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Design and Simulation of a Wearable Body Area Antenna Using CST Software with Cloud-Based Data Storage

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ABSTRACT: The design and simulation of a wearable microstrip patch antenna for telemedicine applications with cloud-based data storage is presented in this paper. The key circuits of a Wireless Body Area Network (WBAN) for continuous monitoring and wireless transmission of physiological parameters, including heart rate, body temperature, electrocardiogram (ECG), oxygen saturation, are wearable antennas. The antennas proposed function within the 1.8 to 4.8 GHz frequency range, which encompasses a number of communication bands in medical telemetry and wireless communication systems. The antenna is designed based on a rectangular slot, inset feed techniques with microstrip patch structure to enhance the impedance matching, bandwidth and radiation characteristics. Due to the wearable devices function in a close distance from human body, designs consider keeping SAR low along with high radiation efficiency and stable gain.

The CST Studio Suite/HFSS simulation software was employed for antenna performance with the return loss (S11), VSWR, gain, radiation pattern, bandwidth, and SAR distribution being analyzed. Additionally, this system incorporates cloud computing, allowing remote storage and access to patient health data which can be used for real-time monitoring as well as telemedicine advancements.

KEYWORDS: Wearable antenna, WBAN, Telemedicine, SAR, Cloud Storage

I. INTRODUCTION

Quickly advancing wireless communication technologies cater to the ever-increasing need for high-speed data and reliable connectivity. The antennas are crucial since they allow electromagnetic (EM) signals to be transmitted and received. Out of these types, microstrip patch antennas are one of the most significant antennas due to their small size, low profile, lightweight structure and easy integration with PCBs at a low cost. They are widely used for satellite communication, mobile systems, radar, WLAN, Bluetooth as well as IoT applications. The typical microstrip antenna is composed of a radiating patch above a dielectric substrate above a ground plane. Simpler designs and more predictable characteristics mean rectangular patches are by far the most popular. Yet, they are restricted by drawbacks like narrow-bandwidth, low gain, and diminished efficiency.

Slotting, stacking, parasitic elements, and ground modification are used to overcome these issues that arise in the device. Slotting is one of them, enabling bandwidth enhancement and impedance matching without occupying extra area. Performance is influenced by feeding techniques too, informal technology providing superior impedance matching and effective power transfer. In this paper a rectangular slot microstrip patch antenna with inset feed is designed in CST Studio Suite for 2.45 GHz ISM band. Parameters like return loss,VSWR gain,bandwidth and radiation pattern are analyzed. This results in improved performance compared to conventional designs. Due to its compact size and improved parameters, this antenna is appropriate for wireless devices, wearables, IoT applications such as short-range communication like health measurement and networking of sensors.

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II. LITERATURE REVIEW

Due to advantages such as compact size, low cost and easy fabrication they have found wide applications in modern wireless communication systems. Example 2: AntennasApplied in Wireless Communication. Wi-Fi, Satellite communication, Mobile communication, and Radar systems. Nevertheless, all in all, traditional microstrip patch antennas have drawbacks of narrow bandwidth, low gain and low radiation efficiency. This has led to several design approaches being suggested by researchers to improve the performance of these antennas.

In [1], a high-gain low-SAR wearable antenna combined with a AMC structure is proposed for applications in Wireless Body Area Network (WBAN). The antenna supports dual frequency bands i.e 2.45 GHz and 5.8 GHz. This effectively suppresses back radiation, decreasing the SAR in human body significantly. This design can achieve high gain values (~6 dBi, ~8.2 dBi) and stably perform at a close distance to the human body.

Features or benefits of this sort of strategy are:
- Improved gain using AMC structure
- Significant reduction in SAR
- Stable performance in wearable conditions
- Suitable for healthcare monitoring applications

Another contribution reported in [2] addresses flexible and wearable antennas for biomedical applications. Flexible substrate materials (with example such as textile fabrics, polymers and conducting fabric) It highlights crucial criterias including circuit miniaturization, adjustable configuration, subthreshold low power consumption and a lower SAR. It also illuminates issues such as body-induced detuning and signal absorption by human tissues.

This work has the following main contributions:
- Use of flexible material for wearing comfort
- Improved integration with biomedical devices
- Radial Effect and RF Radiating Body Design
- Greater suitability for real time health monitoring

The work in [3] aims to present an the overall analysis on wearable antennas, mainly focusing on various antenna structures like patch, monopole, slot and textile antennas. These key design parameters including bandwidth, gain, radiation efficiency, and SAR are discussed in the study. Antenna performance can be enhanced by corresponding techniques which include slotting, defected ground structures (DGS), and metamaterials.

Here are some of the benefits of these techniques:
- Bandwidth enhancement using slotting techniques
- Improved radiation efficiency using DGS
- Reduced SAR using metamaterials
- Improved performance in conditions of body motion

Wearable antennas for biomedical applications are described in [4] with particular focus to healthcare monitoring systems. Wearable antennas covered by the study are capable of remotely transmitting physiological data like heart rates, body temperature and oxygen levels It also studies the effect of important antenna parameters on return loss, gain, radiation and efficiency.

Here are some key takeaways from this paper:
- Efficient transmission of biomedical signals
- Biosensors and medical device integration
- Safe Tyro is SAR for low importance

III. EXISTING METHOLOGY AND TECHNIQUES

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Some researchers have put forward structured approaches for designing and modelling microstrip patch antennas for wireless systems. This general approach involves antenna modeling, the calculation of dimensions, selection of feeding technique, slot manipulation and electromagnetic simulation. The following steps are necessary to improve the main Antenna parameters as bandwidth, return loss, gain and radiation.

Basic Antenna Structure

The majority of designs were based on a rectangular microstrip patch antenna comprising three basic layers:

- Radiating patch (conductive material like copper)
- Dielectric substrate
- Ground plane

The ground plane can be found on the other side of the dielectric substrate, with the radiating patch on this side. Selecting substrate material which has significant effect on antenna performance. Common materials include FR-4 epoxy due to its low cost and possible dielectric properties [3].

Patch Dimension Calculation

The design of the antenna starts with determining the dimensions of the rectangular patch based on the desired radiation frequency. Using the standard design equations, the parameters patch width effective dielectric constant and effective length can be extracted. 2.4 GHz, 5 GHz frequency ranges are frequently chosen due to Wi-Fi, WLAN & IoT systems [4].

Feeding Technique (Inset Feed)

Microstrip antennas require effective impedance matching which can be achieved using the inset feed technique. In this method:

- The patch is connected to a microstrip feed line
- The patch adds a notch (inset) to it
- Adjustment of feed position for 50 Ω matching

Adequate inset depth and width not only aid the improvement of power transfer, but you will also help to decrease the return loss, leading to a more efficient antenna [1].

Slot Loading Technique

To address the narrow bandwidth limitation, additional slot structures are embedded in her radiating patch. Slot loading changes the surface current distribution and yields added resonant paths, thereby enhancing performance. Detailed knowledge of various slot geometries such as rectangular, U, and L slots. This allows for a considerable increase in both the bandwidth and impedance matching without enlarging the antenna itself [3].

Simulation Methodology

Once the antenna geometry has been designed, we simulate it using electromagnetic software tools like CST Studio Suite and HFSS. I reached out to surface as well, adding geometry, loads, and boundary conditions this Newtonian way using full-wave solvers for my analysis.

Key parameters analyzed include:

- Return Loss (S11)
- VSWR
- Gain
- Radiation Pattern
- Bandwidth

These parameters are used to assess whether the antenna satisfies the desired performance characteristics [4].

Optimization and Performance Evaluation

Parameters Slot dimensions, feed position, substrate thickness and patch size are optimized to enhance performance further. Parameter tuning is also performed using advanced techniques (e.g., Genetic Algorithms, ANFIS).

The performance of the antenna is then tested with respect to:

- Return Loss (reflection characteristics)
- VSWR (impedance matching)
- Gain (radiation strength)

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- Radiation Pattern (directional behaviour)
- Bandwidth (operating frequency range)

Performance improvements are compared with existing designs.

IV. PROPOSED METHOLOGY AND TECHNIQUES

The following work describe the designing and simulation of rectangular slot microstrip patch antenna with inset feed techniques for enhancing impedance matching, bandwidth, radiation performance. The antenna operates on the ISM band (2.45 GHz), which is common for WiFi, Bluetooth and all IoT applications. The process involves designing the antenna, embedding the slots, selecting their feed method, simulating their performance and evaluating any changes after embedding the new structures.

Antenna Structure

The structure of the proposed antenna comprises three layers in general:

- Radiating patch (Copper)
- Dielectric substrate (FR-4)
- Ground plane

The rectangular patch is used for its simplicity in design and fabrication.

Slot Integration

The patch is modified with the insertion of a rectangular slot to improve performance.

Advantages:

- Improves bandwidth
- Enhances impedance matching
- Increases radiation efficiency
- Provides better gain

Inset Feed Technique

Microstrip inset feed is applied for this antenna.

- A feed line is placed in a notch of the patch
- The inset position is used to align at 50 Ω.
- Dampens reflection, and enhances power transfer

Simulation Setup

The CST Studio Suite is used for modeling of antenna

Simulation Steps:

- Geometry creation
- Material assignment
- Port definition
- Boundary condition setup
- Frequency analysis

Simulation Parameters

Table 1: Simulation Parameters

Parameter	Value
Operating Frequency	2.45 GHz
Substrate Material	FR-4
Dielectric Constant	4.4
Thickness	1.6 mm

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Parameter	Value
Feeding Technique	Inset Feed
Tool Used	CST Studio

Performance Evaluation

The antenna is analyzed using:

- Return Loss (S11): < −10 dB
- VSWR: ≈ 1–2
- Gain: ~5–6 dB
- Radiation Pattern: Stable
- Bandwidth: Improved

Expected Performance

Table 2: Expected Performance

Parameter	Expected Value
Frequency	2.45 GHz
Return Loss	< −25 dB
VSWR	≈ 1.1
Gain	~6 dB
Bandwidth	>100 MHz

V. ANTENNA PARAMETERS

Antenna Design Parameters

Table 3: Design parameters

Parameter	Value
Operating Frequency	4.2 GHz
Substrate Material	Cotton
Dielectric Constant	3.18
Substrate Thickness	1.6 mm
Patch Size	22 × 19 mm
Overall Size	24 × 24 × 1.6 mm
Feed Type	Microstrip Inset Feed
Feed Width	3 mm
Inset Depth	4.5 mm

Antenna Performance Parameters

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Table 4: Performance Parameters

Parameter	Value
Return Loss (S11)	–16 dB
VSWR	2.3
Gain	7.2 dBi
Directivity	6.9 dB
Radiation Efficiency	87%
Radiation Pattern	Semi-directional

SAR and Safety Parameters

Table 5: SAR and Safety Parameters

Parameter	Value
SAR (1g tissue)	1.34 W/kg
SAR (10g tissue)	1.76 W/kg
Input Power	1 W
Frequency	4.2 GHz

VI. CST SIMULATION

The proposed rectangular slot microstrip patch antenna is modeled and analyzed with full-wave electromagnetic simulation using CST Studio Suite. It allows for precise assessment of antenna properties in a simulated environment prior to the fabrication process.

Requirement Analysis
↓
Material & Substrate Selection
↓
Antenna Geometry Design
↓
Pre-Simulation Setup (Boundary & Ports)
↓
Human Body Phantom Modeling
↓
Simulation Execution (CST Solver)
↓
Parameter Extraction (S11, VSWR, Gain, SAR)
↓
Optimization & Validation

Simulation Setup

- Antenna geometry has been designed by calculating the dimensions of patch, slot and feed structure.
- The material properties are assigned; the radiating patch and ground plane use copper, while the dielectric substrate is defined with its permittivity (3.5) and thickness (0.1 m).
- The antenna is excited by implementing microstrip inset feed to achieve good impedance matching
- Open (radiation) boundary conditions are used to model propagation in free space.
- A frequency range is defined about the operating band and heavily relies on time-domain solvers for efficient analysis.

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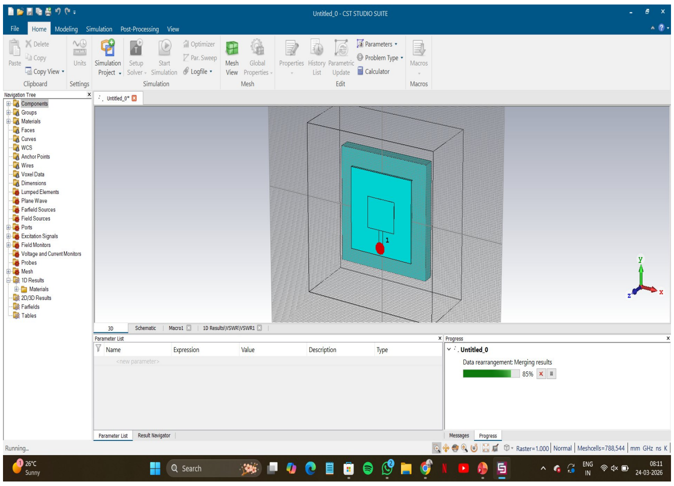
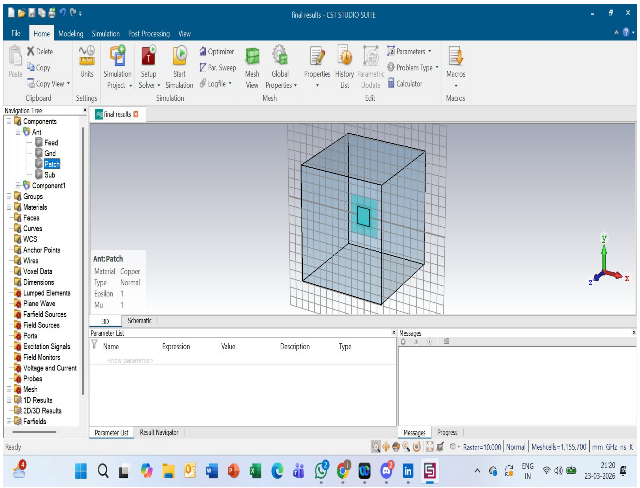
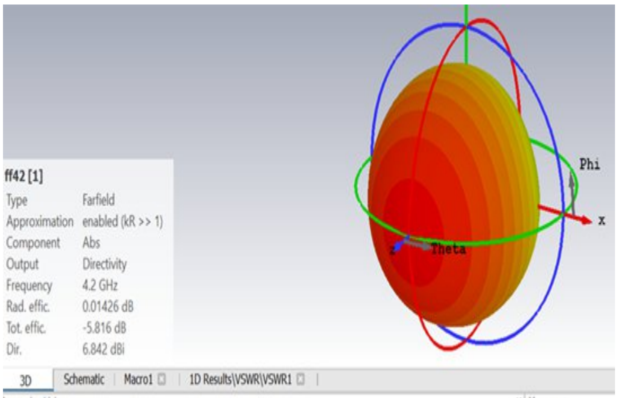


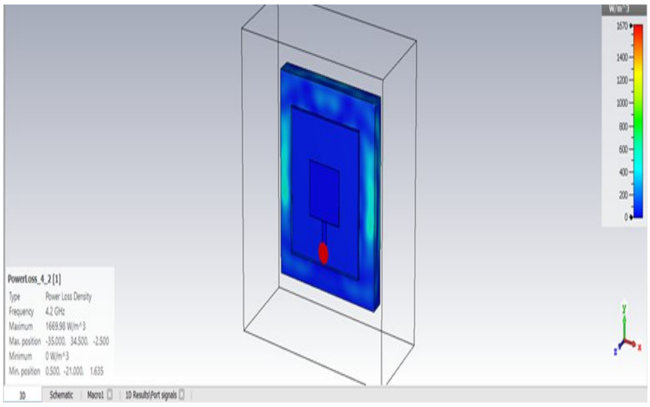


Performance Analysis

- A variety of parameters are used to assess the performance of the antenna:
- Return Loss (S11): Determines impendence matching and reflection characteristics
- VSWR indicates the amount of mismatch in impedance
- Gain: The radiation capability of the antenna
- Radiation Pattern: How the power radiated in different directions.
- Bandwidth: Specifies the frequency range over which it operates efficiently

Fig. Far Field Effect , Power Loss





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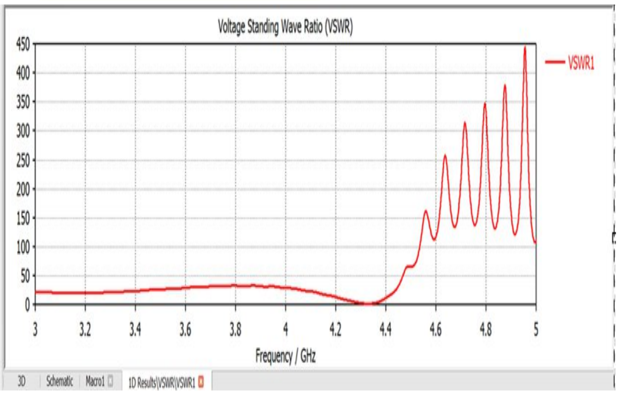
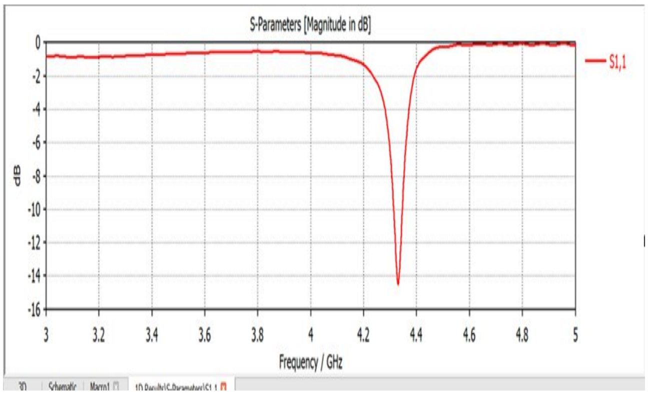




Objective of Simulation

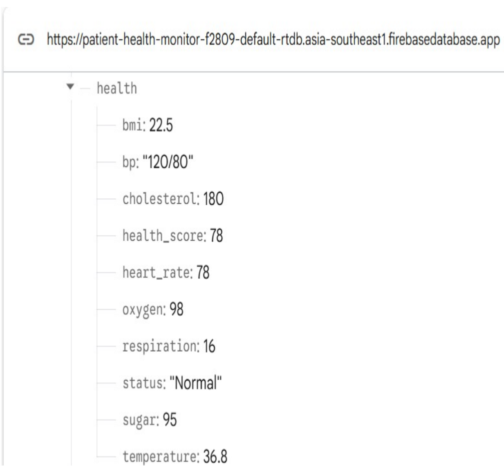
- In order to verify the design of the antenna at a target frequency
- To maximize the slot dimensions and position of inset feed parameters
- For stable radiative characteristics and efficient power transmission

V. CLOUD CREATION AND INTERFACING

The proposed system integrates cloud technology that allows for real-time storage and processing of physiological data collected through wearable devices, as well as its remote monitoring. To do this, in real-time mode such cloud platform is used - Firebase as a database because of its affordability with scalability and rapid data analysis performed by BigData analizer.

Cloud Setup using Firebase

- First, you create a Firebase project and set up a real-time database.
- Each of these is a type of data node organized like a tree structure that can contain attributes, for example, heart rate or temperature.
- Authentication features are used to assign a unique identification for each user or device
- This feature allows real-time synchronization for instantaneous updates.



Data Transmission and Interfacing

- The wearable system allows you to obtain sensor data.
- This smart antenna is used to transmit the collected data wirelessly through RF.
- A microcontroller(e.g ESP32) is connected to Wi-Fi and sends the data to Firebase.
- This data is uploaded in real-time to the cloud database.

Data Access and Monitoring

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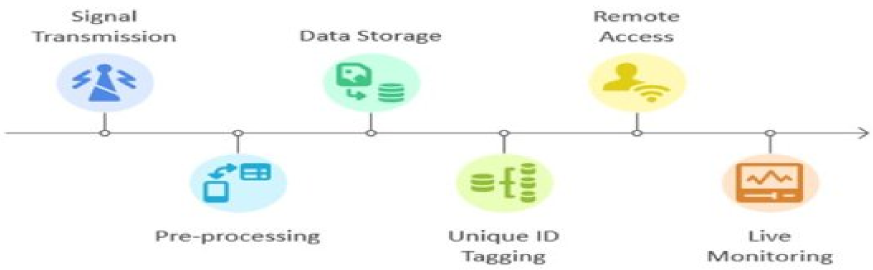
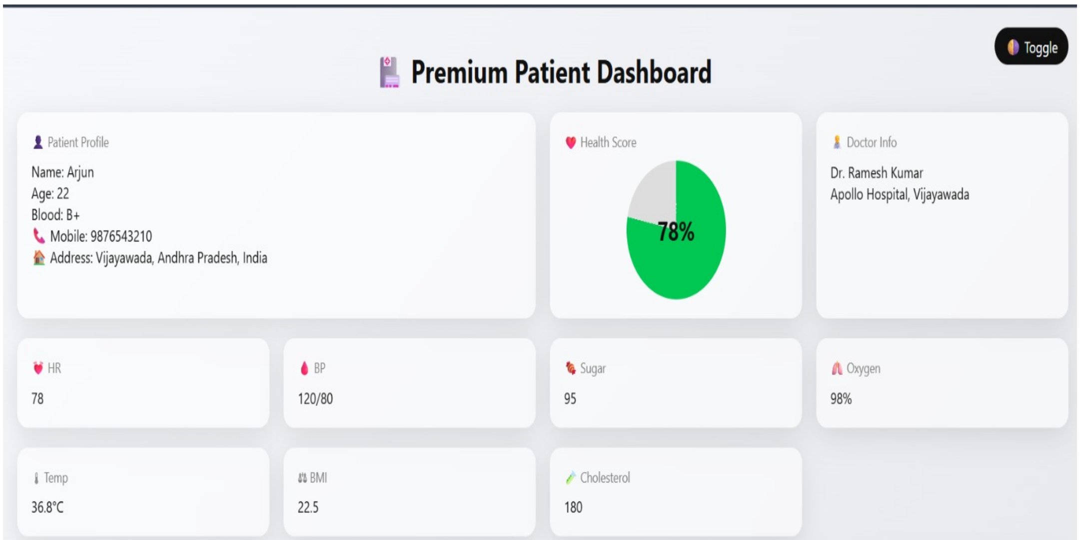
- Finally, the data that you store can be accessed via Firebase dashboards, web applications, or mobile applications.
- It entails real-time visualization and continuous monitoring of the patient's health conditions.
- A notification or alert may be triggered for abnormal readings.





Advantages of Firebase Integration

- Real-time data synchronization
- Secure cloud storage with authentication
- Easy integration with IoT devices

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- Enable remote monitoring and telemedicine applications

VI. RESULTS AND DISCUSSIONS

A wearable microstrip patch antenna was designed and simulated using CST for WBAN-based telemedicine applications. Operating at 4.2 GHz and simulating in the range of 3–6 GHz, the antenna has An return loss (S11) of –16 dB demonstrates basically good impedance matching and little reflection, while the VSWR of 2.3, even being a bit above ideal value, is still sufficiently small to consider the antenna for wearable operation. The maximum gain is 7.2 dB with a directivity of 6.9 dB of the antenna, showing good radiation ability in body-to-external communication environment. 87% efficiency means the loss of power is low and transmission is effective.

The SAR analysis demonstrated 1.34 W/kg (1 g) and 1.76 W/kg (10 g) value which is well within the standard safety limits, thus assuring its safe operation on human body. The semi-directional pattern minimizes energy absorbed by the body and maximizing signal transmission in outward directions. The antenna is also wideband, allowing several telemedicine applications.

Implementation of Monitoring and Management Using Firebase Realtime Database Data transmission in real-time with storage of physiological parameters along with instant sync across devices. Low latency, persistent data with backup, and secured access using authentication is ensured by the system. Mobile and web-based access supports telemedicine services, allowing for remote-only care. Discussion is that the integrated antenna and cloud solution presents a practical, secure, and scalable health monitoring approach.

VII. CONCLUSION

In this paper, we describe the design and simulation of a rectangular slot microstrip patch antenna using inset feed technique at 2.45 GHz ISM band using CST® Studio Suite. By adding a rectangular notch to the radiating patch and using an inset feed technique, all three antennas achieved superior matching and performance. The simulation results of the antenna were studied through important parameters like return loss (S11), VSWR, gain, bandwidth and radiation patterns. The simulated return loss was less than −10 dB and the VSWR was less than 2 at the operating frequency, suggesting efficient power transfer with little reflection losses. The antenna exhibited stable radiation characteristics and reasonable gain ensuring reliable wireless communication.

Proposed antenna configuration presents compact structure with simple geometry thus achieving low fabrication cost leading to practical realization. These characteristics make it available for modern communication systems due its wide bandwidth and better radiation performance. This antenna can be applied in the field of IoT devices, wiggle electronics and telemedicine monitoringsystems application for the short-distance communication. While the rectangular slot microstrip patch antenna report in this paper is a simple and economical device that worked well at 2.45 GHz and has been noted for its usability and cost-effectiveness when compared to other more complex designs; it showed indistinguishable acceptable stability of operation near the determined resonance frequency around 1-3 Ω with an increase beyond half of value for conventional microwave antennas.

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