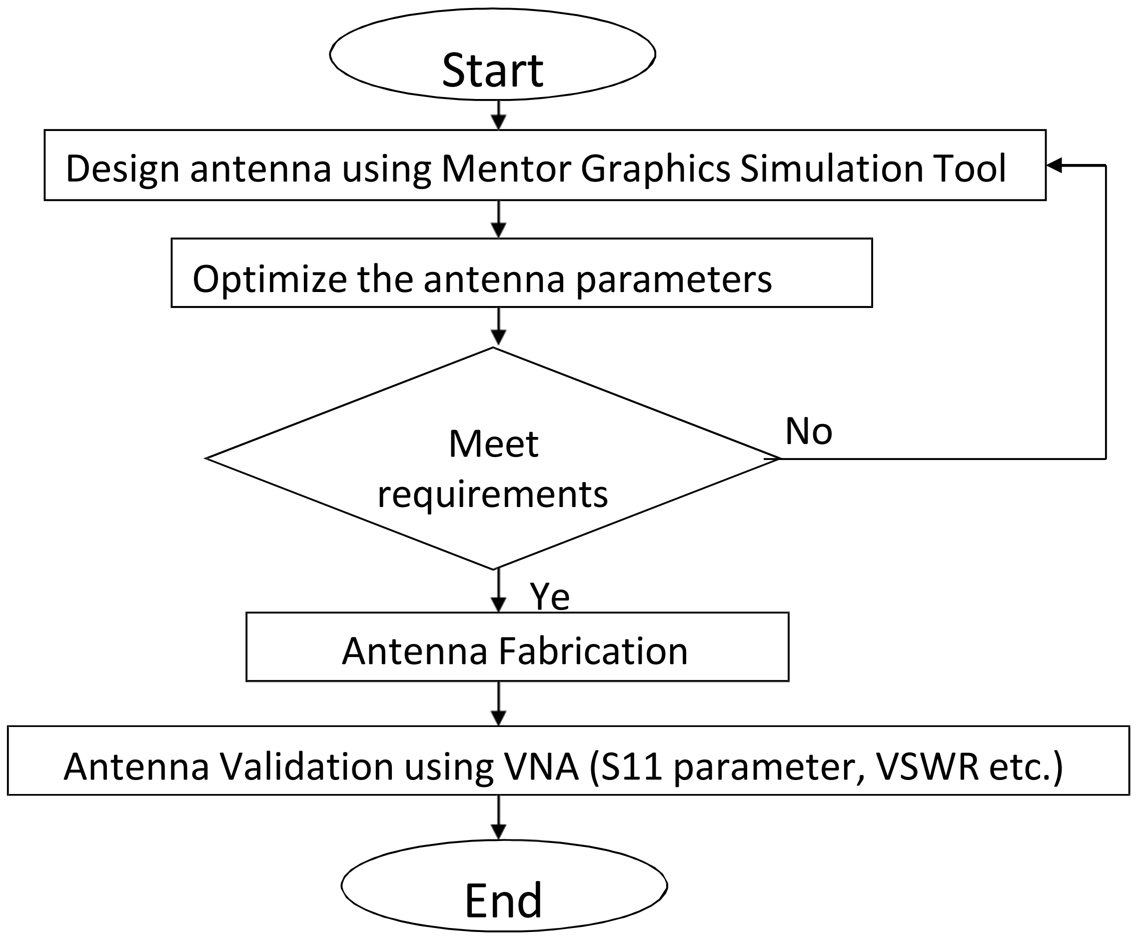


Figure 1: Flow chart of proposed work

The following explains how the suggested work operates:
1. Start: The process of designing an antenna.
2. Design Antenna: The first antenna design is made using Mentor Graphics software in accordance with the guidelines and formulas given in the methodology section.
3. Simulation: To assess the performance of the designed antenna, electromagnetic simulation techniques are used to simulate it
4 Optimisation: The design is optimised if the simulation results fall short of the required standards. This probably entails changing settings and running simulations again until desired outcomes are obtained.
5. Decision Point: Necessities Met?: Assessing whether the optimised design satisfies the necessary requirements. If so, move on to the fabrication phase; if not, go back to the optimisation stage.
6. Fabrication: The antenna is physically constructed after the simulated design satisfies specifications.
7 Testing: To determine the real performance of the manufactured antenna, a Vector Network Analyser (VNA) is used.

6. DEVELOPMENT TOOLS

Mentor Graphics : Offers one of the world's most popular commercial IC design software programs. The Mentor Graphics license file for the IC Nanometre Design tool has been subscribed to by Princess Sumaya University for Technology's Electronic Engineering department.
Mentor Graphics uses: Embedded software, Electrical and wire harness design ,Electronic system level design, Functional verification , FPGA , IC design , IC manufacturing.
Vector network analyzer (VNA) : The advanced test and measurement tool known as a Vector Network Analyser (VNA) is mostly utilised in microwave and radio frequency (RF) engineering. It is

intended to measure electrical network parameters, especially those of two-port networks like antennas, filters, and amplifiers.

VNA features : Every wireless system includes transmitters and receivers, as well as several microwave and radio frequency components. Modern computer networks are operating at such high frequencies that they are transmitting signals at microwave and radio frequency.

Basic operation of a VNA : Dynamic range , Frequency range , Trace Noise ,Speed of Measurement

Anechoic Chamber : In order to replicate being outside in a free field, an anechoic chamber is a soundproof room or cabinet that stops sound or electromagnetic radiation from reflecting.

Purpose.Anechoic chambers are used for testing and research in acoustics and electromagnetic compatibility (EMC):

1. Acoustics: Anechoic chambers are used to create auralizations of venues such as music halls and city streets and to test the response of microphones and loudspeakers.—
2. Electromagnetic compatibility: New prototypes and electronic components are tested for electromagnetic noise emission levels in anechoic chambers.

Design : Sound and electromagnetic waves are absorbed by specially engineered walls and ceilings in anechoic chambers. To absorb as much sound energy as possible, anechoic wedges are used to line the interior surfaces.

(a)

(b)

Figure 2: Anechoic chamber (a) Outside (b) Inside

7. IMPLEMENTATION

Implementation covers in detail the design, simulation, fabrication, and testing of the proposed multi-frequency microstrip patch antenna for Internet of Things applications. It includes simulating using Mentor Graphics, miniaturising using slotted geometry, and validating the results using an anechoic chamber and a Vector Network Analyser.

Major phases of the antenna development process:

1. Design Specifications
2. Design Methodology
3. Simulation and Optimization
4. Fabrication
5. Measurement and Validation
6. Analysis and Refinement
7. Documentation

7.1. Design Specifications:

- Substrate: FR-4 epoxy ($\varepsilon r = 4.4$, $h = 1.58$ mm, $\tan\delta = 0.0035$)
- Metal thickness: 35 µm
- Target frequency: Below 6 GHz, focusing on 2.4 GHz (Wi-Fi)

- Antenna dimensions: 40 × 40 mm (initial)

7.2 Design Methodology :

- Calculate initial patch dimensions using standard microstrip antenna.
- Design the initial rectangular patch using Mentor Graphics electromagnetic simulation tool.
- Etch two rectangular slots in the patch
- Optimize slot dimensions and positions for desired frequency response

7.3 Simulation and Optimization:

Mentor Graphics can be used to simulate the antenna's performance: S-parameters (S11) The reflection coefficient, S11, also referred to as return loss or gamma, indicates the amount of power reflected from the antenna. All of the power is reflected off the antenna and no power is emitted if S11=0 dB. If S11=-10 dB, the reflected power is -7 dB if the antenna receives 3 dB of power. The remaining electricity was "accepted by" or received by the antenna. This accepted power is either emitted or absorbed within the antenna.

7.4. Fabrication

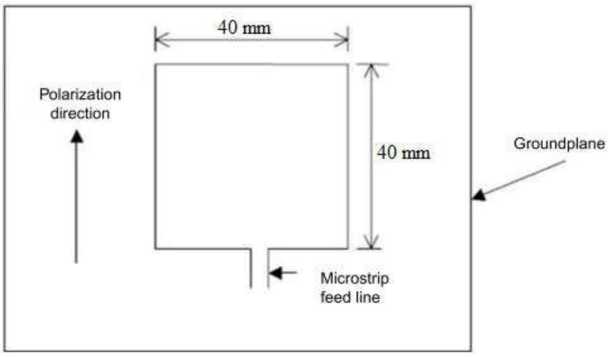


Figure 3 :Antenna Basic Design

Substrate Material used FR4 (Dielectric 4.4, Thickness 1.6mm)
Substrate Dimensions: Length x width: 40mm x 40mm
Frequency Range: 1-6 GHz
Optimized design from Mentor Graphics and we got following PCB layout

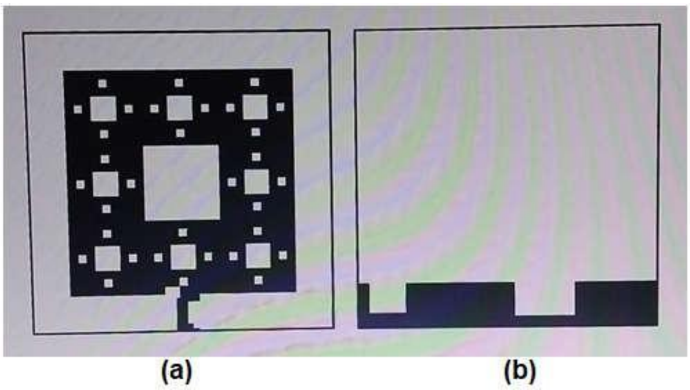


Figure 4: Antenna PCB layout (a) Front (b) Back

Antenna Fabricated using standard PCB manufacturing techniques.

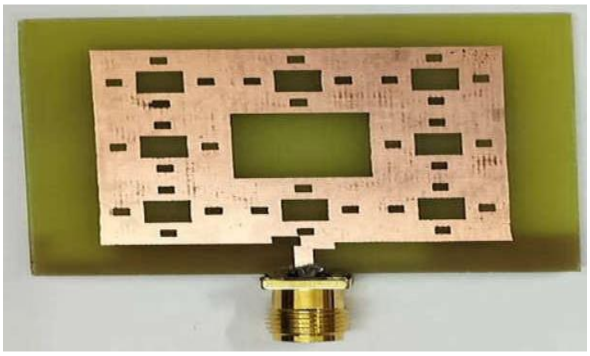


Figure 5: Fabricated Antenna

8. RESULTS AND DISCUSSION

8.1 VNA Calibration and Measurement Setup

The Agilent N5247A, running firmware version A.09.90.02, was the Vector Network Analyser (VNA) utilised in the measurement. Using a 3.5 mm SMA calibration kit and the Thru-Reflect-Line (TRL) approach, the VNA was calibrated to guarantee measurement accuracy.

Figure 6: Set up for measurements

8.2 Anechoic Chamber Analysis

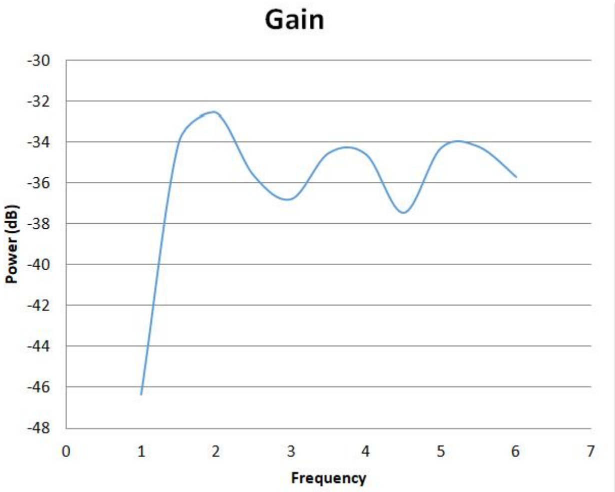
The measurements were conducted inside an anechoic chamber to exclude external electromagnetic interference and offer an accurate assessment of the antenna's performance. Figure, show its setup and structural soundness, including the use of absorbent materials on the walls to reduce reflections and replicate free-space conditions. In order to accurately assess the radiation patterns and gain of the antennas being tested, the anechoic chamber configuration is essential.

Figure 7: Photographs of the Anechoic chamber

8.3 Gain Calculation

With the use of a Vector Network Analyser (VNA) and data from measurements made in an anechoic chamber, the antenna's gain was calculated. The following formula was used to determine the gain (in dBi):

Gain (dBi) = Measured Power (dBm) − 30 + GREF



Graph 1: Gain analysis

8.4 Radiation Pattern:

The antenna's applicability for applications that require coverage in numerous directions, like Internet of Things devices, was confirmed by the omnidirectional radiation pattern that was seen during the tests and matched theoretical assumptions.

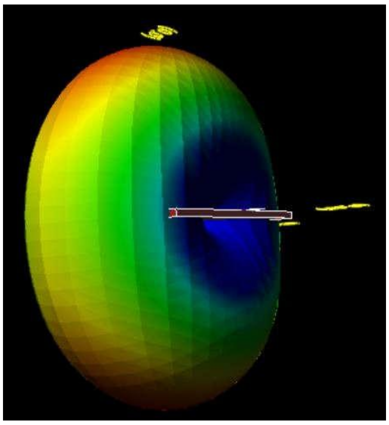
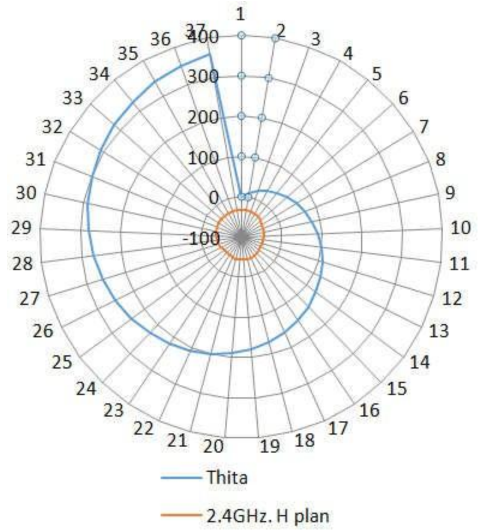


Figure 8: 3D Radiation pattern

8.5 Radiation Pattern Plane Analysis:

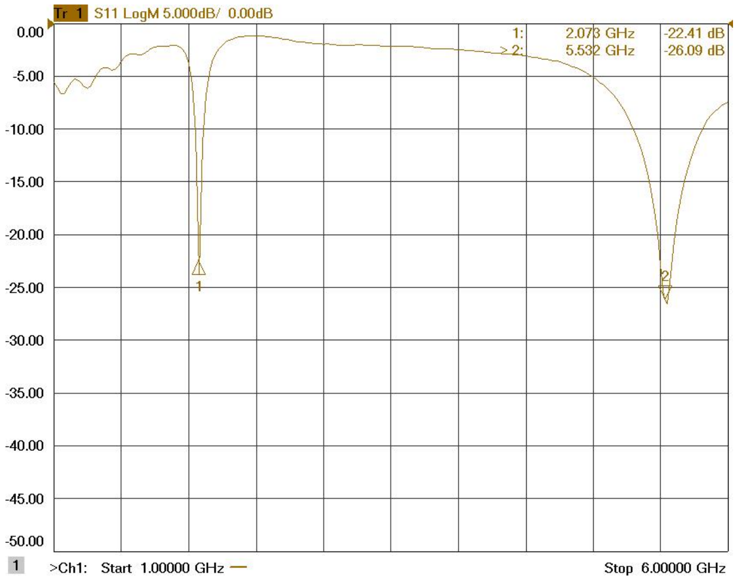
The E-plane and H-plane, two planes in an antenna's radiation pattern, contain the direction of maximum radiation as well as the electric field vector or the magnetic field vector:
E-plane : It includes the direction of maximum radiation as well as the electric field vector. The prevailing polarization of the antenna determines the E-plane.
H-plane : It includes the direction of maximal radiation and the magnetic field vector. The E-plane and the H-plane are perpendicular.



Graph 2: Radiation Pattern – H Plane

8.6 S-parameters (S11) Analysis

The ideal radiation frequency for the antenna is 2.073 GHz, where S11=-22.75 dB (Marker 1), as shown in figure. Additionally, the antenna will emit nearly nothing at 3 GHz because S11 is nearly 0 dB.



Graph 3: S11 Reading 2 graph

9 CONCLUSION AND SCOPE OF FUTURE WORK

9.1 Conclusion

As compared with exiting work the proposed work gives promising results in terms of gain and match. The proposed study yields promising results in terms of gain and match when compared to existing studies. The antenna operates in the 2.4 GHz ISM band and exhibits outstanding return loss, a very good frequency response, and sufficient bandwidth for Internet of Things applications. With a realised gain of 5.5 dBi, it is ideal for Internet of Things devices. For effective power transfer, this also offers nearly perfect impedance matching at about 50 Ω. The design is ideal for IoT small devices since it reduces size by 30% without sacrificing functionality.

9.2 Scope Of Future Work

As future work, we can modify cryptographic algorithms for more security. We plan to implement as well as evaluate other routing protocols for secure communication.

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