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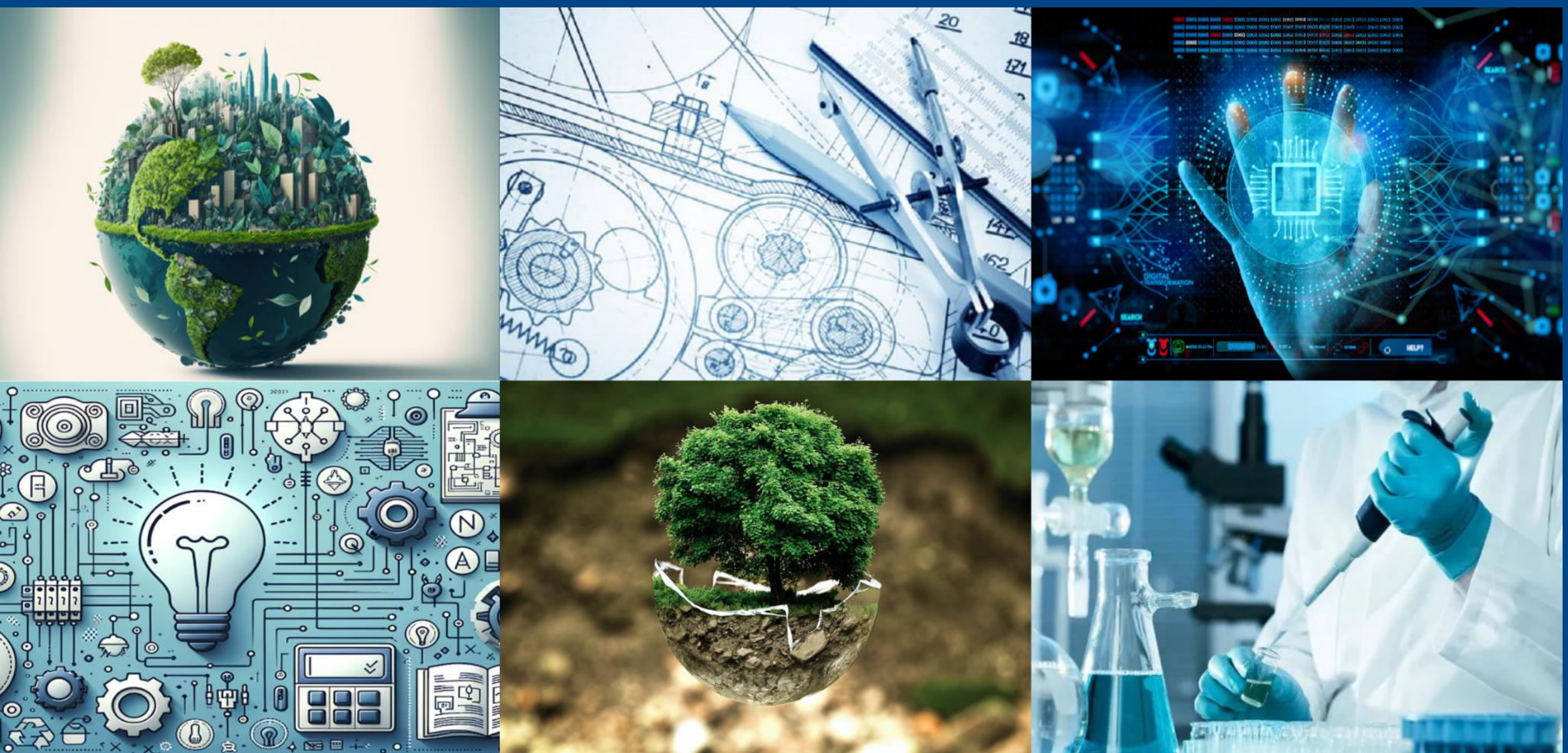

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Implementation of a Miniaturized Planar Tri-Band Microstrip Patch Antenna for Wireless Sensors in Mobile Applications

P.Bhavana[1], R.Komalisri[2], P. Hima Sri Lakshmi[3], N.PremPal[4]

UG Student, Department of ECE, R.V.R & J.C College of Engineering, Chowdavaram, India[1]

UG Student, Department of ECE, R.V.R & J.C College of Engineering, Chowdavaram, India[2]

UG Student, Department of ECE, R.V.R & J.C College of Engineering, Chowdavaram, India[3]

UG Student, Department of ECE, R.V.R & J.C College of Engineering, Chowdavaram, India[4]

ABSTRACT: Antennas in wireless sensor networks (WSNs) are characterized by the enhanced capacity of the network, longer range of transmission, better spatial reuse, and lower interference. A planar patch antenna for mobile communication applications operates at 1 – 6 GHz. In modern mobile communication systems, there is a growing demand for compact antennas are capable of operating over multiple frequency bands. Conventional designs often require multiple antennas or complex reconfigurable structures to support different applications. These approaches increase system complexity, size, making them less suitable for compact, portable, or mobile devices where fixed frequency operation is sufficient.To address this, a compact triband microstrip antenna can be designed and simulated using electromagnetic simulation software such as CST Microwave Studio..Due to its compact size and simple geometry,the proposed antenna is suitable candidate for integration in portable wireless devices and sensor networks.

KEYWORDS: Tri-Band Antenna, CST Microwave Studio, Wireless Sensor Networks (WSNs)

I. INTRODUCTION

The rapid growth of wireless communication technologies and Wireless Sensor Networks (WSNs) has significantly increased the demand for efficient, compact, and high performance antennas.

In mobile communication systems, antennas act as a key component responsible for transmitting and receiving electromagnetic signals. With the evolution of technologies such as WLAN, WiMAX, and satellite communication, there is a growing need for antennas capable of operating across multiple frequency bands. Traditional antenna designs often rely on multiple antennas or complex reconfigurable structures to support different frequency bands, which increases system complexity and power consumption.

Microstrip patch antennas have emerged as a preferred choice due to their advantages such as compact size. However, conventional MPAs suffer from limitations such as narrow bandwidth and single-band operation, making them unsuitable for modern multiband applications.

To overcome these limitations, multiband antenna designs incorporating slots, resonators, and modified geometries have been widely explored. In particular, planar patch antennas with simple geometries offer a promising solution for achieving multiband operation while maintaining compact size. Therefore, designing a compact, efficient, and multiband microstrip antenna suitable for mobile and WSN applications.

A. Problem Statement

Despite the advancements in antenna design, several challenges still exist in developing antennas for modern wireless communication systems. Conventional approaches for achieving multiband operation often involve the use of multiple antennas or complex reconfigurable structures, which lead to increased hardware complexity, larger size, and higher power consumption. These limitations make such designs unsuitable for compact and portable wireless devices.

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Furthermore, wireless sensor networks require antennas that are not only compact but also capable of providing reliable performance, adequate gain, and efficient radiation characteristics across multiple frequency bands. Achieving all these requirements simultaneously in a single antenna structure remains a significant challenge.

Therefore, there is a need to design a compact, and simple structure microstrip patch antenna capable of operating at multiple frequency bands with improved performance characteristics. The proposed work addresses this challenge by developing a planar tri-band microstrip antenna using a simple geometry that ensures reduced size, and suitability for portable wireless devices and WSN applications.

II. LITERATURE REVIEW

Recent advancements in wireless communication systems have led to extensive research in the design of compact and multiband antennas. Microstrip patch antennas (MPAs) are widely used due to their low profile and light weight. However, conventional MPAs are limited by narrow bandwidth and single-band operation, which restrict their applicability in modern communication systems.

Several techniques have been proposed to achieve multiband operation. Slot-based designs such as U-slot, E-slot, and H-slot antennas are commonly used to improve bandwidth and generate multiple resonant frequencies.

For instance, designs incorporating U-shaped and L-shaped slots have demonstrated improved multiband characteristics, while fractal antennas provide wideband and multiband capabilities with compact size.

In addition, some studies have reported antennas operating over multiple frequency bands such as 2.4 GHz, 5 GHz, and higher frequency ranges for WLAN and WiMAX applications. However, many of these designs suffer from large physical dimensions or complicated structures.Therefore, there is a need for a compact and simple antenna design that can support multiple frequency bands while maintaining good performance characteristics such as gain, return loss, and radiation efficiency.

III. DESIGN METHODOLOGY

The proposed antenna is a compact planar tri-band microstrip patch antenna designed to operate at multiple frequency bands suitable for mobile communication and wireless sensor network applications.
The antenna is designed on an FR-4 substrate with a thickness of 1.6 mm and relative permittivity of 4.3. The overall structure consists of:
*A radiating patch
*A partial ground plane
*A coaxial feed
To achieve multiband operation, the antenna incorporates:
1) Two F-shaped resonators for lower and middle frequency bands.
2) A truncated patch structure for higher frequency operation.

A. Design Approach

Fig-1 illustrates the geometric configuration of the proposed triband flexible single element antenna. The planar patch antenna is simple with two F-shaped resonators relative to a resonator at the lower and middle frequency bands while the middle-truncated patch helps operations at 5.4 GHz. Ground plane dimensions are reported as $Lg \times Wg$ =50 mm ×40.8 mm; the dielectric material used above the rectangular ground plane is FR-4 possessing a height of Hs = 1.6 mm and a relative permittivity of r = 4.3.Generally, the overall dimensions of the designed antenna are 60 × 50 × 1.6 mm3.The antenna is fed by using a 50-ohm coaxial probe.The feed point is 2 mm above from the center of the feed patch.

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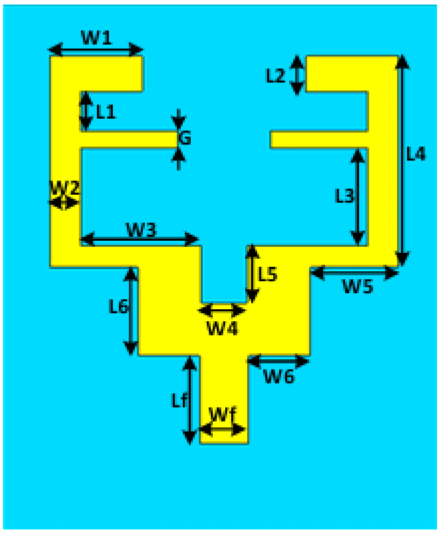

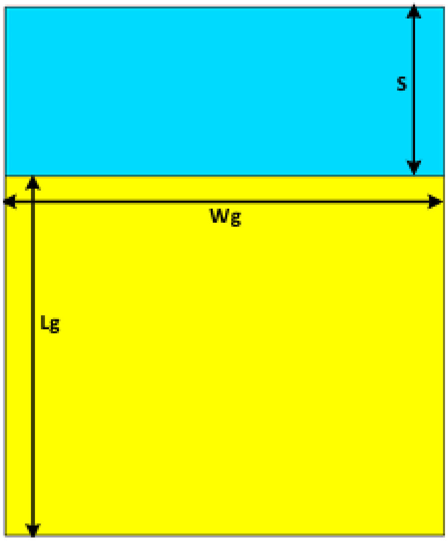

Fig-1: Front View **Fig-2: Back View**

(i)The width of the patch (Wp) can be calculated by using the following expression:

$$Wp = \frac{\lambda_o}{2\sqrt{0.5(\varepsilon_r + 1)}}$$

where λo is the free space wavelength and εr is the substrate relative permittivity.
(ii)The patch length Lp can be found by utilizing the following:

$$Lp = \frac{c_o}{2f_o\sqrt{\varepsilon_{eff}}} - 2\Delta L_p$$

Where the light speed is co, the extra length due to fringing effect is ΔLp and εeff is the effective dielectric constant.
(iii)The εeff can be found by using the following:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1/\sqrt{1 + 12\frac{Hs}{W_p}}\right)$$

where h is the thickness of the substrate.
(iv) The change in length resulting from fringing fields can be calculated by using the following:

$$\Delta Lp = 0.421h\left(\frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.3}\right)\left(\frac{W_p/Hs + 0.264}{W_p/Hs + 0.813}\right)$$

B. Design Evolution
The antenna design is developed in four stages:
1.Initial Patch Design: A rectangular planar patch is designed to possess a width of 40 mm and a length of 44 mm centered at the middle of the FR-4 substrate. After that, a feed extension is designed to possess a length of 10 mm and a width of 5 mm starting from the center of lower edge of the rectangular planar patch in STEP-I.
2. Truncated Patch: Then in the second step both bottom sides of the patch are truncated and the patch width is kept unchanged in the case of STEP- II.A partial ground plane is created in each step of the design procedure, possessing a length of 40.8 mm and width of 50 mm.
3.Slot Introduction: In the third step a U-shaped patch is introduced, which is obtained from STEP- II.Then,a small size rectangular slot is created in the middle portion of the planar patch as shown.

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4.Final Design: In the final step, two F shaped resonators are utilized, and the proposed planar patches are introduced (STEP- IV) and each resonator has a length of 21 mm.

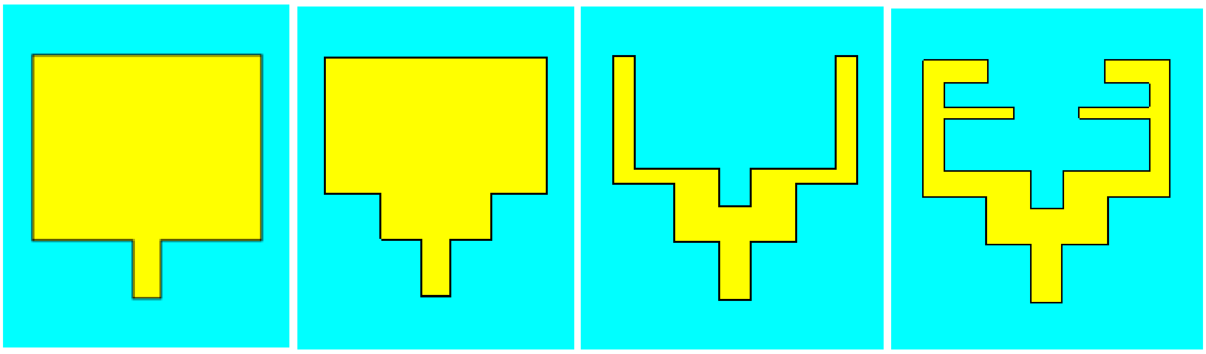

Fig-3: a) STEP-I b) STEP-II c) STEP-III d) STEP-IV

C. Design Flow

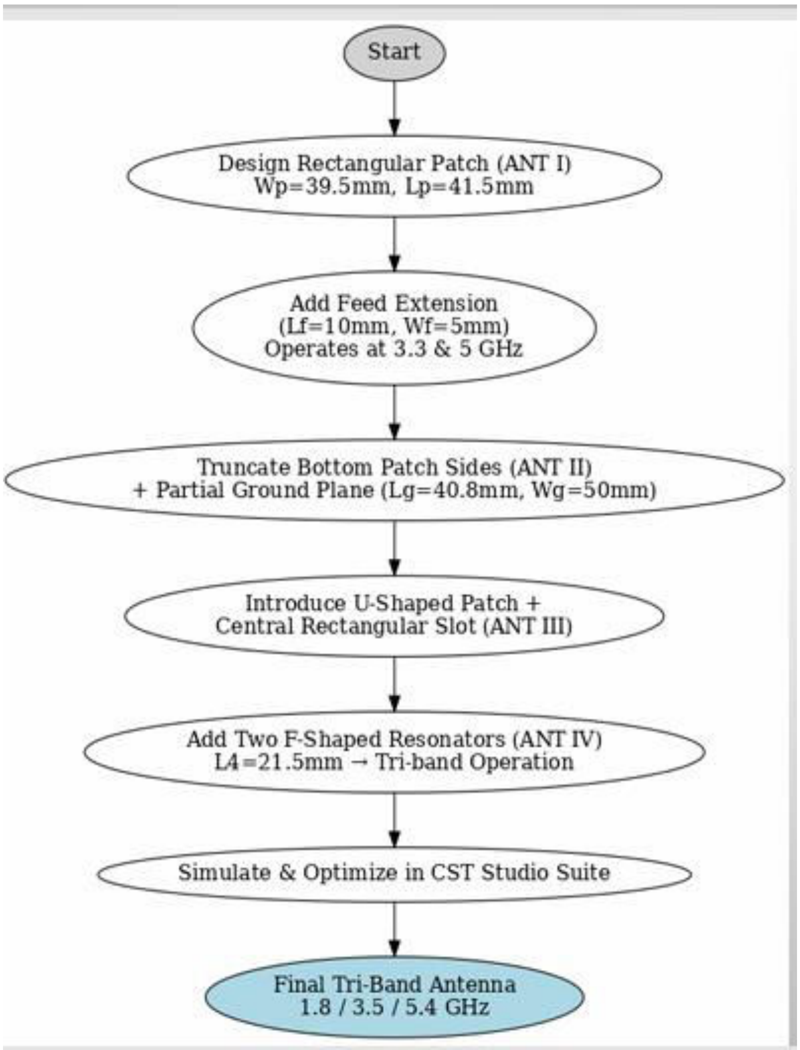

Fig-4: Flow Chart

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D. Parameters and Dimensions

Parameters	Value(mm)	Parameters	Value(mm)
Lg	40.8	Wg	50
L1	3	W1	10.5
L2	4	W2	3.5
L3	12	W3	15
L4	24	W4	3
L5	4	W5	10
L6	10	W6	10
Lf	10	Wf	5
G	2	S	19.2

Fig-5: Parameters & Dimensions

IV. RESULTS AND DISCUSSION

The proposed tri-band microstrip patch antenna is simulated using CST Studio Suite, and its performance is evaluated in terms of S-parameters, gain, diversity characteristics, and surface current distribution.

A. S-Parameters (S11)

The reflection coefficient (S11) is a critical parameter used to evaluate impedance matching and antenna performance. The simulated S11 results show that the antenna resonates at three distinct frequency bands centered around 1.8 GHz, 3.5 GHz, and 5.4 GHz.

At these frequencies:

i) The s11 values are below-10 dB, indicating good impedance matching.

ii) The antenna exhibits stable multiband operation suitable for wireless applications.

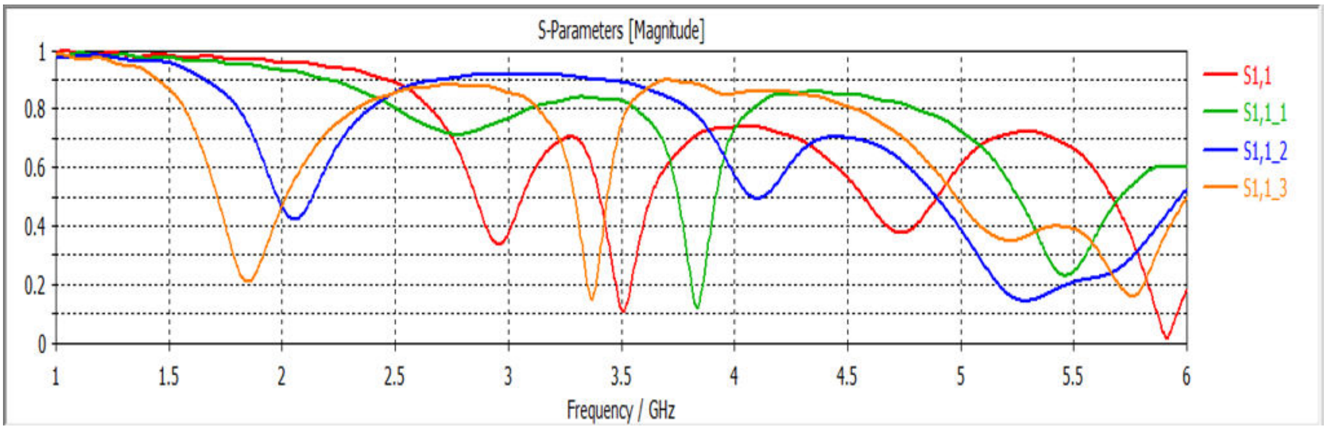

Fig-6: S-Parameters of four Steps

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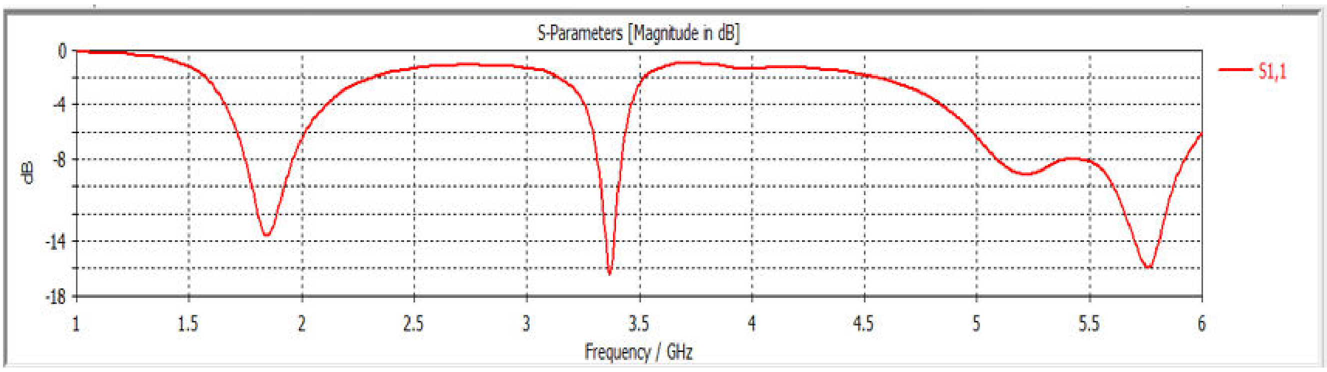


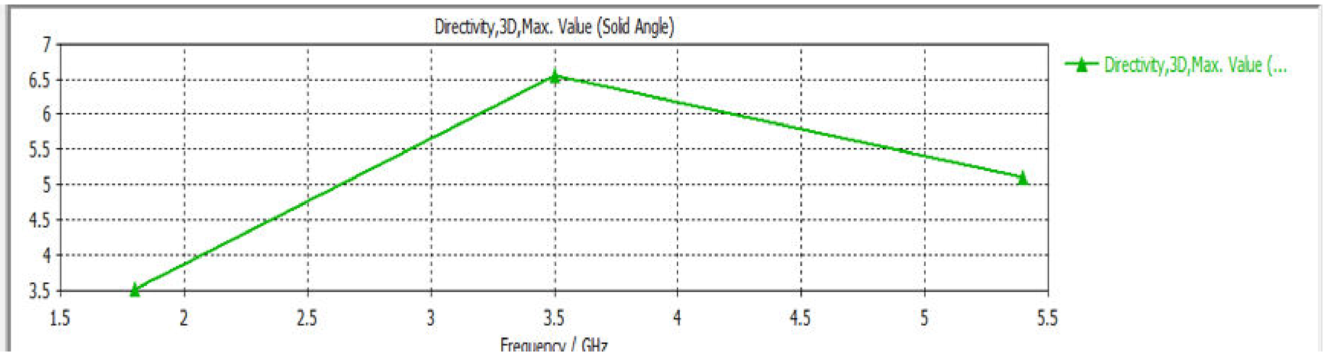
Fig-7: Final Result

B. Directivity

Directivity is an important antenna parameter that describes the ability of an antenna to concentrate radiated power in a particular direction.

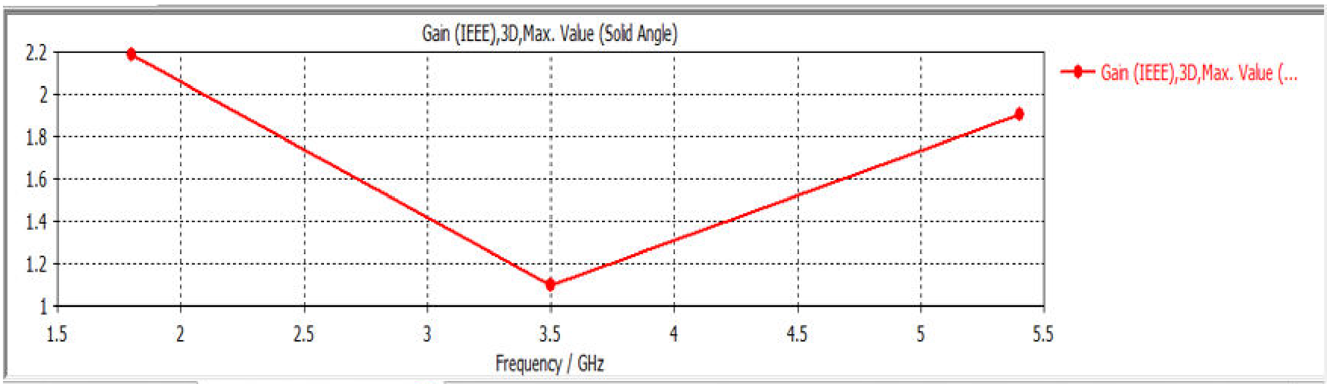
The proposed antenna exhibits moderate directivity at all three operating frequencies. Lower directivity is observed at 1.8 GHz due to wider radiation, while improved directivity at 3.5 GHz and 5.4 GHz is achieved due to better current distribution and directional radiation.

The results confirm that the antenna provides an effective balance between coverage and directional performance.



C. Gain

The gain of the proposed tri-band microstrip patch antenna is evaluated using CST Studio Suite. The simulated results show that the antenna achieves different gain values at the three operating frequencies.



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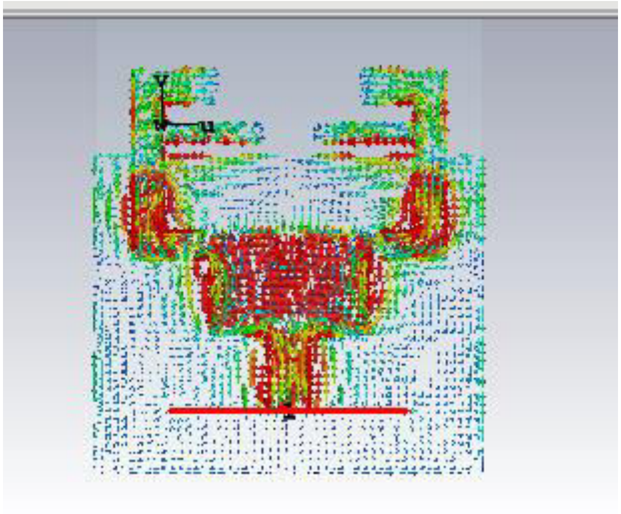
D. Surface Current

The surface current distribution provides insight into the working mechanism of the antenna at different frequencies.

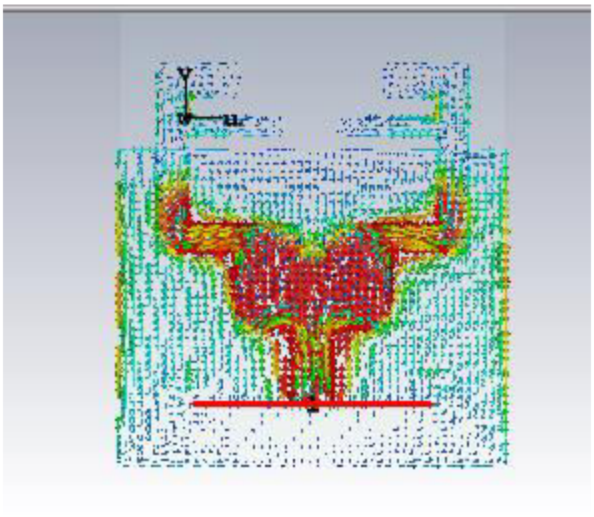
i)At 1.8 GHz Current is concentrated along the main patch structure Indicates fundamental resonance of the patch.

ii) At 3.5 GHz Strong current distribution observed in F shaped resonators Confirms their role in generating the second resonant band.

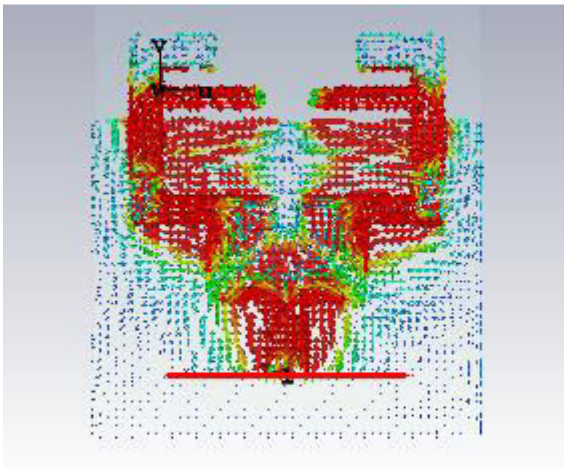
iii) At 5.4 GHz Current spreads across: Truncated patch edges Partial ground plane.



At 1.8 GHz



At 3.5 GHz



At 5.4 GHz

E. VSWR

Voltage Standing Wave Ratio (VSWR) is a key parameter used to evaluate the impedance matching between a transmission line and an antenna. It indicates how efficiently RF power is transmitted from the source to the antenna without reflections.

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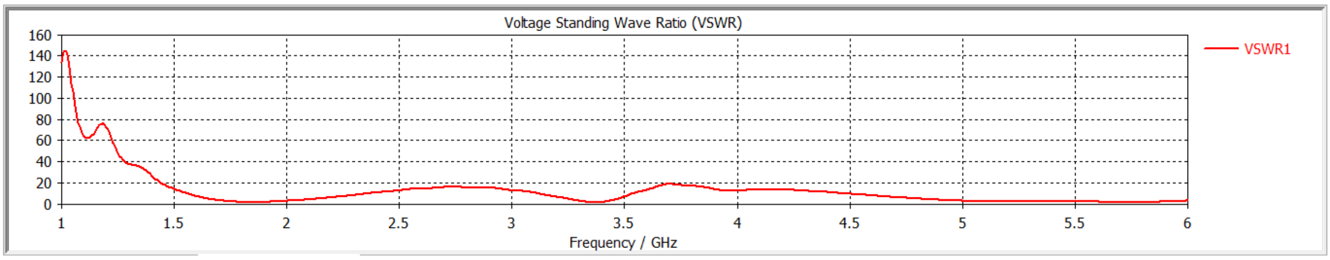

V. CONCLUSION

A compact planar tri-band microstrip patch antenna has been successfully designed for wireless sensor and mobile communication applications. The proposed antenna operates at three distinct frequency bands centered around 1.8 GHz, 3.5 GHz, and 5.4 GHz, covering important applications such as Digital Communication Systems (DCS), WiMAX, and Wireless Local Area Networks (WLAN).

The multiband performance is achieved using a simple and efficient design approach that incorporates F-shaped resonators and a truncated patch structure on a FR-4 substrate. The antenna demonstrates good impedance matching with reflection coefficient (S11) values below 10 dB at all operating frequencies. Additionally, the antenna provides acceptable gain and stable radiation characteristics across the three bands.

The simulated results confirm that the proposed antenna offers a good balance between compact size, and satisfactory performance. Compared to conventional multiband antennas, the design avoids complex multilayer structures and maintains simplicity while achieving efficient tri-band operation.

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