Design and Analysis of Microstrip Patch Antenna for Wireless Communication Devices

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***Abstract*—Due to their low profile and small size, microstrip patch antennas (MPAs) are widely used in modern communication devices. Research has shown that the primary goal of MPA design is to create compact microstrip antennas. A printed monopole antenna can be used in wireless communication devices across various operating frequency ranges. In this rapidly evolving world of wireless communication, dual or multiband antennas are playing a crucial role in meeting the demands of wireless services. An antenna transmits and receives information, making it an essential component of microwave communication. This research paper discusses various feeding techniques applicable to microstrip patch antennas, which are a critical aspect of their design. Achieving good impedance matching between the line and the patch without any additional matching components heavily depends on the feeding technique used. After discussing different feeding techniques, this paper provides a better understanding of the design parameters of an antenna and their impact on bandwidth and gain.**

***Index Terms*—Microstrip patch antenna, operating frequency, feeding techniques.**

I. INTRODUCTION

Generally, microwave imaging systems for detecting cancerous tissue are constructed with a circular cylindrical array of antennas. Microwave imaging systems require small antennas with omnidirectional radiation patterns and high data capacity. Therefore, in microwave imaging systems, one of the main challenges across the entire operating band is designing a compact antenna that provides wideband characteristics. It is well known that the physical characteristics of compact monopole antennas, such as simple structure, small size, and low cost, are highly attractive [2-4]. As a result, several planar monopoles with different geometries have been developed through automated design techniques and experimentation to achieve an optimal compact form [5]. With the development of broadband wireless communication systems, ultra-wideband (UWB) systems are rapidly growing. The Federal Communications Commission has allocated the 3.1~10.6 GHz frequency band for UWB services. These UWB systems have been used for radiolocation applications, localization, data communication, etc. The antennas of UWB systems are embedded in these transmission devices, and home networking systems are widely used in transmission devices such as HDTVs, DVDs, cameras, and personal computers through UWB service channels [6].

The most commonly used microstrip patch antenna is a rectangular patch. A rectangular patch antenna is essentially a section of a rectangular microstrip transmission line approximately one wavelength long. The antenna is loaded with a dielectric as its substrate; the length of the antenna decreases as the relative dielectric constant of the substrate increases. When air is the substrate of the antenna, the length of the rectangular microstrip antenna is approximately half the free-space wavelength. A suitably small antenna will improve transmission and reception. Microstrip resonators can be divided into two categories based on the length and width of the antenna. Resonators with thin conductors are called microstrip dipoles, and those with wide conductors are called microstrip patches. Resonance occurs when the dimensions of the dipole or patch are equal to half the guided wavelength. Their radiation patterns and gain are similar due to the similar longitudinal current distribution, although other characteristics (such as input electrical properties and polarization) may differ. When the signal frequency is in the resonance region, a microstrip resonator radiates a relatively broad beam perpendicular to the plane of the substrate. A large portion of the signal participates in radiation, and therefore the resonator acts as an antenna. Since the size of the patch must be comparable to the radio-controlled wavelength, its directivity is quite low; for example, the gain of a half-wavelength dipole is typically around 5-6 dB, and the beamwidth is between 70 and 80 degrees. The design of a microstrip antenna begins with determining the size of the patch used for the antenna. Due to fringing fields at the radiating edges of the antenna, there is a line extension associated with the patch.

II. LITERATURE SURVEY

Microstrip patch antennas offer several advantages, such as small size, light weight, ease of fabrication, and easy integration with the mounting host. Additionally, size reduction and bandwidth enhancement are major design considerations for practical applications of microstrip antennas. To reduce computational complexity when designing microstrip patch antennas, various researchers have developed several numerical methods [1], including MoM-based methods. The MoM method uses Sommerfeld-type integrals to solve the Green's function of the dielectric slab. A comparison of different feeding techniques is presented. Finally, a microstrip patch antenna was designed at a specific frequency of 1.25 GHz, and simulations were performed using IE3D design software to gain a better understanding of the antenna design parameters and their effect on the bandwidth and gain patterns. The input data for the ANN model was generated from the IE3D simulation software. The input data includes the variation of the antenna reflection coefficient S(1, 1) and antenna impedance Z(1, 1) with various antenna parameters such as patch length and width, dielectric height, patch offset in X and Y directions, probe radius, slot length, stub length, probe center, patch center, etc., for S-band aperture coupled microstrip antennas and L-band capacitively coupled microstrip antennas. This dataset was used to train and validate the ANN model.

This technological trend has focused on the design of microstrip antennas with simple geometries. Patch antennas offer many advantages that are not typically found in other types of antenna configurations. Microstrip antennas can be easily and inexpensively fabricated using printed circuit board technology. They are extremely compact and lightweight [2-4]. These are compatible with microwave and millimeter-wave integrated circuits and have the ability to conform to both flat and non-flat surfaces. Furthermore, once the patch shape and operating mode are selected, the designs become highly versatile in terms of operating frequency, polarization pattern, and impedance. The low efficiency, high Q value, poor polarization purity, poor scanning performance, unwanted feed radiation, and extremely narrow frequency bandwidth of a microstrip patch antenna have reduced its versatility. However, in some applications where a narrow bandwidth is desirable, such as in government security systems, microstrip patch antennas are indispensable [5]. However, it is possible to achieve a larger bandwidth (up to 90 percent) and improved efficiency (up to approximately 35 percent) for the desired microstrip antenna by increasing the thickness of the dielectric material [6]. But when the height of the dielectric material increases, some energy is lost due to surface waves [7]-[8]. However, several methods, including the cavity method and stacking method, are used to reduce surface waves and the resulting energy loss, while simultaneously maintaining a larger bandwidth and improved efficiency [9]. Additionally, the ability of a rectangular microstrip patch antenna to exhibit both linear and circular polarization has increased its versatility. Before the revolution in electronic circuit miniaturization and large-scale integration in wireless communication (i.e., before 1970), microstrip antennas (MSAs) with conductive patches on a ground substrate were underdeveloped. Since then, many researchers have investigated the radiation emitted from the radiating patch of microstrip antennas of various configurations. Munson's early work focused on a low-profile flush-mounted microstrip antenna for practical applications in rockets and missiles. Due to the increasing demands in communication systems, it has become possible to achieve multiband frequency mode operation using multilayer structures. Various mathematical models have also been developed to enhance the performance of these antennas. The research papers and articles published in journals over the past decade on these antennas highlight their growing importance. It is currently one of the preferred methods for microstrip antenna design among antenna designers [10-12].

A wider bandwidth antenna has been achieved, which is 2.5 times greater than a typical edge-fed patch antenna. Furthermore, it has been possible to fabricate an antenna with smaller physical dimensions compared to previous studies, yet with higher output. Chiba et al. presented a dual-frequency planar antenna for handsets. The authors described a dual-band antenna with an outer quarter-wavelength annular ring with a short-circuit plane for the lower resonance frequency and an inner quarter-wavelength rectangular patch for the higher frequency response [13]. In this paper, the authors achieved a 36% impedance bandwidth and an average gain of approximately 7 dBi using an attractive L-shaped probe feed for a thick microstrip antenna. Here, due to the design of the broadband slot patch antenna on a microwave substrate, the thickness of the antenna was increased by using foam material. However, the measured resonance frequency and far-field pattern are significantly better than previously measured data, and the desired antenna gain is approximately 6.5 dB. The authors used a U-slot circular patch antenna with L-probe feeding, and also utilized a foam substrate as described by Guo et al. This resulted in a wider bandwidth, which is approximately 15% greater than using only the U-slot and approximately 14% greater than using only the L-probe [14-15].

III. APERTURE COUPLED FEED

In a basic aperture-coupled patch antenna, the radiating microstrip patch element is etched on top of the antenna substrate, and the microstrip feed line is etched on the bottom of the feed substrate. Consequently, the thickness and dielectric constant of these two substrates can be independently selected to optimize the separate electrical functions of radiation and circuitry. Although the original prototype antenna used a circular coupling aperture, it was soon realized that using a rectangular slot would improve coupling for a given aperture area due to its enhanced magnetic polarization capabilities. The aperture-coupled microstrip antenna involves more than a dozen component and dimensional parameters, and we briefly summarize the fundamental trends associated with variations in these parameters below: antenna substrate dielectric constant, antenna substrate thickness, microstrip patch length, microstrip patch width, feed substrate dielectric constant, feed substrate thickness, slot length, slot width, feed line width, feed line position relative to the slot, and patch position relative to the slot. In this technique, a ground plane separates the radiating patch and the microstrip feed line. Coupling between the patch and the feed line is achieved through a slot or aperture in the ground plane (typically located centrally beneath the patch), thereby minimizing unwanted radiation.

IV. STUDY OF ANTENNA DESIGNING PARAMETERS

There are three essential parameters for designing a rectangular microstrip patch antenna. First, the resonant frequency (f0) of the antenna must be chosen correctly. For ultra-wideband applications, the frequency range is 3.1 to 10.6 GHz, and the designed antenna should be able to operate within this frequency range. The second important parameter of the antenna is the thickness of the substrate. For this reason, the height of the dielectric substrate used in this antenna design is h = 1.6 mm. The third important parameter for a good antenna design is the dielectric constant (εr) of the dielectric substrate. A thicker dielectric substrate with a low dielectric constant is preferable. This provides better efficiency, wider bandwidth, and improved radiation. A lower value of the dielectric constant increases the fringing fields at the edge of the patch, leading to increased radiated power and a lower quality factor Q. FR-4 epoxy, which has a dielectric constant of 4.4 and a loss tangent of 0.02, can be used for the new antenna design. The patch will be fed by a microstrip transmission line. The patch acts as a conductor. This antenna structure has a length L, width W, dielectric substrate height h, and loss tangent. The dielectric constant of the substrate material is a crucial design parameter. These are placed on an infinite ground plane. The length is formed around Lg/2 where the patch begins to radiate, typically involving a 50Ω impedance. The antenna is typically fed at the separated ends of width W because this provides the proper polarization, but its disadvantages include spurious radiation and the need for electrical impedance matching, which is due to the typical terminal resistance range of 1500 to 300 ohms for microstrip antennas.

V. FEED LOCATION DESIGN

For radiation from the antenna, a feed is used to excite it through direct or indirect contact. Microstrip antennas can have several feed configurations, such as microstrip line, coaxial, aperture coupling, and proximity coupling. However, microstrip line and coaxial feeds are more commonly used because they are easier to fabricate. The coaxial probe feed is preferred because it is easy to implement, and the input impedance of a coaxial cable is typically 50 ohms. There are several points on the patch where the impedance is 50 ohms. We need to find these points and match them to the input impedance. The feed point is chosen such that it covers the maximum possible area of the radiating patch at that point.

VI. PROPOSED MODEL

Figure 1 shows the structure of the printed patch antenna and the fabricated antenna. The antenna substrate is placed between two copper metallic layers. The dimensions of the proposed antenna are given. The parametric dimensions of the slot and the ground plane have been varied equally in both the X and Y directions. As shown in the figure, a simple rectangular slot is placed on the ground plane. The slot placed on the ground plane is confined within a distance of 6 mm from its top edge and 3 mm from its left edge. The feed point is located at a distance of 2 mm from the bottom edge and 3 mm from the left edge of the patch.

VII. FABRICATION ADVANTAGES

CST software is used for the simulation of electromagnetic fields across the entire electromagnetic spectrum. All the microstrip patch antennas of varying sizes mentioned above are fabricated on a dielectric substrate material using conventional milling techniques with the help of a machine. A computer numerical control unit helps minimize errors during antenna fabrication. CST is based on the Finite Integration Technique (FIT) and is quite popular among antenna designers due to its ease of use in simulations. CST Studio Suite is a high-performance 3D EM analysis software package for designing, analyzing, and optimizing electromagnetic (EM) components and systems. CST Studio Suite includes electromagnetic field solvers for various applications across the EM spectrum within a single user interface.

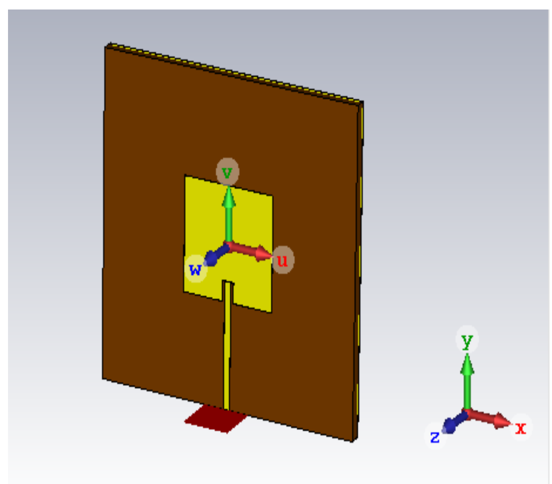

Figure 1. Geometry of microstrip patch antenna with strip

VIII. RESULTS AND DISCUSSION

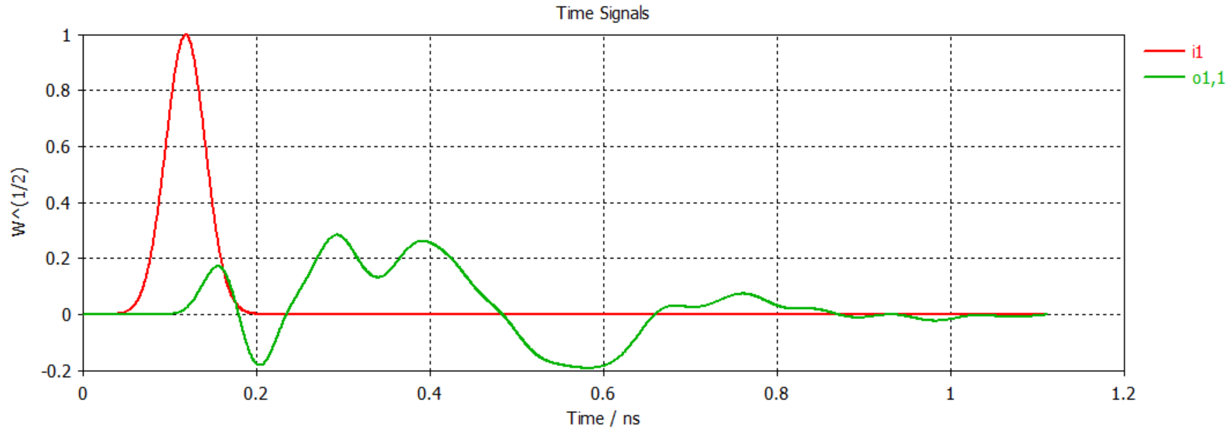

Figure 2. Time Signals

The first parameter, S_11, is also called the reflection coefficient. In fact, the most common parameter related to antennas is S11. S11 indicates the amount of power reflected from the antenna and is therefore known as the reflection coefficient (sometimes written as gamma: or return loss). If S11 = 0 dB, then all the power is reflected back towards the antenna. Power is transmitted, reflected, but nothing is radiated.)

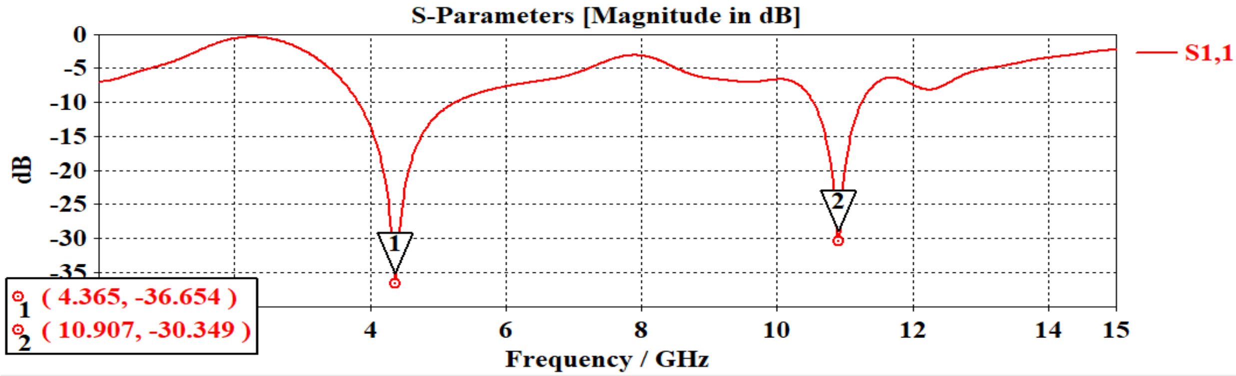

Figure 3. S-factor (S-parameters are a way of characterizing a device using traveling waveforms instead of voltage and current. They tell us how much of a wave is reflected from or transmitted through a device. In the case of a device like an antenna, there isn't just one S-parameter, but four S-parameters.

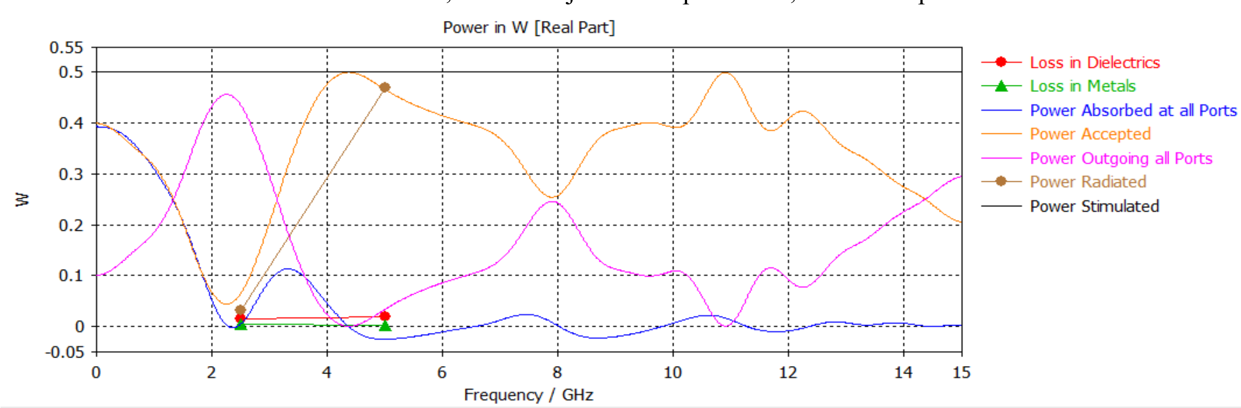

Figure 4. Power (W) (The energy radiated per unit area is obtained by multiplying Planck's energy density by c/4. Its numerical value can be estimated by multiplying the sum of the values of Planck's radiation intensity by the wavelength period. The region where the interaction of the electromagnetic field begins to transform into radiation is called the radiating near-field region or Fresnel zone.)

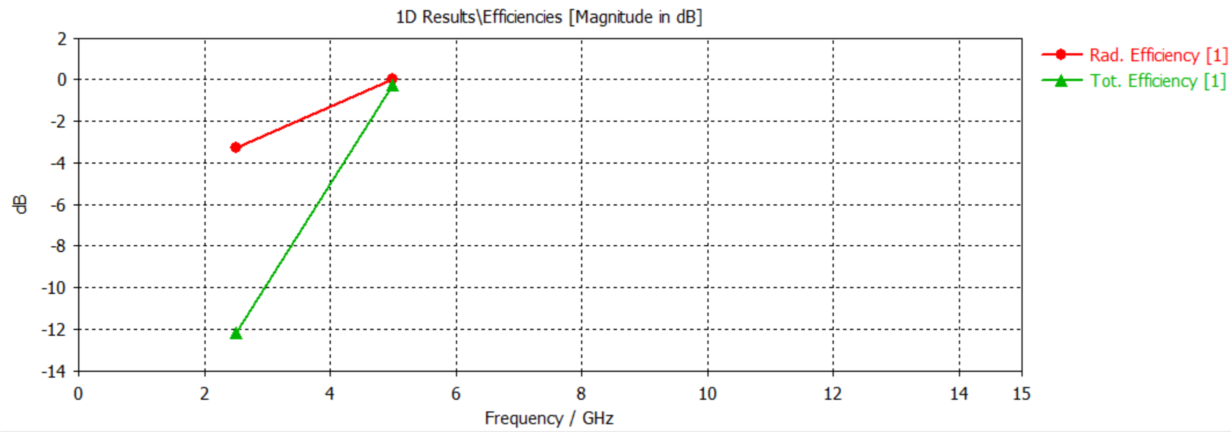

Figure 5. Efficiencies (Antenna efficiency is a parameter that takes into account the amount of losses occurring at the antenna terminals and within the antenna structure.)

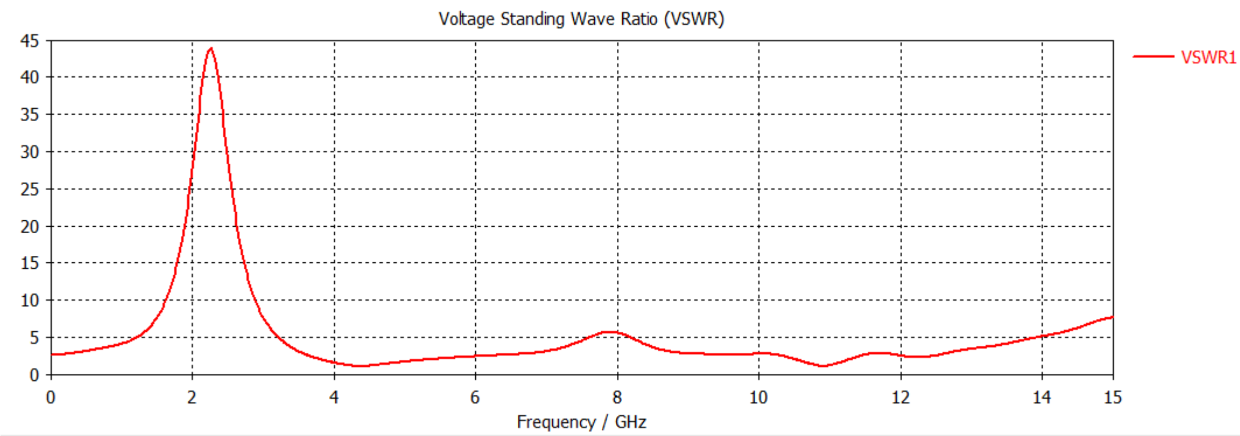

Figure 6. VSWR (Voltage Standing Wave Ratio is essentially a measure of the impedance mismatch between the transmitter and the antenna. The higher the VSWR, the greater the mismatch.)

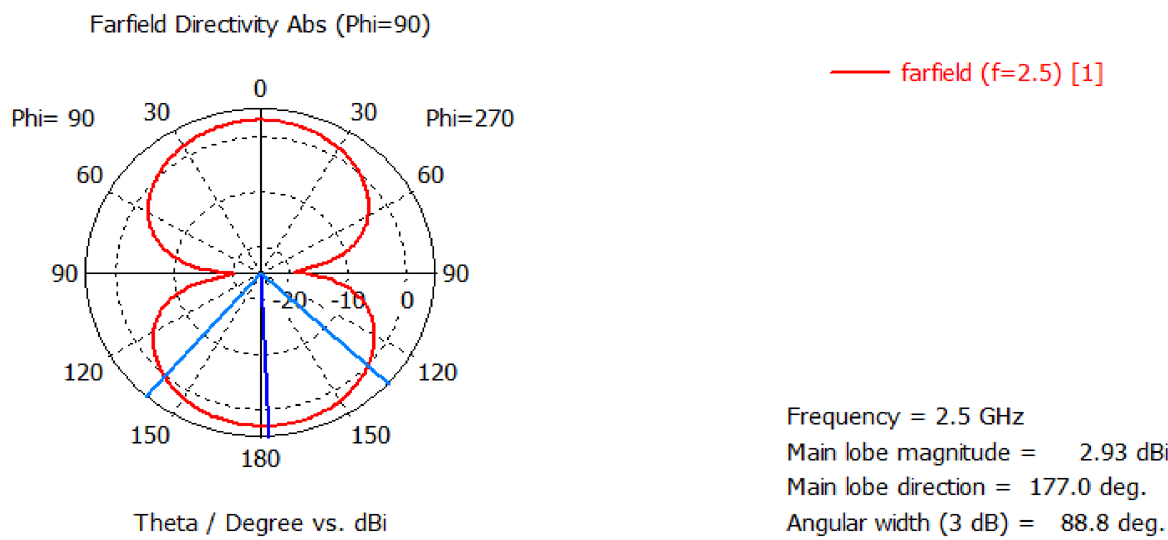

Figure 7. Farfields, one band (Based on the analysis of a transmission line model, a simple formula has been developed that describes the far-field radiation emanating from a rectangular microstrip patch. The electric current and polarization distributions are derived using the volume equivalence theorem. Specifically, analytical formulas are presented to describe the radiation pattern in the E-plane and the worst-case cross-polarization level.)

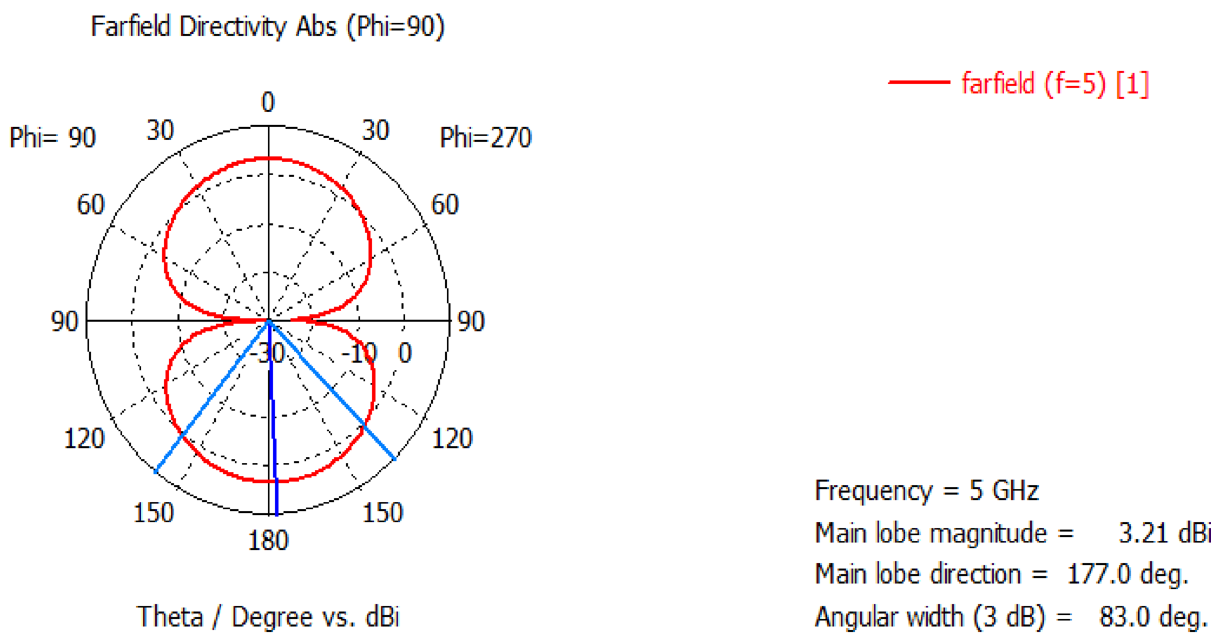

Figure 8. Far fields, other band

IX. CONCLUSIONS

In this research paper, we primarily focused on the design and simulation of a single-band rectangular microstrip patch antenna and extended it to a dual-band rectangular microstrip patch antenna. We studied various parameters such as return loss, impedance, VSWR, directivity, gain, bandwidth, and operating frequency, and also investigated the effect of physical parameters on the performance of the designed antenna. In our paper, we first consider the design and simulation of a single-band narrow-band rectangular patch antenna and then extend it to a dual-band narrow-band rectangular patch antenna. Here, we studied various parameters such as return loss, impedance, voltage standing wave ratio, directivity, gain, bandwidth, and operating frequency, and also investigated the effect of physical parameters on the performance of the designed antenna. The results obtained from the simulation show that it is a good option for wireless communication systems. In the future, it can be fabricated to compare the simulation results with practical results. From the simulation, the return loss, gain, radiation efficiency, and S-factor show a return loss of -36.654 dB and -30.349 dB.

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