Efficient Microstrip Monopole Antenna Design for Multi Technology Wireless Applications

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Abstract — The demand for compact, efficient antennas capable of supporting multiple wireless communication standards continues to drive innovation in the field. In this paper, we present a novel approach to designing microstrip monopole antennas, leveraging a unique set of design equations to achieve superior performance across 3GHz and 6GHz frequency bands.

Additionally, we explore the development of array antennas by combining two microstrip monopoles, offering enhanced gain and radiation characteristics compared to single-element designs. By varying array substrate material, we aim to further optimize performance for applications such as WiFi, LTE, and WiMax.

Keywords- *Microstrip antenna, broadband monopole antenna, dual band monopole antenna, compact monopole.*

I. INTRODUCTION

In recent years, the rapid advancement in both software and hardware for communication systems has paved the way for the development of diverse wireless applications. This includes the emergence of broadband (BB), wideband (WB), and ultra-wideband (UWB) microwave transceivers. Among the various antenna structures available, planar multiband antennas, such as microstrip (MS), coplanar waveguide (CPW), and stripline (SL) configurations, have gained significant popularity. Their compact size, low cost, lightweight nature, and ease of installation make them highly appealing for integration with modern microwave wireless devices, contrasting with conventional wire antennas like helical, yagi-Uda, and spiral types.

Attention has been increasingly focused on designing efficient multiband antenna modules capable of achieving desired characteristics within the effective operating frequency band. Multiband antennas offer the advantage of using filter circuits to suppress band interferences, enhancing their performance in complex communication environments. Among these, compact printed microstrip monopole antennas have emerged as crucial structures for numerous wireless applications, including GPS, WLAN, RFID, LTE, WiMax, and UWB. Compared to other planar structures like CPW and SL, microstrip antennas offer superior advantages in terms of easy fabrication and compatibility with modern microwave circuits. Various printed monopole antenna configurations have been proposed, analyzed, and reported for a multitude of wireless applications. These include broadband/wideband microstrip monopole structures covering applications such as WLAN and WiMax, as well as dual-band microstrip configurations for GPS, UMTS, Bluetooth, and other standards. However, designing an efficient multiband monopole antenna involves several considerations, including overall antenna dimensions, effective percentage bandwidth, average gain, efficiency, and desired radiation pattern. Therefore, thorough investigation and optimization of these parameters are essential to meet the requirements of specific applications.

This paper introduces a novel approach to address these challenges by proposing compact and broadband microstrip monopole antennas. The proposed antennas, named Compact Microstrip Antenna (CMP) and Microstrip Monopole Linear Array Antenna (MPA), are designed, analyzed. Leveraging a full-wave electromagnetic simulator (CST-microwave Studio ver. 2024), the simulation results, including return loss, gain, percentage bandwidth, VSWR, and radiation pattern, are presented, investigated, and discussed.

II. MICROSTRIP PATCH ANTENNA

Microstrip monopole antennas represent a fundamental component in the realm of wireless communication systems. Their significance stems from their compactness, ease of integration, and versatility across a wide range of applications. In recent years, research and development efforts have focused on enhancing the performance and capabilities of these antennas to meet the evolving demands of modern communication technologies.

At its core, a microstrip monopole antenna consists of a conducting patch printed on one side of a dielectric substrate, with a ground plane on the opposite side. The simplicity of this design, coupled with the ability to easily adjust the dimensions of the patch and substrate, allows for precise tuning of the antenna's characteristics to match specific frequency bands and performance requirements. One of the key advantages of microstrip monopole antennas is their ability to operate over multiple frequency bands, making them well-suited for multiband communication systems. This versatility is achieved through various design techniques, such as adding parasitic elements, incorporating tuning stubs, or utilizing fractal geometries. By carefully optimizing these parameters, researchers can tailor the antenna's impedance bandwidth and radiation pattern to meet the needs of diverse applications, ranging from wireless LANs and cellular networks to satellite communication systems

.

In the context of research, microstrip monopole antennas offer a rich landscape for exploration and innovation. Researchers are continually exploring novel materials, geometries, and feeding techniques to improve antenna performance in terms of bandwidth, efficiency, and radiation characteristics. Advanced simulation tools, such as electromagnetic field solvers and optimization algorithms, play a crucial role in this endeavor by enabling rapid prototyping and evaluation of antenna designs before physical fabrication.

III. DESIGN EQUATIONS

STEP 1: Calculation of Monopole Width (w)

$$w = \frac{C}{2f_0\sqrt{\frac{\varepsilon_R+1}{2}}} \tag{3.1}$$

STEP 2: Calculation of Effective Dielectric Constant

$$\varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R-1}{2}\left[1+12\left(\frac{h}{w}\right)\right]^{1/2} \tag{3.2}$$

STEP 3: Calculation of Actual Length of Monopole(L)

$$L = leff - 2\Delta l \tag{3.3}$$

$$l_{eff} = \frac{C}{2f_0\sqrt{\varepsilon_{eff}}} \tag{3.4}$$

$$\Delta l = 0\cdot 412h\frac{\left(\varepsilon_{eff}+0.3\right)\left(\frac{w}{h}+0.265\right)}{\left(\varepsilon_{eff}-0.258\right)\left(\frac{w}{h}+0.8\right)} \tag{3.5}$$

STEP 4: Calculation of Substrate Width and Length [2]

$$L_s = 6h + L \tag{3.6}$$

$$W_s = 6h + w \tag{3.7}$$

Where,
C = Speed of Light
f_0 = Resonant frequency
ε_R = Dielectric constant
h = height of the substrate
w = Patch Width
Δl= fractional length
$leff$ = effective length

Applying the designated formulas facilitates the extraction of fundamental design metrics crucial for refining antenna performance. Through rigorous refinement utilizing Computer Simulation Technology (CST), an advanced electromagnetic simulation tool, these metrics undergo meticulous optimization. The resulting optimized values are systematically cataloged and presented in a tabular format, serving as a tangible manifestation of the exhaustive endeavors dedicated to the design process. This comprehensive approach ensures that each aspect of the antenna's performance is thoroughly examined and refined to achieve optimal functionality. The 1D representation of top view and bottom view of designed antenna along with the parameters table is as follows:

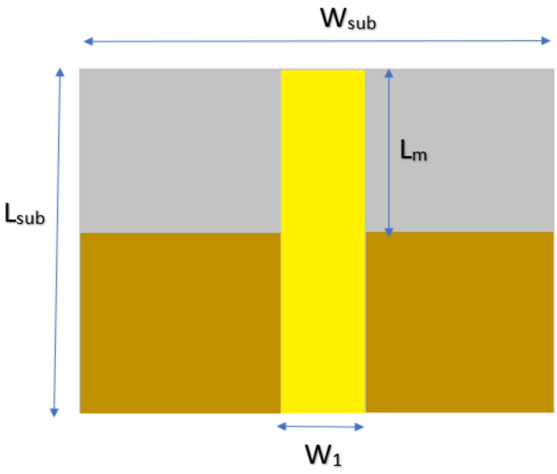

FIGURE 1. *Top View Design*

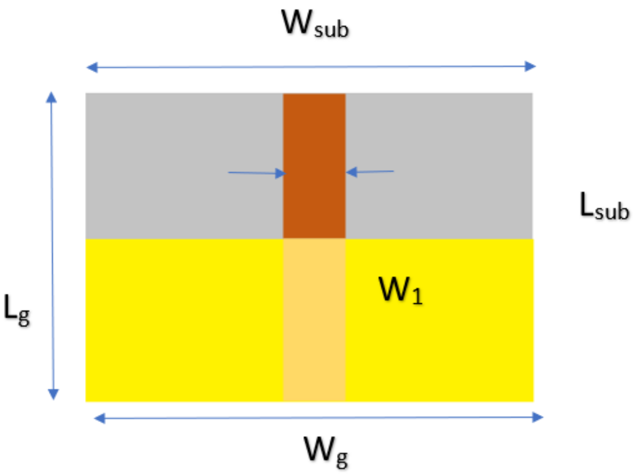

FIGURE 2. *Bottom View Design*

TABLE I: OPTIMIZED DESIGN METRICS OF SINGLE MONOPOLE ANTENNA

Name of Parameter	Optimized Value (in mm)
Length of Substrate (L_{sub})	36.6
Width of substrate (W_{sub})	45.75
Length of Ground (L_g)	18.3
Width of Ground (W_g)	45.75
Length of Monopole (L_m)	18.3
Width of Monopole (W1)	3

IV. DESIGN OF SINGLE MONOPOLE ANTENNA

This section delves into the intricate design architecture of the microstrip monopole antenna. The design process commences with a meticulous examination of the metrics delineated in Table-1, serving as indispensable benchmarks for shaping an optimized antenna configuration. Harnessing the robust capabilities of Computer Simulation Technology (CST), the antenna design is methodically crafted, integrating precise dimensions and parameters to ensure unparalleled performance.

Figures 3 and 4 serve as indispensable visual aids, presenting comprehensive front and rear views of the antenna design. These meticulously rendered illustrations provide an in-depth portrayal of the antenna's structural intricacies and geometric configurations, offering invaluable insights into its design nuances. Through CST simulation, every facet of the antenna's layout is meticulously refined, culminating in an optimized design poised to deliver exceptional functionality and efficiency.

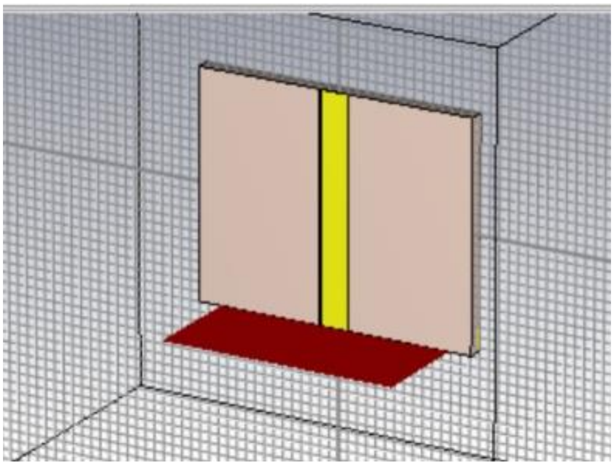

FIGURE 3. *Front View of Dual-Band Microstrip Monopole antenna*

Figure 3 presents the front view of the microstrip monopole antenna, with axes u, v, and w aligning with the x, y, and z coordinates respectively. The illustration prominently showcases the antenna's placement on the x-y plane, positioned perpendicular to the z-axis. This deliberate orientation is strategically chosen to optimize radiation in the z-direction, thereby maximizing the antenna's efficiency and performance for its intended applications. The intricate visualization depicted in Figure 3 offers profound insights into the spatial configuration and alignment of the antenna, facilitating a comprehensive comprehension of its operational dynamics.

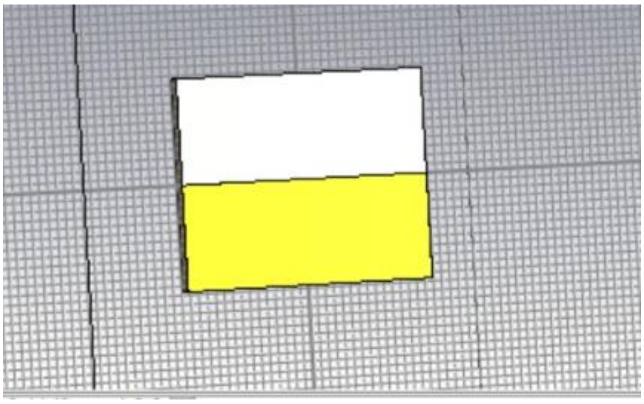

FIGURE 4. *Bottom View of Dual-Band Microstrip Monopole antenna*

Figure 4 offers a panoramic view of the entire ground structure, presenting a comprehensive perspective of the antenna's architecture. Of particular significance is the port, prominently featured as a rectangular structure within the visualization. It's essential to acknowledge that the detailed design composition, encompassing all vital components, is thoroughly illustrated across Figures 3 and 4. Together, these visual representations provide a detailed depiction of the antenna's intricate architectural details, offering valuable insights into its holistic design configuration and spatial orientation.The core design predominantly comprises two distinct materials: copper and FR-4. Copper, renowned for its exceptional electrical conductivity, is strategically utilized to fabricate the antenna's radiating elements and feed structures. This selection ensures efficient transmission and reception of electromagnetic signals, thereby optimizing the antenna's overall performance. Conversely, FR-4, a widely used dielectric substrate material, serves as essential support and insulation. Its incorporation ensures the structural robustness and stability of the antenna while maintaining optimal signal propagation characteristics. This deliberate choice of materials underscores the meticulous consideration given to electrical performance, mechanical durability, and manufacturability in the antenna's design and fabrication process.

V. DESIGN OF ARRAY MONOPOLE ANTENNA

This section delves into the intricate design architecture of the array microstrip monopole antenna. The design process initiates with a meticulous examination of the metrics outlined in Table-1, serving as indispensable benchmarks for shaping an optimized antenna configuration. Leveraging the robust capabilities of Computer Simulation Technology (CST), the antenna design is methodically crafted, integrating precise dimensions and parameters to ensure unparalleled performance. The 1D representation of top view and bottom view of designed antenna along with the parameters table is as follows:

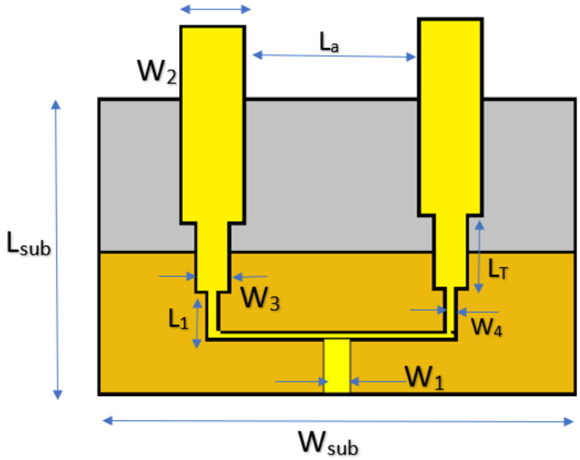

FIGURE 5. *Top View Design of monopole array antenna*

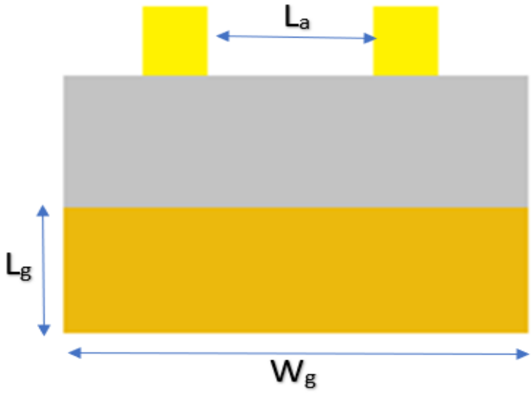

FIGURE 6. *Bottom View Design of monopole array antenna*

TABLE II: OPTIMIZED DESIGN METRICS OF ARRAY MONOPOLE ANTENNA

Name of Parameter	Optimized Value (in mm)
Length of Substrate (L_{sub})	38
Width of substrate (W_{sub})	36
Length of Ground (L_g)	21.7
Width of Ground (W_g)	36
W_1	3
W_2	3
W_3	3
L_1	4.6
L_T	6.8

VI. SIMULATION RESULTS

(i) MONOPOLE ARRAY ANTENNA

This section presents design, simulation, evaluation, investigation, and experimental verification of the proposed antenna. The main parameters that are required to evaluate the performance of the antenna are VSWR, gain of the antenna, S – parameters, directivity and farfield of the antenna.

(ii) VOLTAGE STANDING WAVE RATIO (VSWR)

VSWR servers as a crucial metric for evaluating impedance matching effectiveness. It quantifies the variations in voltage (or current) along the transmission line caused by signal reflections. A VSWR of 1:1 indicates a perfect match, with no reflections and efficient power transfer. Conversely, the higher VSWR values signify greater impedance mismatch, leading to reflected power traveling back towards the transmitter.A high VSWR can negatively impact a system's performance. Reflected power can overheat the transmitter, reduce transmitted power, and even damage equipment. To achieve optimal performance, it's essential to maintain low VSWR. This can be achieved by using properly designed antennas and transmission lines, employing impedance matching transformers, or adjusting antenna characteristics. Regularly monitoring VSWR helps ensure smooth operation and efficient signal transmission.

Based on the antenna design the simulated VSWR from frequencies 4.5GHz - 7.5GHz is between 1-2, which implies that reflections from the receiver end is not much. A VSWR value of 1 means the antenna has a perfect impedance match which is an ideal case, so generally a VSWR value less than 2 is considered a good antenna. Observe fig.7

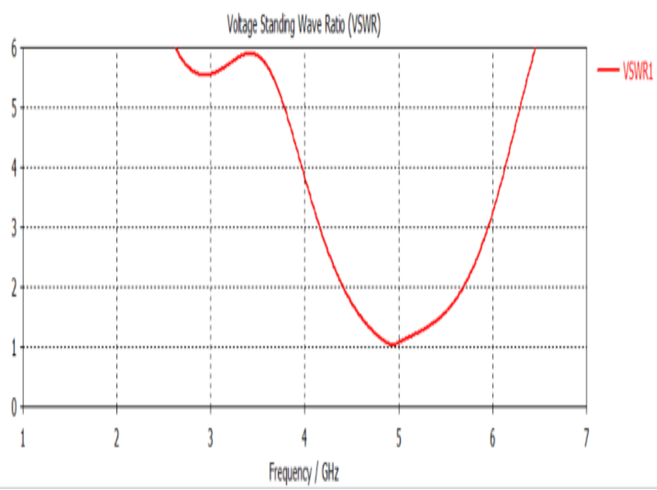

FIGURE 6. *VSWR of the monopole array antenna*

(iii) S11 -PARAMETER

The S11 parameter, also known as the reflection coefficient or return loss, plays a vital role in evaluating impedance matching within an antenna system. It represents the ration of reflected power to the incident power at the antenna's input port. A perfect impedance match, where all the power enters the antenna and is radiated, results in a S11 value of 0 dB(decibels). In reality, some degree of mismatch is usually present, leading to reflected power and an S11 value less than 0dB (negative values indicate reflection). A lower S11 magnitude (closer to 0dB) signifies better impedance matching and higher antenna efficiency. By monitoring and minimizing S11 through design techniques or matching circuits, we can ensure maximum power is radiated and the antenna functions optimally. So lesser the value of S11 better is the impedance matching, in this simulation the value of S11 is ranging from -16dB to -38dB. In practical applications of antennas, the value less than –11dB is considered to be a good return loss factor. In fig.7 we can observe the s11 of monopole array antenna.

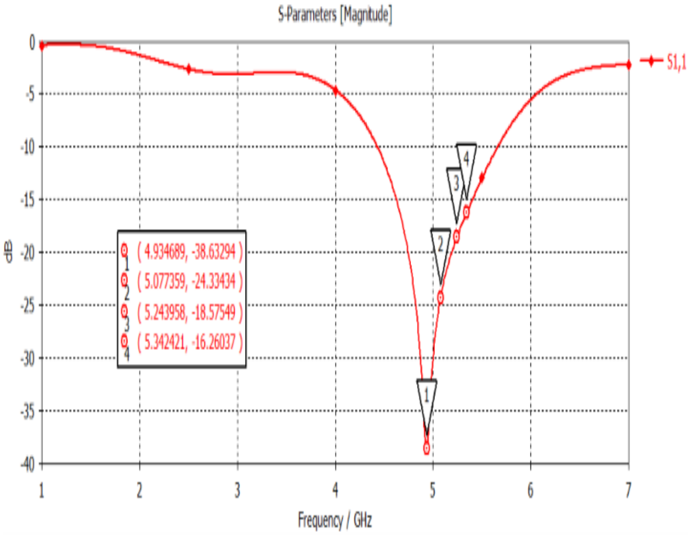

FIGURE 7. *s11 parameter of monopole array antenna*

(iv) FARFIELD AND GAIN

An antenna's electromagnetic field behavior can be categorized into two regions: the near-field and the far-field. The near-field encompasses the area immediately surrounding the antenna. In this region, the electromagnetic field characteristics are complex and vary significantly with distance. Measurements of antenna performance are typically not conducted here. As we move away from the antenna, we enter far-field, also known as the Fraunhofer region. Here the electromagnetic field transitions into a more predictable form. The electric and magnetic fields became perpendicular to each other and the direction of propagation, resembling the characteristics of plane waves.

The far-field is the region of primary interest for antenna characterization. Here, we can accurately measure critical parameters like radiation pattern, gain, and directivity using well-defined formulas and techniques. Understanding the far-field is essential for designing and deploying antennas for efficient wireless communication. In Fig8. and Fig9. We can observe the farfield radiation pattern at 4.5GHz and 5.75GHz. Comparative gain is higher at 4.5GHz than 5.75GHz. Antenna gain is a key performance parameter that quantifies an antenna's ability to focus radio waves in a particular direction compared to an isotropic radiator.

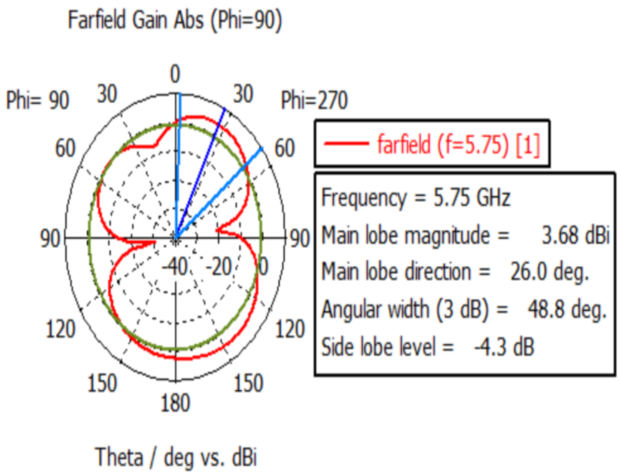

FIGURE 8. *farfield 1D plot of the monopole array antenna at 5.75GHz, main lobe magnitude represents the gain of antenna*

A higher gain antenna concentrates radio waves into a narrower beam, like how a magnifying glass focuses light. This amplification translates to stronger signals in the targeted direction, leading to increased range and improved signal quality. Conversely lower gain antennas radiate more uniformly, providing wider coverage but with weaker signals at any given point. The ideal antenna gain depends on a specific application. For long-range, point to point communication, a high gain antenna is preferred to direct the signal towards the receiver.

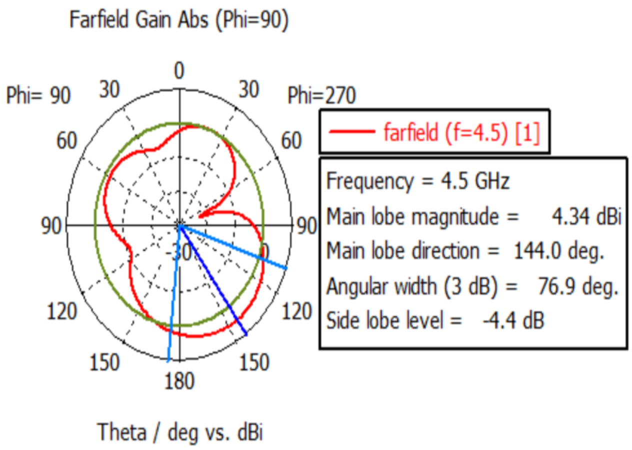

FIGURE 9. *farfield 1D plot of the monopole array antenna at 4.5GHz, main lobe magnitude represents the gain of antenna*

(v) DIRECTIVITY

Antennas don't just radiate radio waves; they do so with a specific pattern. Directivity is a fundamental parameter that quantifies how well an antenna concentrates its radiated power in a particular direction compared to an isotropic radiator (an imaginary antenna radiating equally in all directions). A highly directive antenna focuses its energy into a narrower beam, like how a flashlight concentrates light compared to a bare bulb. This translates to a stronger signal in the targeted direciton. Imagine a spotlight versus general room lighting. The higher the directivity, the more focused the beam and the stronger the signal within that beam.

The ideal directivity depends on the application. Long-range, point-to-point communication like satellite dishes benefits from high directivity to concentrate the signal on a distant reciever. Conversely, applications requiring broader coverage, like Wi-Fi routers or cell phone base stations, utilize antennas with lower directivity for wider signal distribution. Directivity at different frequencies for monopole array antenna is shown below.

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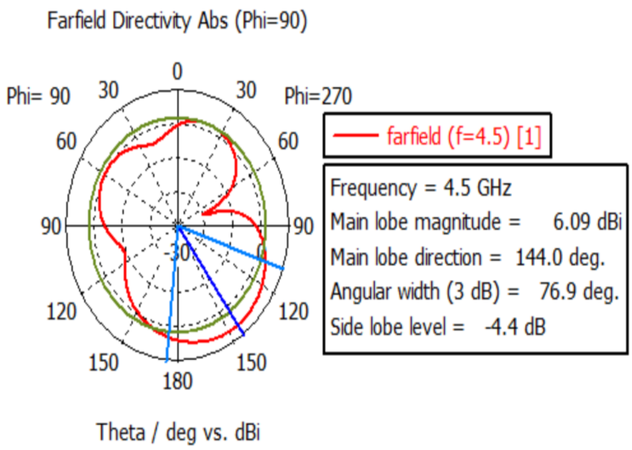

FIGURE 10. *Directivity of the monopole array antenna at 4.5GHz, main lobe magnitude represents directivity.*

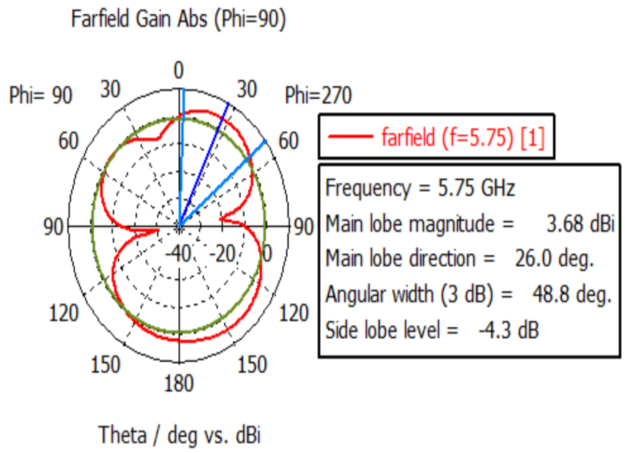

FIGURE 10. *Directivity of the monopole array antenna at 5.75GHz, main lobe magnitude represents directivity.*

(vi) MONOPOLE ANTENNA AT 3GHz AND 5GHz

1. VOLTAGE STANDING WAVE RATIO(VSWR)

Designed for versatile frequency operation, the monopole antenna exhibits exceptional performance characteristics at both 3GHz and 5GHz frequencies. With a consistent VSWR of 1-2 across these bands, the antenna ensures reliable signal transmission and reception, making it an ideal choice for applications requiring seamless connectivity in diverse environments. In fig11. And fig12. We can observe the VSWR for the frequencies.

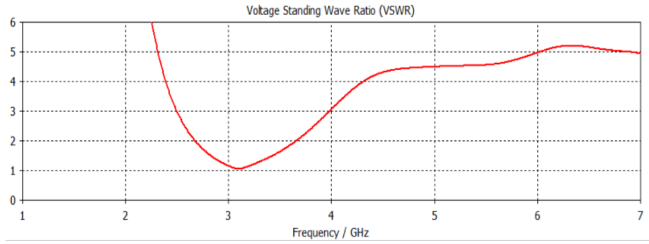

FIGURE 11. *VSWR of monopole antenna at 3GHz*

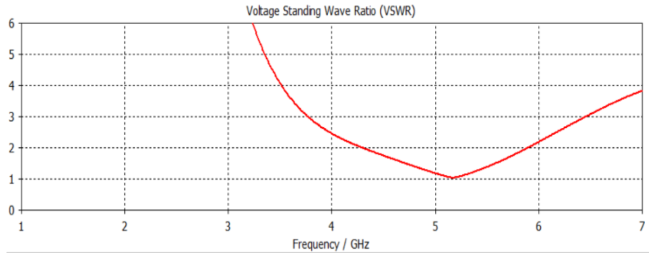

FIGURE 12. *VSWR of monopole antenna at 5GHz*

2. S-11 PARAMETER

Operating at 3GHz and 5GHz, the monopole antenna boasts impressive s11 parameters of –32dB and –34dB respectively. These values signify excellent impedance matching, ensuring efficient signal transmission and reception. Ideal for diverse applications such as wireless networking and satellite communication, this antenna's consistent performance across frequencies underscores its versatility and reliability in modern communication systems. The graphs below show the s11 parameters for the antenna at their respective frequencies.

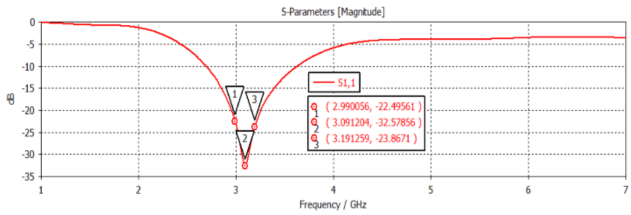

FIGURE 13. *s11 parameter of monopole antenna at 3GHz*

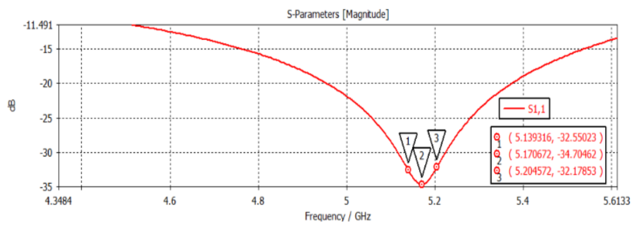

FIGURE 14. *s11 parameter of monopole antenna at 5GHz*

3. FARFIELD AND GAIN

The monopole antenna delivers reliable signal amplification across a wide frequency spectrum. This consistent performance ensures efficient transmission and reception of electromagnetic waves, making it dependable choice for many communication applications. This antenna's robust gain characteristics enhance signal strength and coverage,

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facilitating seamless connectivity. The farfield and gain plot of 3GHz and 5GHz is shown below respectively.

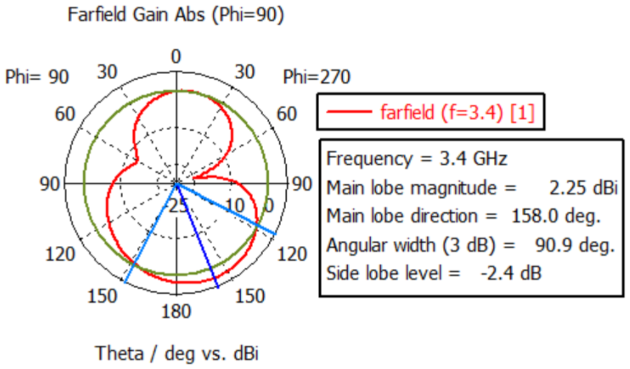

FIGURE 14. *Farfield plot of monopole antenna at 3GHz, the main lobe magnitude represents the gain*.

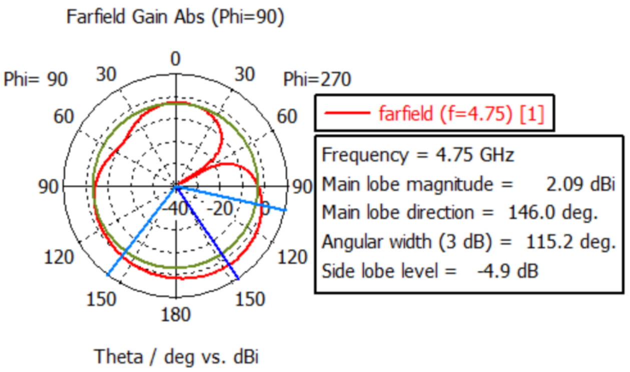

FIGURE 15. *Farfield plot of monopole antenna at 4.75GHz, the main lobe magnitude represents the gain*.

VII. CONCLUSION

A monopole array antenna has been proposed, designed, simulated and verified. The antenna design is based on the equations proposed and they are simulated using the CST-simulator. These design equations have been verified through a detailed parametric study and the antenna performance has been investigated and optimized. Low VSWR, adequate maximum gain and bandwidth have been achieved. The simulation results obtained through CST showcase the efficiency of monopole antenna design at 3GHz and 5GHz frequencies. With achieved VSWR, S11 and gain values will within desirable ranges, the antenna demonstrates robust performance characteristics essential for modern communication systems. These findings underscore the effectiveness of CST simulation in optimizing antenna parameters for enhanced signal transmission and reception. Moreover, the achieved directivity values highlight the antenna's ability to focus and amplify signals in specific directions, further enhancing its utility across various applications.

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