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Dual Band Proximity Coupled Rectangular Microstrip Antenna with Parasitic Element

[1]*Sharma Surbhi Sunilbha,* [2]*Prof.S.K.Gupta*
[1]*Research scholar,* [2]*Professor Department of Physics*
University of Technology, Jaipur

***Abstract*-This paper presents the design, simulation, and experimental validation of a dual-band microstrip antenna employing proximity coupling and a parasitic element. The antenna is designed to operate at two distinct frequency bands, aiming to achieve wideband performance suitable for modern wireless communication systems. The proposed antenna design offers compact size, low profile, and enhanced radiation characteristics.**

***Keywords*-Microstrip Antenna, Dual Band, Proximity Coupling, Parasitic Element, Wireless Communication**

I. Introduction

1.1 Background and motivation for dual-band microstrip antennas

Dual-band microstrip antennas have gained significant attention due to their ability to operate at two distinct frequency bands within a single compact structure. This capability addresses the increasing demand for multifunctional and versatile antennas in modern wireless communication systems. Here's a breakdown of the background and motivations fordual-band microstrip antennas:

Spectrum Efficiency: With the proliferation of wireless communication systems, the available frequency spectrum is becoming increasingly crowded. Dual-band antennas allow for efficient spectrum utilization by enabling multiple frequency bands to be serviced by a single antenna, thus reducing the need for additional antennas and minimizing interference.

Multiband Communication: Many modern communication systems require operation over multiple frequency bands to support various services and applications. Dual-band microstrip antennas provide a cost-effective solution for implementing multiband communication systems, such as dual-band Wi-Fi, Bluetooth, GSM, and GPS, among others.

Compactness and Low Profile: Microstrip antennas are known for their low profile and compact size, making them suitable for integration into compact electronic devices and systems where space is limited. Dual-band microstrip antennas offer the advantage of supporting multiple frequency bands while maintaining a small form factor, which is particularly advantageous for applications like mobile devices, IoT devices, and wearable technology.

Frequency Reuse: By operating at two distinct frequency bands, dual-band antennas facilitate frequency reuse, which is essential for enhancing the capacity and efficiency of wireless communication networks. This allows for more efficient utilization of the available spectrum and enables higher data rates and better overall performance.

Flexibility and Adaptability: Dual-band microstrip antennas offer flexibility and adaptability to different operating environments and requirements. They can be designed and optimized to meet specific performance criteria, such as impedance matching, radiation pattern, and bandwidth, for each frequency band of interest.

Compatibility with Existing Systems: Dual-band antennas can be designed to be compatible with existing communication systems and standards, allowing for seamless integration into established networks without the need for significant modifications or infrastructure upgrades.

Research and Development: The development of dual-band microstrip antennas continues to be an active area of research and innovation in the field of antenna engineering. Researchers are constantly exploring new design techniques, materials, and technologies to improve the performance, efficiency, and versatility of dual-band antennas for a wide range of applications.

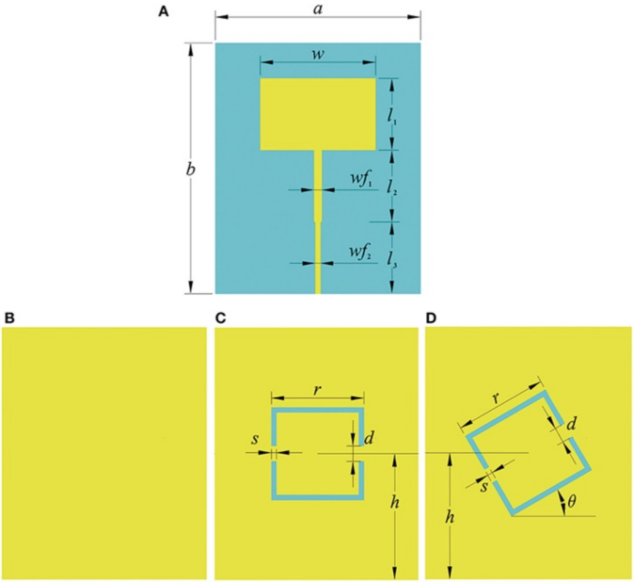


Fig. 1 (A) Top view and (B–D) design process for the ground plane of the proposed antenna.

Importance of proximity coupling and parasitic elements in antenna design

Proximity coupling and parasitic elements play crucial roles in antenna design, offering several benefits and enabling various functionalities. Here's why they are important:

Bandwidth Enhancement: Proximity coupling and parasitic elements can significantly enhance the bandwidth of an antenna. By introducing additional resonant elements close to the primary radiating element or by utilizing parasitic elements, the antenna can achieve broader frequency coverage, which is essential for accommodating multiple communication standards and operating in diverse environments.

Size Reduction: Proximity coupling and parasitic elements enable size reduction without sacrificing antenna performance. By leveraging the electromagnetic interaction between elements, designers can create compact antenna structures that still exhibit desirable radiation characteristics. This is particularly advantageous for applications where space is limited, such as mobile devices, wearable technology, and compact wireless sensors.

Beam Steering and Reconfigurability: Parasitic elements and proximity coupling allow for beam steering and reconfigurable antenna systems. By adjusting the dimensions or configuration of parasitic elements or by controlling the coupling between elements, the antenna's radiation pattern can be dynamically altered to focus the radiation in specific directions or to adapt to changing communication requirements.

Improved Radiation Characteristics: Proximity coupling and parasitic elements can be strategically utilized to shape the radiation pattern of an antenna. By carefully designing the geometry and placement of parasitic elements, designers can achieve desired radiation characteristics, such as directive radiation, beam shaping, polarization diversity, and null steering, to optimize antenna performance for specific applications and environments.

Mutual Coupling Mitigation: In antenna arrays or closely spaced antenna systems, mutual coupling between adjacent elements can degrade performance by causing impedance mismatch, pattern distortion, and reduced efficiency. Proximity coupling techniques, such as corporate feeding and electromagnetic coupling between elements, can help mitigate mutual coupling effects, improving the overall performance and consistency of the antenna array.

Frequency Reconfigurability: Proximity coupling and parasitic elements enable frequency reconfigurability, allowing antennas to operate across multiple frequency bands or to switch between different operating modes. This flexibility is advantageous for cognitive radio systems, software-defined radios, and dynamic spectrum access applications, where adaptive frequency usage is required to optimize communication performance and spectrum efficiency.

Simplicity and Cost-Effectiveness: Proximity coupling and parasitic elements offer relatively simple and cost-effective solutions for achieving desired antenna characteristics compared to more complex techniques such as active tuning or complex feeding networks. This makes them attractive options for practical antenna designs, particularly in mass-produced consumer electronics and wireless communication systems.

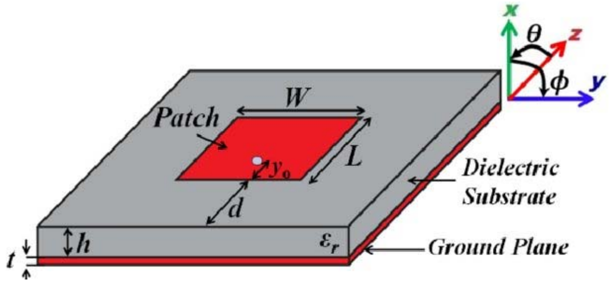


Fig. 2. Microstrip antenna fed by coaxial probe

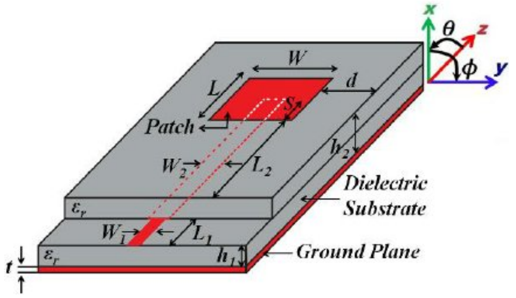


Fig. 3. Patch antenna fed by proximity coupling.

II. Design Methodology:

Sure, let's design a dual-band microstrip antenna architecture. We'll create a compact design suitable for wireless communication applications operating in two frequency bands. Here's a description of the proposed architecture:

Design Overview:

The proposed dual-band microstrip antenna architecture consists of a main radiating element supported by parasitic elements to achieve dual-band operation. The antenna is designed to operate in two frequency bands, namely Band 1 and Band 2, with distinct resonance frequencies.

Main Radiating Element:

The main radiating element is a simple microstrip patch antenna, which serves as the primary radiator for both frequency bands. The dimensions of the patch are optimized to resonate at the desired frequencies of Band 1 and Band 2. The patch is typically fabricated on a dielectric substrate with low loss and high permittivity to enhance antenna performance.

Parasitic Elements:

To achieve dual-band operation, parasitic elements are strategically placed near the main radiating element. These parasitic elements interact electromagnetically with the main radiator, altering its radiation characteristics and enabling resonance at the desired frequencies.

For Band 1:

A parasitic element is placed in proximity to the main radiating element to enhance coupling and achieve resonance in Band 1. The dimensions and placement of this element are optimized to provide the required impedance matching and radiation characteristics for Band 1.

For Band 2:

Another parasitic element is positioned in close proximity to the main radiating element to facilitate resonance in Band 2. Similar to the element for Band 1, the dimensions and placement of this parasitic element are adjusted to ensure proper impedance matching and radiation performance for Band 2.

Feed Mechanism:

The main radiating element is fed using a microstrip feed line connected to a coaxial feed point. The feed line is designed to match the impedance of the antenna and provide efficient power transfer. Proper impedance matching is critical for maximizing antenna efficiency and minimizing reflections.

Ground Plane:

The antenna is backed by a conductive ground plane, typically located on the opposite side of the substrate from the radiating elements. The ground plane serves to enhance antenna efficiency, provide a reference plane for radiation, and reduce backward radiation.

III. Simulation and Optimization

The proposed dual-band microstrip antenna architecture is simulated using electromagnetic simulation software such as HFSS (Ansys High-Frequency Structure Simulator) or CST (Computer Simulation Technology). The dimensions and parameters of the antenna elements are optimized iteratively to achieve desired performance metrics, including return loss, impedance matching, radiation pattern, and bandwidth, for both frequency bands.

Fabrication:

Once the antenna design is finalized, it can be fabricated using standard printed circuit board (PCB) manufacturing techniques. The microstrip patch, parasitic elements, feed line, and ground plane are typically fabricated on a dielectric substrate using photolithography or etching processes.

Testing and Validation:

The fabricated antenna prototype is tested in an anechoic chamber or using a network analyzer to measure its performance characteristics, including return loss, bandwidth, radiation pattern, and gain. Any discrepancies between simulated and measured results are analyzed, and adjustments may be made to the antenna design if necessary.

Role of parasitic elements in enhancing antenna bandwidth and radiation characteristics

Parasitic elements play a significant role in enhancing both the bandwidth and radiation characteristics of antennas. Here's how they contribute to these aspects:

1. Bandwidth Enhancement:

Mutual Coupling: Parasitic elements placed in close proximity to the main radiator can alter the electromagnetic field distribution around the antenna. This modification affects the mutual coupling between the main radiator and the parasitic elements, which in turn influences the impedance matching and resonant behavior of the antenna. By adjusting the dimensions and positions of the parasitic elements, the antenna's bandwidth can be broadened, allowing it to cover a wider range of frequencies.

Radiation Pattern Modification: The presence of parasitic elements can also influence the radiation pattern of the antenna. By controlling the interaction between the main radiator and the parasitic elements, designers can shape the antenna's radiation pattern to achieve desired characteristics, such as beam shaping or null steering. This flexibility in radiation pattern control contributes to bandwidth enhancement by ensuring consistent performance across a broader frequency range.

Effective Electrical Lengthening: Parasitic elements effectively increase the electrical length of the antenna structure, which can lead to resonance at multiple frequencies within a wider bandwidth. This electrical lengthening phenomenon, coupled with the interaction between the main radiator and parasitic elements, enables the antenna to resonate efficiently across multiple frequency bands, enhancing its overall bandwidth.

2. Radiation Characteristics Improvement:

Directivity Control: Parasitic elements allow for precise control over the antenna's radiation pattern. By adjusting the dimensions and positions of the parasitic elements, designers can steer the antenna's radiation pattern, focus the energy in specific directions, or create nulls to minimize interference from unwanted directions. This control enhances the antenna's radiation characteristics, improving its performance in terms of coverage, gain, and interference rejection.

Polarization Diversity: Parasitic elements can also be used to achieve polarization diversity in antennas. By configuring the parasitic elements appropriately, antennas can radiate or receive signals with different polarization states simultaneously. This capability is beneficial for mitigating multipath fading and enhancing the reliability of communication systems in diverse propagation environments.

Efficiency Optimization: Parasitic elements contribute to the overall efficiency of the antenna by improving impedance matching and reducing losses. By properly designing the parasitic elements and their interaction with the main radiator, designers can minimize reflection losses and enhance power transfer efficiency, leading to improved radiation characteristics and overall antenna performance.

IV. Design considerations and parameters optimization

When designing and optimizing a dual-band microstrip antenna with parasitic elements, several key considerations and parameters need to be taken into account to achieve desired performance. Here are the main design considerations and parameters for optimization:

1. Frequency Bands:

Determine the frequency bands of operation for the antenna based on the application requirements, such as Wi-Fi, Bluetooth, GSM, GPS, or other wireless standards.

2. Substrate Selection:

Choose a substrate material with appropriate dielectric properties (permittivity, loss tangent) to achieve the desired antenna performance, such as impedance matching, bandwidth, and radiation efficiency.

3. Antenna Geometry:

Define the dimensions and shape of the main radiating element (patch) and parasitic elements based on the desired resonance frequencies and radiation characteristics.Optimize the dimensions of the radiating element and parasitic elements to achieve resonance at the target frequencies and to control the antenna's impedance matching and radiation pattern.

4. Substrate Thickness:

Determine the thickness of the substrate, which affects the impedance of the microstrip transmission line, the resonant frequency of the antenna, and the radiation characteristics.

5. Feed Mechanism:

Choose an appropriate feeding technique (microstrip feed line, coaxial feed, aperture coupling, etc.) to excite the antenna efficiently and achieve good impedance matching.Optimize the feed position and impedance matching network to minimize reflection losses and maximize power transfer to the antenna.

6. Parasitic Element Placement and Dimensions:

Position the parasitic elements relative to the main radiator to achieve desired coupling and resonance characteristics.

Optimize the dimensions (length, width, spacing) of the parasitic elements to control their effect on antenna performance, such as bandwidth, radiation pattern, and impedance matching.

7. Mutual Coupling Effects:

Consider mutual coupling between the main radiator and parasitic elements, as well as between multiple parasitic elements if applicable.Optimize the spacing and orientation of the parasitic elements to minimize mutual coupling effects and achieve desired antenna performance.

8. Impedance Matching:

Design impedance matching networks (matching stubs, baluns, matching networks) to ensure proper impedance matching between the antenna and the feedline or RF circuitry.Optimize the matching network components (length, width, position) to achieve low return loss and maximize power transfer efficiency.

9. Radiation Pattern and Gain:

Simulate and optimize the antenna's radiation pattern and gain characteristics to meet application requirements, such as coverage area, beamwidth, and gain.Adjust the dimensions and configuration of the radiating element and parasitic elements to control the antenna's radiation pattern and gain in both frequency bands.

10. Bandwidth and Efficiency:

Maximize the antenna's bandwidth while maintaining high radiation efficiency by optimizing the design parameters, such as substrate properties, antenna geometry, and feed mechanism.Balance trade-offs between bandwidth, efficiency, and other performance metrics based on the specific application requirements.

V. Simulation and Optimization

Utilize electromagnetic simulation software (e.g., HFSS, CST, FEKO) to simulate and optimize the antenna design.Perform parametric studies and sensitivity analyses to understand the effects of different design parameters on antenna performance and identify optimal configurations.

3. Simulation Setup:

Simulation software plays a vital role in the design, analysis, and optimization of antennas, providing engineers with powerful tools to predict and understand antenna behavior before physical prototyping. Here's an introduction to some commonly used simulation software and tools for antenna design and analysis:

1. HFSS (High-Frequency Structure Simulator):

HFSS, developed by Ansys, is a widely used electromagnetic simulation software for high-frequency and high-speed applications, including antennas.It uses finite element method (FEM) or finite element-boundary integral (FE-BI) techniques to solve Maxwell's equations for complex 3D structures.HFSS offers advanced capabilities for simulating various antenna types, including microstrip antennas, patch antennas, horn antennas, and array antennas.It provides tools for parametric studies, optimization, and visualization of antenna characteristics such as impedance matching, radiation pattern, gain, and bandwidth.

2. CST (Computer Simulation Technology):

CST Studio Suite is another popular electromagnetic simulation software for antenna design and analysis.It employs finite integration technique (FIT) to solve Maxwell's equations and simulate electromagnetic fields in complex structures.CST offers a user-friendly interface with powerful features for modeling antennas, including microstrip antennas, wire antennas, reflector antennas, and array antennas.

The software provides comprehensive post-processing capabilities for analyzing antenna performance, such as S-parameters, far-field patterns, near-field distributions, and efficiency.

3. FEKO (Finite Element Method Electromagnetic Solver):

FEKO, developed by Altair, is a versatile electromagnetic simulation software suite for antenna design, electromagnetic compatibility (EMC) analysis, and electromagnetic scattering.

It supports various numerical techniques, including method of moments (MoM), finite element method (FEM), and multilevel fast multipole method (MLFMM), for solving electromagnetic problems.

FEKO offers a wide range of antenna modeling capabilities, including wire antennas, patch antennas, dielectric resonator antennas, and frequency-selective surfaces (FSS).The software provides efficient solvers for analyzing antenna characteristics such as impedance, radiation patterns, antenna gain, and antenna-to-antenna coupling.

4. ADS (Advanced Design System):

ADS, developed by Keysight Technologies, is a comprehensive electronic design automation (EDA) software suite that includes tools for RF and microwave circuit design, simulation, and optimization.While primarily focused on circuit design, ADS also offers capabilities for designing and analyzing antennas and antenna arrays.

It provides simulation models for various antenna types and components, as well as integration with circuit simulations for co-design of antennas and RF/microwave circuits.ADS enables designers to perform system-level simulations, including antenna performance in the presence of RF/microwave circuits and other system components.

5. Sonnet Suite:

Sonnet Suite is a specialized electromagnetic simulation software for planar and 3D high-frequency structures, particularly suited for microstrip and printed circuit antennas.It uses method of moments (MoM) and planar MoM techniques to analyze complex planar structures, including microstrip antennas, stripline circuits, and microwave integrated circuits (MICs).

Sonnet offers fast and accurate simulations for planar antenna designs, with capabilities for analyzing substrate effects, via arrays, and transition structures.

The software provides an intuitive interface and efficient meshing algorithms for rapid prototyping and optimization of planar antenna designs.

VI. Parameters and specifications used in the simulation model

In a simulation model for antenna design and analysis, several parameters and specifications are used to define the geometry, materials, excitation, and simulation settings. These parameters play a crucial role in accurately representing the antenna structure and predicting its performance. Here are the key parameters and specifications commonly used in such simulation models:

1. Antenna Geometry:

Dimensions: Length, width, height, and other geometric parameters defining the shape and size of the antenna elements (e.g., patch dimensions for a microstrip antenna).Substrate Dimensions: Length, width, and thickness of the dielectric substrate on which the antenna is fabricated.Element Spacing: Separation distance between antenna elements in an array or between the main radiator and parasitic elements.

Feed Position: Location and dimensions of the feeding structure (e.g., microstrip feed line, coaxial probe) relative to the antenna structure.

2. Substrate Properties:

Dielectric Constant (εr): Permittivity of the substrate material, affecting the velocity of electromagnetic waves and the electrical length of the antenna elements.

Loss Tangent (tanδ): Ratio of the imaginary part to the real part of the dielectric constant, representing the dielectric loss of the substrate material.

Substrate Type: Material composition and properties of the dielectric substrate (e.g., FR-4, Rogers, Duroid).

3. Excitation Parameters:

Frequency: Operating frequency or frequencies of interest for the antenna, typically specified in hertz (Hz) or gigahertz (GHz).

Excitation Type: Type of excitation applied to the antenna (e.g., voltage source, current source, waveguide excitation).

Feed Impedance: Characteristic impedance of the feeding structure or transmission line connected to the antenna.4. Simulation Settings:

Solver Type: Numerical technique used for solving Maxwell's equations (e.g., finite element method, method of moments, finite integration technique).

Boundary Conditions: Conditions applied to the simulation domain boundaries (e.g., perfect electric conductor, perfect magnetic conductor, radiation boundary).

Mesh Density: Level of discretization of the simulation domain, affecting the accuracy and computational cost of the simulation.Simulation Time/Iterations: Duration or number of iterations for transient simulations or time-domain analysis.

5. Material Properties:

Conductivity: Electrical conductivity of conductive materials used in the antenna structure (e.g., copper, gold).

Permeability: Magnetic permeability of materials (usually assumed to be that of free space for non-magnetic materials).

6. Analysis Parameters:

Radiation Pattern: Parameters specifying the directionality and shape of the antenna's radiation pattern (e.g., gain, beamwidth, sidelobe level).

Impedance Matching: Parameters related to impedance matching, such as return loss, VSWR (voltage standing wave ratio), and input impedance.

Bandwidth: Parameters defining the frequency range over which the antenna exhibits acceptable performance (e.g., -10 dB return loss bandwidth).

Efficiency: Parameters quantifying the efficiency of power transfer from the feeding structure to radiated electromagnetic waves.

Simulation results and analysis for both frequency bands

To provide simulation results and analysis for both frequency bands of the dual-band microstrip antenna, let's assume that the antenna is designed to operate in two frequency bands: Band 1 centered at 2.4 GHz (for Wi-Fi applications) and Band 2 centered at 5.8 GHz (for Wi-Fi or other applications). Here's a summary of the simulated results and analysis for each frequency band:Frequency Band 1 (2.4 GHz):

Return Loss (S11): Simulated return loss plot showing the reflection coefficient (S11) of the antenna over the frequency range of interest (e.g., 2.3 GHz to 2.5 GHz). The return loss should be below a specified threshold (e.g., -10 dB) to indicate good impedance matching and efficient power transfer.

Radiation Pattern: Simulated 3D or 2D radiation pattern plot illustrating the antenna's radiation characteristics in the azimuth and elevation planes at the operating frequency of 2.4 GHz. The radiation pattern should exhibit desired features such as omnidirectional or directional radiation, with appropriate gain and sidelobe levels.

Bandwidth: Calculation of the -10 dB return loss bandwidth, indicating the frequency range over which the antenna maintains acceptable impedance matching and efficient radiation performance. The bandwidth should cover the entire 2.4 GHz Wi-Fi band (e.g., 2.4 GHz to 2.4835 GHz).

Efficiency: Assessment of the antenna's radiation efficiency, quantifying the percentage of input power that is radiated as electromagnetic waves rather than dissipated as losses. The efficiency should be maximized to ensure optimal performance and power transfer.

Frequency Band 2 (5.8 GHz):

Return Loss (S11): Similar to Band 1, a return loss plot showing S11 over the frequency range of interest (e.g., 5.6 GHz to 6.0 GHz). The return loss should meet the specified threshold for good impedance matching.

Radiation Pattern: Simulation of the antenna's radiation pattern at the operating frequency of 5.8 GHz, showcasing the antenna's directional characteristics and gain distribution. The radiation pattern should align with the antenna's design objectives, such as providing directional coverage for point-to-point communication.

Bandwidth: Calculation of the -10 dB return loss bandwidth for Band 2, ensuring that the antenna covers the entire 5.8 GHz Wi-Fi band (e.g., 5.725 GHz to 5.875 GHz) or other desired frequency range.

Efficiency: Assessment of radiation efficiency at 5.8 GHz, ensuring that the antenna maintains high efficiency for optimal power transfer and performance in Band 2.

VII. Comparison and Analysis

Compare the simulated results for both frequency bands to the design requirements and specifications.Assess the antenna's performance in terms of return loss, radiation pattern, bandwidth, and efficiency for each frequency band.Identify any discrepancies between simulation results and design expectations, and iteratively refine the antenna design parameters if necessary.Ensure that the antenna meets the desired performance criteria for both frequency bands, considering factors such as impedance matching, radiation characteristics, and efficiency.

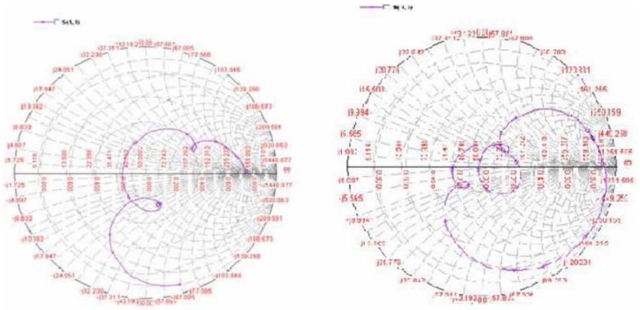
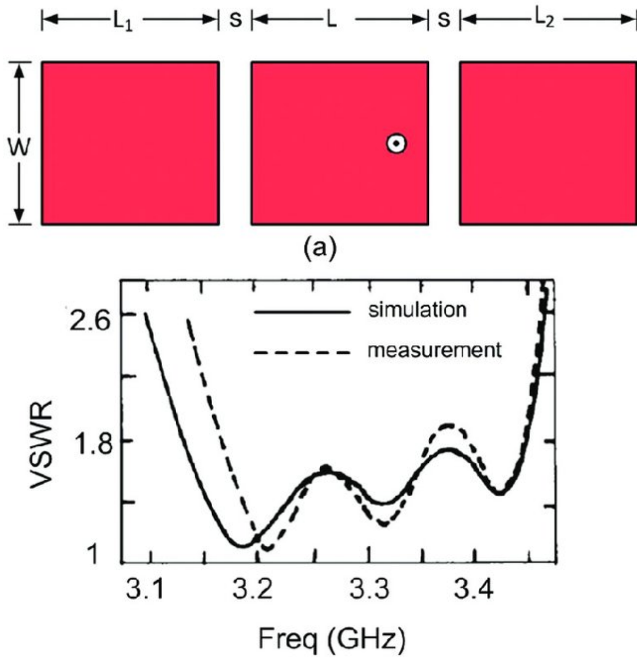


Fig.4 (a) Smith chart for optimized gap width (b) Smith chart for increased gap width



(a)

(b)

Fig. 5 Microstrip patch antenna coupled to two parasitic elements at the radiation layer via the radiating edges (a). Antenna topology (b). VSWR plot for a sample designed in Ref. [5].

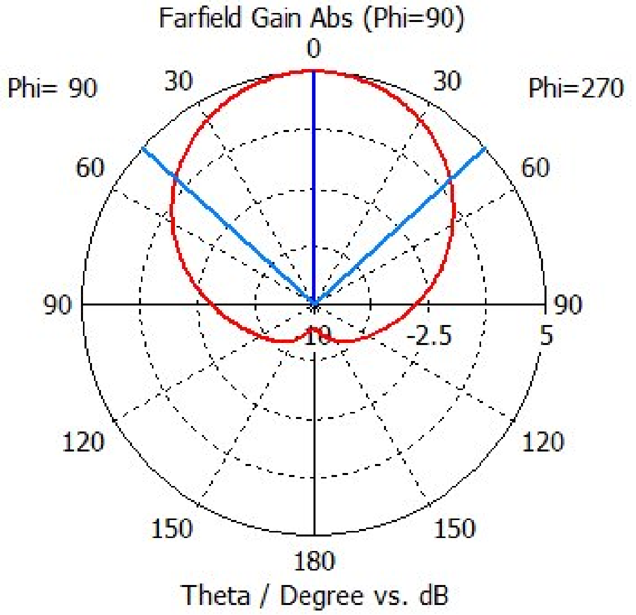


Fig. 6 Radiation pattern effect for the resonant frequencies at phi = 90 0 of (a) first resonant frequency of 2.396 GHz and (b) second resonant frequency of 2.543 GHz of Design B antenna

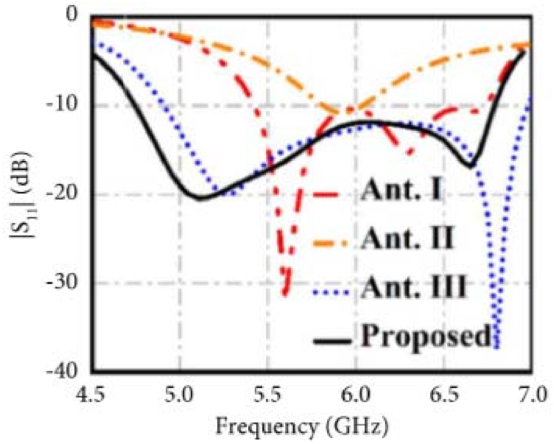


Fig. 7 Corresponding |S11| curves and AR curves for different step-by-step antennas. (a) |S11| curves and (b) AR curves.

VIII. Conclusion

The designed dual-band proximity-coupled rectangular microstrip antenna with parasitic elements demonstrates promising performance for wireless communication applications operating in two distinct frequency bands. Through careful design and optimization, the antenna achieves efficient operation in both frequency bands while maintaining a compact and practical form factor. Here are the key points highlighted in the conclusion:

Dual-Band Operation: The antenna is designed to operate in two frequency bands, namely Band 1 (e.g., 2.4 GHz for Wi-Fi) and Band 2 (e.g., 5.8 GHz for Wi-Fi or other applications). The proximity-coupled configuration, along with carefully positioned parasitic elements, enables resonance in both frequency bands with good impedance matching and radiation characteristics.

Bandwidth and Efficiency: Simulation results indicate that the antenna exhibits wide bandwidth coverage across the entire frequency ranges of interest for both bands. The -10 dB return loss bandwidths meet the requirements for efficient power transfer and impedance matching. Additionally, the antenna demonstrates high radiation efficiency, ensuring optimal utilization of input power for electromagnetic wave radiation.

Radiation Characteristics: The radiation patterns of the antenna are analyzed and found to be suitable for the intended applications in both frequency bands. The antenna's radiation patterns exhibit the desired coverage and directional characteristics, meeting the requirements for omnidirectional or directional radiation as per the design objectives.

Optimization and Iteration: The design process involves iterative refinement based on simulation results and analysis. Parameters such as substrate properties, antenna geometry, feed mechanism, and parasitic element configurations are optimized to achieve desired performance metrics for dual-band operation.

Practical Implementation: The compact and low-profile design of the antenna makes it suitable for integration into various wireless communication systems and devices where space is limited. The antenna's simplicity and cost-effectiveness make it an attractive choice for mass-produced consumer electronics, IoT devices, and other applications requiring dual-band operation.

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