RF REPORT

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November 2024

ABSTRACT

A flexible, planar electrically small antenna (ESA) with omnidirectional radiation pattern is designed and fabricated for GPS and WLAN applications resonating at 1.5 GHz and 3.7 GHz. The design consists of a circular loop attached with 3 rectangular bars, and it is fed by a 50 Ω feed line. The circular loop in the antenna provides impedance matching. Generally, these electrically small antennas have narrow bandwidth. Here the antenna is fabricated on a polyimide substrate having a thickness of 0.1 mm, ε_r of 3.4 mm, and it occupies a size of 38 mm 34 mm. Electrically small antenna is designed at 1.5 GHz, 3.7 GHz, and the parameters that are measured are S_{11}, VSWR, Ka values, quality factor, and radiation patterns.

LITERATURE SURVEY

Electrically small antennas (ESAs) are integral to modern wireless communication systems, especially in applications like GPS, where compactness and reliability are essential. Defined by the parameter ka<0.5ka < 0.5ka<0.5, where kkk is the wave number and aaa is the radius of the smallest sphere enclosing the antenna, ESAs provide efficient performance despite their minimal physical dimensions relative to operating wavelengths. ESAs are increasingly critical in portable devices where space constraints and reliable signal reception are vital. In GPS applications, antennas operate primarily at 1.575 GHz (L1 band) and, in some cases, at 1.227 GHz (L2 band), necessitating a careful balance between miniaturization, efficiency, and bandwidth. Recent research has made significant progress in addressing the unique challenges associated with ESA design for GPS by developing innovative approaches that enhance antenna performance, bandwidth, and multiband capability.

In recent years, various ESA designs have been proposed for GPS applications, focusing on compactness without compromising radiation efficiency or bandwidth. Below is a comprehensive review of the primary types of ESA designs currently being explored.

➢ Metamaterial-Enhanced ESAs

- One of the most prominent advancements in ESA design is the integration of metamaterials to address size and bandwidth limitations. Metamaterials are engineered to exhibit unique electromagnetic properties—such as negative permittivity or permeability—that are not naturally occurring. These properties allow designers to circumvent conventional size constraints while maintaining performance levels essential for effective GPS operation. Metamaterial-enhanced ESAs can facilitate dual-band performance, supporting both the L1 (1.575 GHz) and L2 (1.227 GHz) frequencies crucial for GPS applications.
- Advantages of Metamaterials in ESAs:
  - Enable compact, dual-band operation at GPS-relevant frequencies.
  - Improve radiation efficiency by leveraging novel phase properties, even in small designs.

  - Enhance bandwidth and impedance matching, which are essential for reliable GPS signal reception.
- These metamaterial-based designs have proven especially beneficial for dual-band GPS applications, where they provide robust signal handling capabilities within limited physical space.

Non-Foster Circuits for Bandwidth Enhancement

- Another challenge in ESA design is the inherent limitation on bandwidth, a result of the small physical dimensions. Non-Foster circuits have emerged as a solution to this issue, employing active circuit elements to produce negative reactance. By countering the capacitive reactance typically present in ESAs, non-Foster circuits significantly extend the available bandwidth.
- Key Features of Non-Foster Circuits in ESAs**:**
  - Allow for substantial bandwidth extension, enhancing GPS signal coverage.
  - Compensate for reactive limitations to improve signal transmission efficiency.
  - Are particularly effective when combined with circular and slot-loaded ESA configurations.
  - Provide a promising solution for multiband and wideband antenna designs.
- Integrating non-Foster circuits into ESAs has demonstrated practical benefits in expanding bandwidth, thus ensuring consistent performance for GPS signal requirements.

Advanced Slot Configurations

- Slot-loaded ESAs have gained popularity due to their ability to achieve significant size reduction with relative ease of fabrication. Recent advancements have focused on utilizing complex slot geometries, including cross-slots, spiral slots, and annular slots. These configurations create additional resonance paths, which enhance impedance matching and allow for multiband operation.
- Benefits of Advanced Slot Configurations**:**
  - Support multiband functionality without a significant increase in antenna size.
  - Improve impedance matching, ensuring reliable GPS signal reception.
  - Simplify fabrication processes, keeping costs low and production scalable.
  - Offer flexibility for customization based on specific frequency requirements.
- These advancements in slot configurations represent a promising area of research in ESA design, contributing to the development of compact, efficient GPS antennas that can operate across multiple bands.

Meander Line and Fractal Geometries

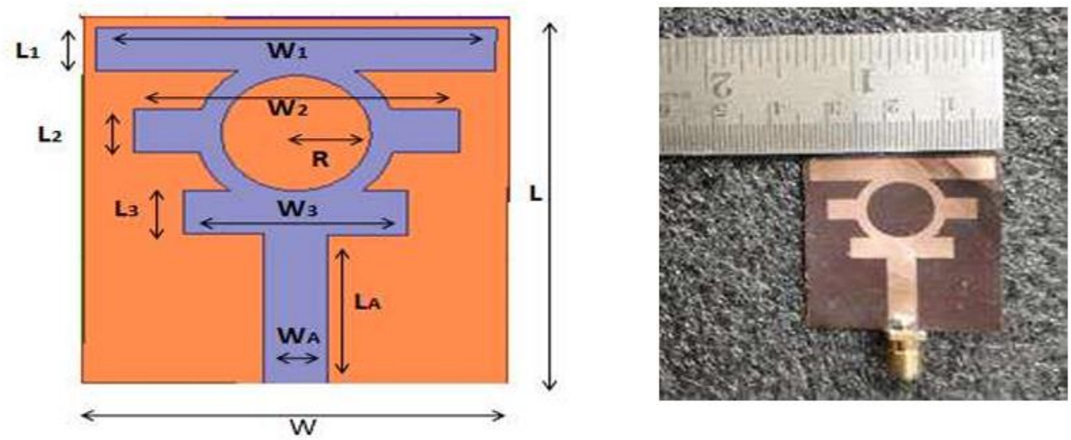
- Meander line and fractal geometries are popular strategies for achieving size reduction in ESAs. Meander line antennas use folded conductor patterns to extend the electrical path length beyond the physical dimensions of the antenna. This design allows for substantial size reduction, though it can lead to decreased radiation efficiency due to closely spaced conductors.

- Key Characteristics of Meander Line and Fractal ESAs**:**
    - Achieve significant size reduction while maintaining resonance capabilities.
    - Use extended electrical path lengths to enhance efficiency in confined spaces.
- These meander line and fractal ESA designs show great potential for GPS applications where multiband functionality and size reduction are essential.

➢ Emerging Trends in ESA Design for GPS Applications

- The ongoing advancements in ESA technology reflect a growing emphasis on optimizing performance in size-constrained environments. Current trends in ESA research include:
- Multiband Capability**:** To meet the demands of modern GPS applications, there is a shift toward ESAs that can operate across multiple frequency bands, particularly the L1 and L2 bands.

The design of antenna which is to be simulated is given below:



(a) (b)

Parameter	Values (mm)	Parameter	Values (mm)
L	38	L_3	4.5
W	34	W_3	18
L_1	4.5	L_A	17
W_1	32	W_A	5.05
L_2	4.5	T_s	0.1
W_2	26	R	6

BRIEF THEORY AND CALCULATIONS ABOUT THE DESIGNED ANTENNA

An electrically small antenna is designed by utilizing a circular patch, and a circular slot in the proposed design will provide better return loss. A rectangular bar is attached to the antenna, and it is tapped by an impedance of Z_0 having 50 Ω. The simulated antenna is modelled on a polyimide substrate material having 0.1 mm thickness with (ε_r) of 3.4 and loss tangent (tan δ) of 0.006. The basic structure of an antenna has a feeding path, and it is tapped by an impedance of 50 Ω.

1. Design Fundamentals:
   - The antenna operates at dual frequencies: 1.5 GHz (GPS) and 3.7 GHz (WLAN)
   - Built on polyimide substrate with:
     - Thickness = 0.1 mm
     - Dielectric constant (εr) = 3.4
     - Loss tangent (tan δ) = 0.006
   - Overall size: 38 mm × 34 mm
2. Key Calculations:

   a) Width (W) calculation:

   W = (V0/2Fr) × √(2/(εr + 1))
   =((3×10^8m/s)/(2×3.7 GHz) × √(2/(3.4 + 1)))
   =34 mm

   Where:
   - V0 = speed of light
   - Fr = resonant frequency
   - εr = dielectric constant

   b) Effective dielectric constant:

   εreff = ((εr + 1)/2) + ((εr - 1)/2) × [1 + 12h/W]^(-1/2)
   = ((3.4 + 1)/2) + ((3.4 - 1)/2) × [1 + 12(0.1)/34]^(-1/2)
   = 1.016

   Where h = substrate thickness

   c) Length (L) calculation:

   Where Δl is the length extension:

   Δl = 0.412h × ((εreff + 0.03)(W + 0.264h))/((εreff - 0.258)(W + 0.8h))
   = (0.412(0.1)) × ((1.016 + 0.03)(34 + 0.264(0.1)))/((1.016 - 0.258)(34 + 0.8(0.1)))
   = 1.111mm

   L = V0/(2Fr × √εreff) - 2Δl
   = (3×10^8m/s) /((2×3.7 GHz) × (√1.016mm)) – 2(1.111 mm)
   =38mm

EXPLANATION OF THE PROPOSED ANTENNA

The proposed antenna is a compact, dual-band electrically small antenna (ESA) designed for GPS (1.5 GHz) and WLAN (3.7 GHz) applications. It uses a unique combination of a circular slot and rectangular bars to achieve efficient operation in a minimal footprint of 38 mm × 34 mm. Here's a detailed overview of its features and design:

- Structure and Design Elements: The antenna consists of a circular slot for effective impedance matching and three rectangular bars that enhance its performance at the desired frequencies. These elements create a balance of inductance and capacitance, critical for dual-band operation, and enable tuning to both resonant frequencies. By adding rectangular bars in iterative design stages, the antenna's resonance was fine-tuned to target 1.5 GHz and 3.7 GHz.
- Substrate and Feeding Mechanism: Constructed on a polyimide substrate with a thickness of 0.1 mm and a relative permittivity (εr\varepsilon_rεr) of 3.4, the antenna is fed by a 50 Ω line. This substrate choice supports both compactness and flexibility, essential for wireless applications. The 50 Ω feed line helps maintain good impedance matching, contributing to strong performance at both frequencies.
- Performance Metrics:
    - Return Loss and VSWR: The antenna shows excellent return loss at both bands, achieving values of 21 dB at 1.5 GHz and 37 dB at 3.7 GHz, which indicates efficient signal transmission. The voltage standing wave ratio (VSWR) values are below 2 across both frequencies, with measurements of 0.55 at 1.5 GHz and 0.9 at 3.7 GHz, further confirming efficient power transfer.
    - Bandwidth and Quality Factor (Q): The antenna provides a bandwidth of 1.25–1.75 GHz and 3.6–3.75 GHz, suitable for GPS and WLAN applications. The design closely approaches the Chu limit for quality factor, maximizing efficiency for an electrically small antenna.
- Radiation Pattern and Gain: The antenna exhibits an omnidirectional radiation pattern, providing consistent coverage needed for GPS and WLAN. The gain values are optimized for compact size, making this antenna comparable to larger antennas in terms of coverage efficiency.
- Comparative Advantages: Compared with similar dual-band ESAs, this design offers compact size, efficient return loss, and VSWR in a minimized footprint. The proposed design thus meets the requirements of compact, dual-band functionality essential for GPS and WLAN, making it ideal for space-constrained devices.

SIMULATION AND MEASUREMENT RESULTS

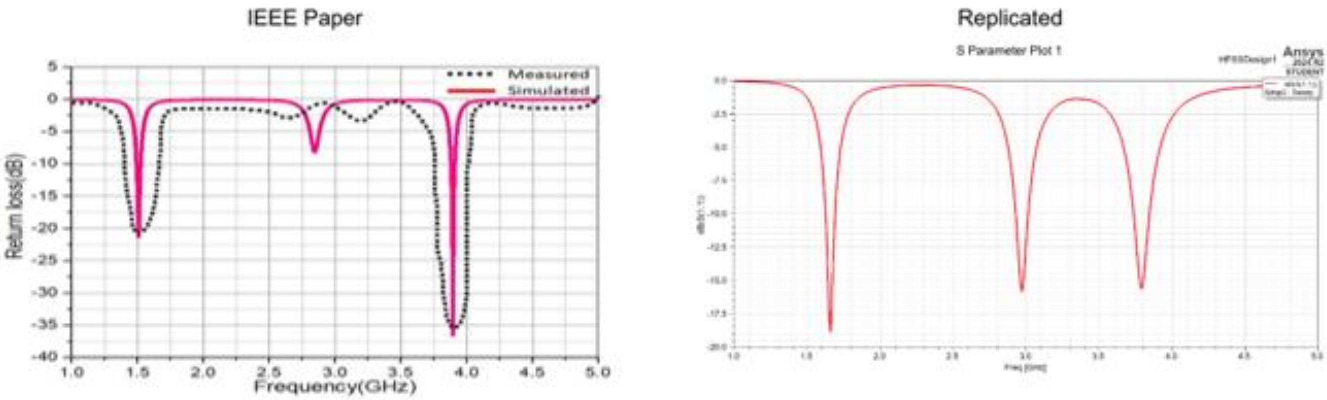


Figure 1 : Simulated S11 of a Circular Slotted Electrically Small Antenna

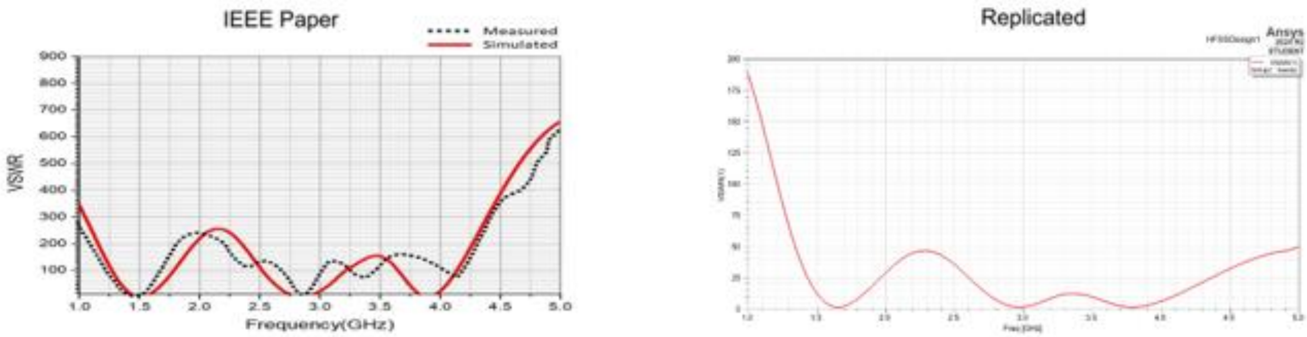


Figure 2 : Simulated VSWR of a Circular Slotted Electrically Small Antenna

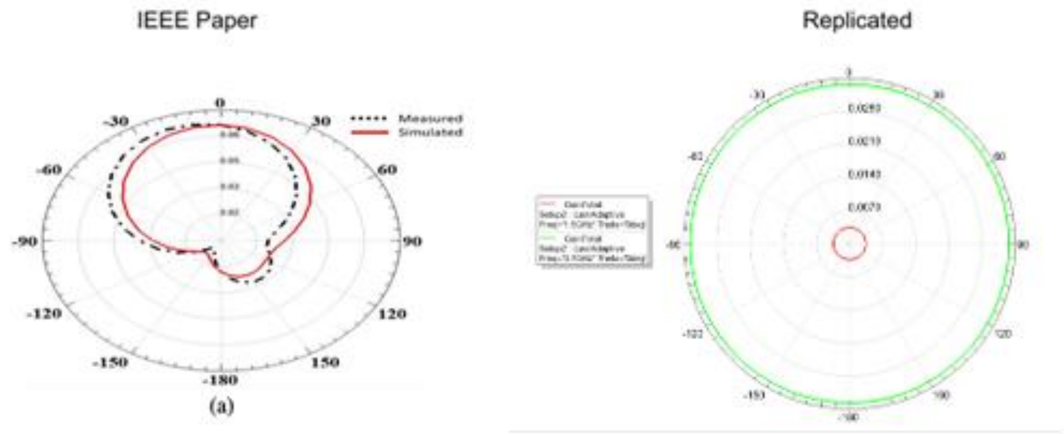
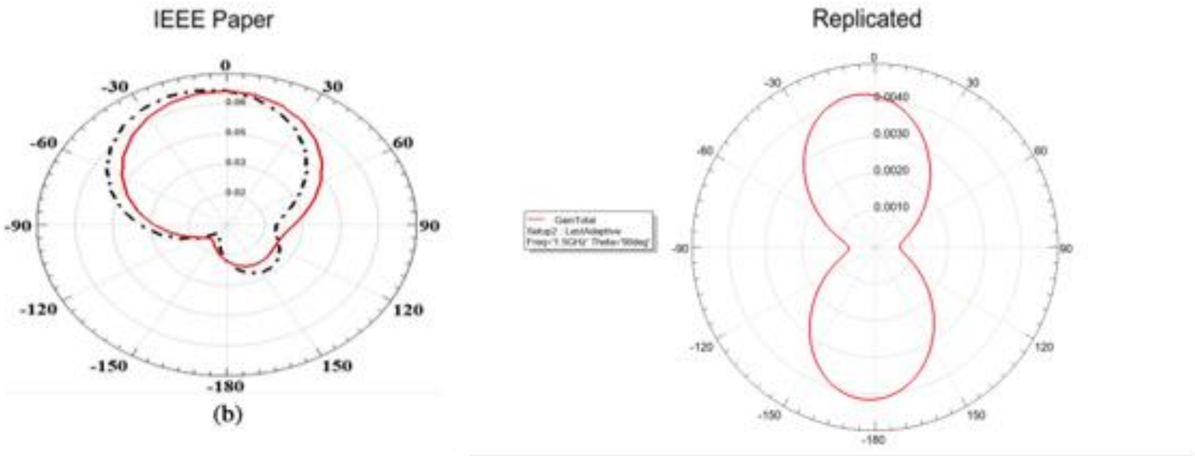


Figure 3,4. Simulated radiation pattern of electrically small antenna in terms of elevation angle with a circular slot. (a) θ = 0°, (b) θ = 90°



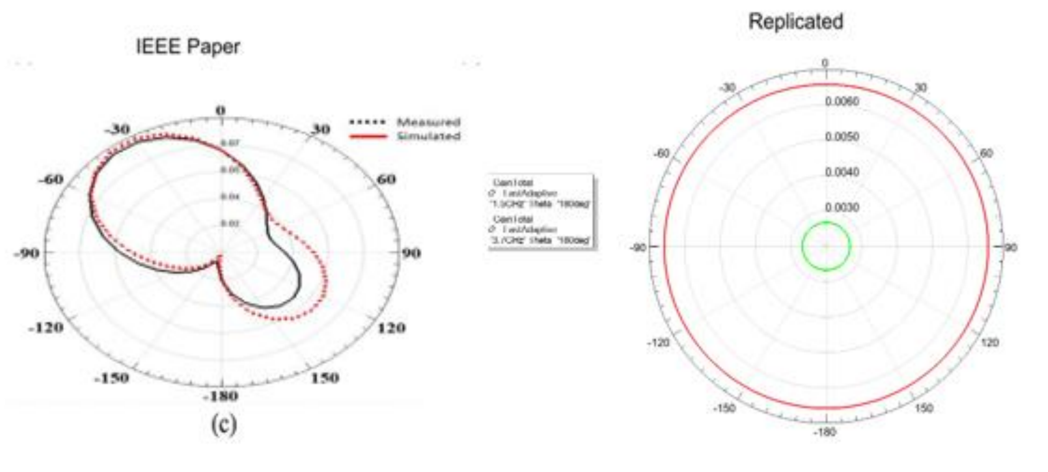


Figure 5. Simulated radiation pattern of electrically small antenna in terms of elevation angle with a circular slot (c) θ = 180°."

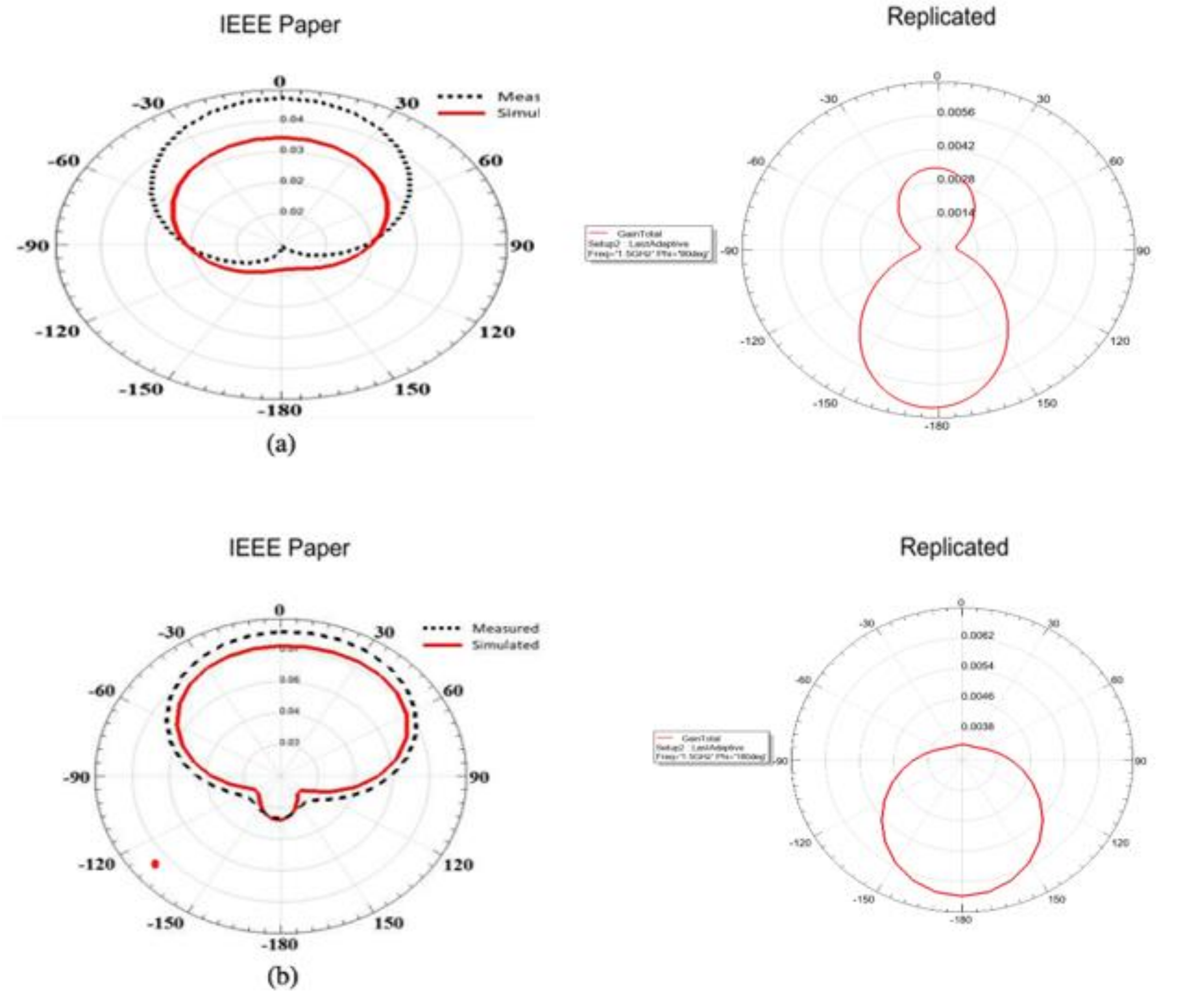
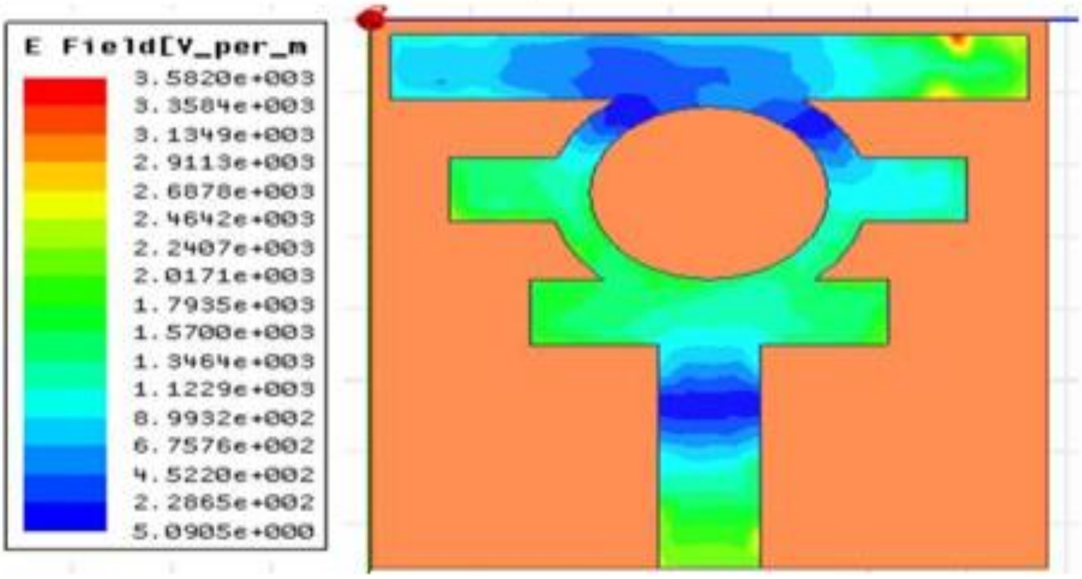


Figure 7. Simulated radiation pattern of electrically small antenna with a circular slot. (a) ϕ = 90°, (b) ϕ = 180°



Replicated

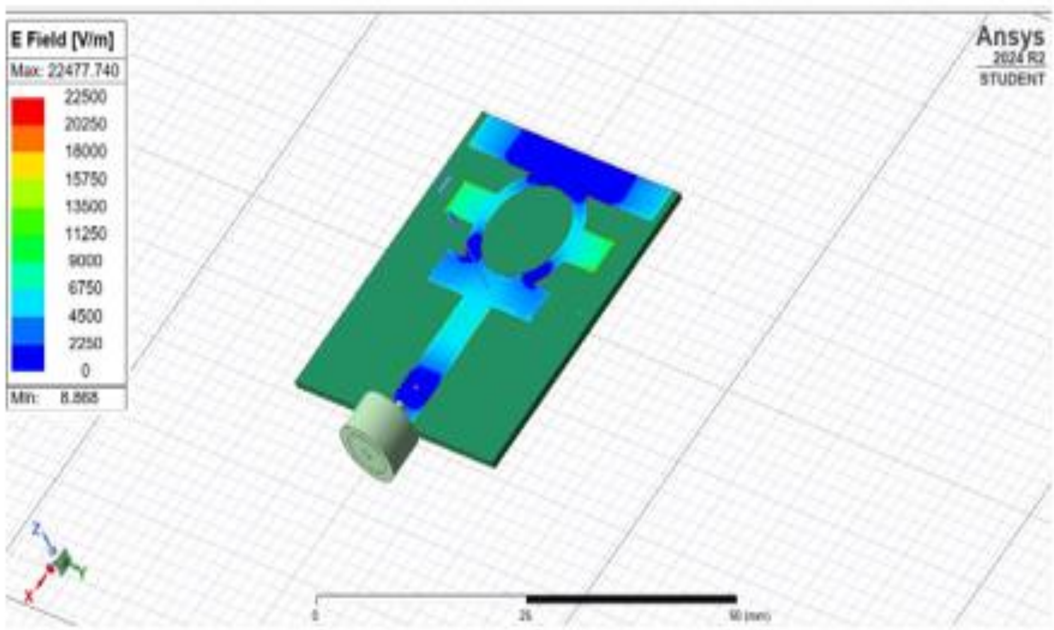


Figure 6. E-field distribution of a circular slotted electrically small antenna."

CONCLUSIONS

The proposed dual-band electrically small antenna with a circular slot exhibits promising performance based on both simulation and experimental results obtained through Ansys HFSS and measurements. The antenna resonates at 1.5 GHz and 3.7 GHz, offering return losses of 21 dB and 37 dB, respectively, and a VSWR consistently below 2, indicating efficient impedance matching. The radiation patterns reveal an omnidirectional radiation characteristic for both frequencies, with minor variations between simulated and measured outcomes due to fabrication and measurement tolerances. Additionally, the antenna's compact size (38 mm × 34 mm) and superior return loss values compare favorably with similar antennas in the literature, making it a highly efficient design for dual-band applications. The results demonstrate the effectiveness of the finite element method in optimizing the antenna's design using HFSS, ensuring performance within the expected operational bands.

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