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Original Article

Design and Analysis of an Omnidirectional Multi-Range Circularly Polarized Printed Patch Antenna

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Abstract *- In nowadays communications, the reliability of the entire communication system is directly related to the performance of the antenna involved in such systems. The aim of this paper is to design a novel compact printed patch antenna capable of providing omnidirectional radiation patterns and resonating at multiple specific frequency bands with a high level of radiation efficiency and lower cost. On top of that, for better performance, especially in bad weather conditions, the proposed antenna would provide circular polarization and omnidirectionality of the radiation pattern by simply inserting short-circuited conducting wires known as "vias" within the dielectric substrate of the patch. Based on CST software simulations, properly selecting the number, dimensions, and locations of the vias within the substrate has led to significantly competent electrical parameters of the designed antenna.*

Keywords *- Frequency bands, Radiation efficiency, Circular polarization, Antennas, Vias.*

1. Introduction

The world of communication systems has witnessed tremendous advancement in wireless technology, becoming one of the main research areas. The effectiveness of wireless communication systems is directly proportional to the antenna's performance in such systems. Therefore, it is crucial for the antenna to possess specific electrical and mechanical properties that satisfy the conditions set by the entire communication network. This paper aims to highlight the importance of antennas in wireless communication technology and the specific properties that make them effective in ensuring reliable communication.

Circularly Polarized (CP) antennas have gained widespread popularity due to their ability to combat multipath distortion and polarization mismatch losses. However, omnidirectional radiation patterns are also in high demand because they provide a larger signal coverage area and stabilize signal transmission. In recent years, various omnidirectional CP antennas have been proposed and investigated [1,2].

In this project, our aim is to develop a compact antenna element that meets the requirements and is compatible with existing antennas on the market. Our research aims to contribute to the advancement of wireless communication technology by proposing an efficient and effective antenna.

Theoretically, it is evident that the fundamental principle of achieving circular polarization is to have two electrical fields that are orthogonal to each other. These fields should have the same amplitude but differ in phase by 90 degrees. Using this principle, the resulting electromagnetic wave will have a rotating electric field, thus producing circular polarization. This principle is essential in designing and developing circularly polarized antennas, which have gained widespread popularity in modern wireless communication systems.

2. Problem Statement

It has been clear that the development of circularly polarized omnidirectional antennas gained significant attention vs linearly polarized ones. The reason for this is because such antennas offer several advantages, including larger signal coverage and the ability to alleviate multipath distortion and polarization mismatch losses between the receiving and transmitting antennas. The modern communication network requires the exchange of voice, data, and multimedia information, which necessitates the use of multiband within the same network. Therefore, circularly polarized omnidirectional antennas have become an essential component in modern wireless communication systems, and their design and development are crucial in achieving reliable and efficient communication.

The aim of this paper is to seek a compact printed antenna that can effectively cover useful multiband frequencies while providing circular polarization at the desired bands. This is crucial in ensuring that the antenna is immune to noise caused by various obstacles or weather conditions, whether it is used indoors or outdoors. Developing such an antenna is essential for achieving reliable and efficient communication in modern wireless communication systems. We aim to contribute to advancing wireless technology by designing and developing an antenna that meets these requirements.

3. Paper Methodology

This paper presents a design procedure for circular microstrip antennas based on the cavity model formulation. The procedure provides practical designs for the dominant mode [4]. To initiate the process, some specific information is required, such as the dielectric constant of the substrate (εr), the resonant frequency (fr), and the height of the substrate h. The procedure is outlined below, with each step elaborated in detail. The procedure is as follows:

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \epsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}} \quad (1)$$

$$F = \frac{8.791 \times 10^9}{f_r\sqrt{\epsilon_r}} \quad (2)$$

Where:
a - is the actual radius (cm).
f_r - is the resonant frequency (GHz).
h - is the height of the substrate (cm).
ε_r - is the dielectric constant of the substrate.

The dielectric material used for the reference Microstrip patch antenna is FR4 with a dielectric constant of 4.35, and the patch is made up of a perfect electric conductor (PEC).

So, by using (1) and (2), a conventional circular patch antenna is designed at the operating frequency 2.4GHz, with a patch radius of 1.70695 cm, as shown below (See Fig.1).

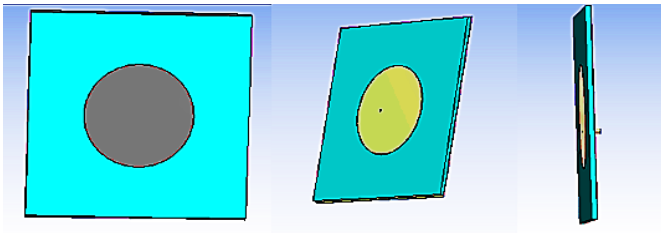


Fig. 1 Circular patch operating at 2.4 GHz

The S11 and Axial Ratio characteristics of the conventional patch antenna show that they are narrowband and are linearly polarized, as shown in Fig.2 and Fig.3. On top of that, the conventional designed patch antenna is radiating unidirectionally as shown below (See Fig.4).

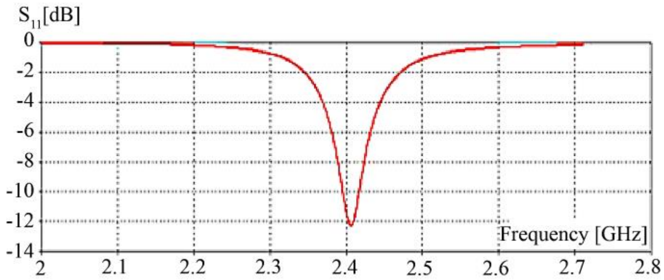


Fig. 2 Reflection loss vs frequency (Reference)

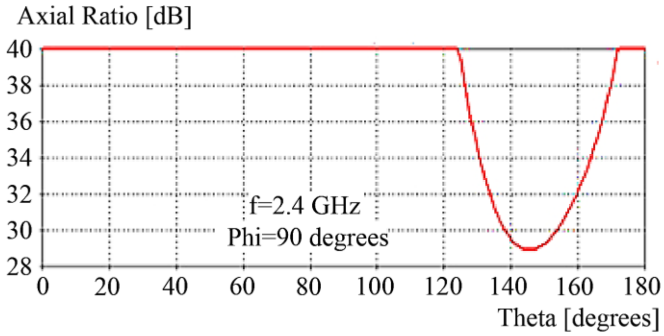


Fig. 3 Axial ratio at f = 2.4GHz (Reference)

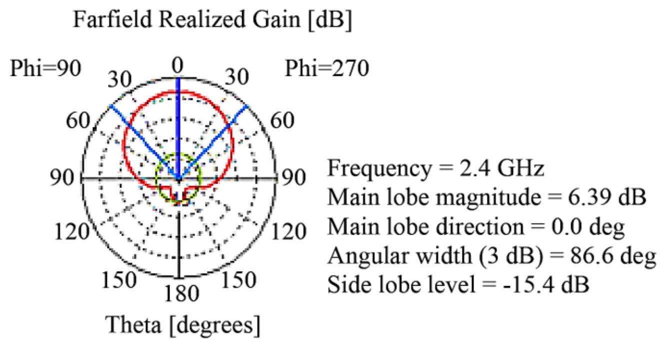


Fig. 4 Radiation pattern at f = 2.4GHz (Reference)

After conducting simulations on conventional patch antennas, it has become evident that their electrical characteristics are not competitive enough for modern communication systems. As a result, a new strategy in this paper to enhance the performance of circular loop antennas is proposed. The primary goal is to increase the bandwidth, improve radiation efficiency, and provide a circularly polarized mode of operation. These improvements are crucial in enhancing the antenna's immunity to various forms of noise, which are common in wireless communication systems. This strategy will hopefully lead to the developing of more efficient and reliable antennas suitable for modern communication systems.

This strategy is divided into three main steps:

- *Step1*- Providing circular polarization.
- *Step2*- Providing omnidirectional radiation pattern.
- *Step3*- Enhancing the bandwidth characteristics of the designed antenna.

4. Simulation Results

4.1. Obtaining Circular Polarization

In this paper, a step-by-step approach to enhance the axial ratio of an antenna is proposed. The first step involves working with an elliptical configuration of the patch. By carefully modifying the ratio between the major and minor axis of the elliptical patch, one can vary the axial ratio in a suitable manner. This variation will continue until acceptable values are achieved below the (3-5) dB threshold [6] at the desired frequency under consideration. This approach is also expected to lead to the development of more efficient and reliable antennas suitable for modern wireless communication systems.

Through a series of simulations, it has been discovered that optimizing the patch radius along the x and y-axes of an antenna and rotating the patch 45 degrees with respect to the x-axis yields the most desirable axial ratio values at the desired operating frequency. Specifically, these simulations have shown that setting the patch radius along the major x-axis to 33.8 mm and the radius along the minor y-axis to 33.05 mm, with a major/minor ratio of 1.02269289, results in optimal axial ratio values. Results shown in Figures 5, 6, and 7 demonstrate the effectiveness of the proposed approach and its potential for enhancing the performance of antennas in modern wireless communication systems.

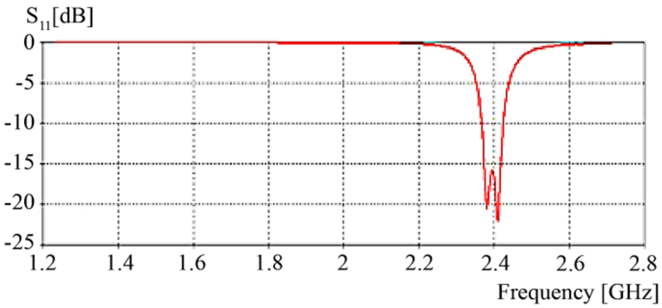


Fig. 5 Reflection loss vs frequency (Enhanced)

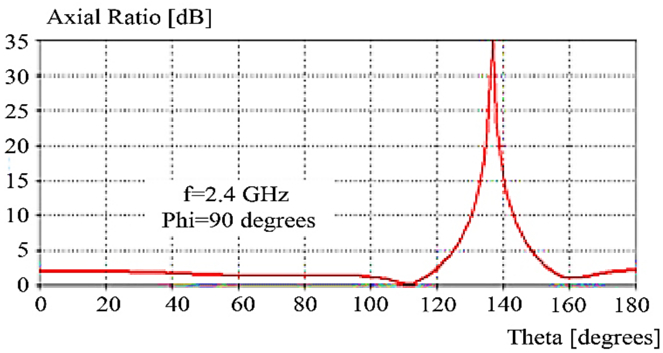


Fig. 6 Axial ratio at f = 2.4GHz (Enhanced)

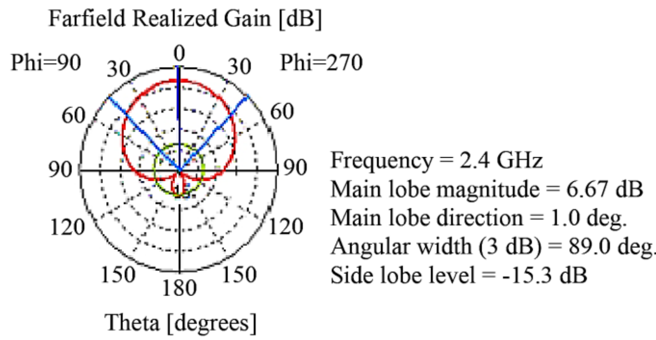


Fig. 7 Radiation pattern at f = 2.4GHz (Enhanced)

So, one can conclude that at f = 2.4 GHz, S11 is equal to -16 dB, and the axial ratio is 1.5 dB at an angle theta = 90˚, which means that the elliptical patch is now operating with a good enough level of circular polarization at the desired resonant frequency.

4.2. Obtaining Omnidirectional Radiation Pattern

The second step of our approach aims to modify the antenna's radiation pattern from unidirectional to omnidirectional without compromising other electrical properties such as S11 and Axial Ratio (AR). As shown in Fig. 4 and Fig.7, the antenna's radiation pattern is unidirectional, which is unsuitable for modern communication systems. Thus, a simple technique to achieve omni-directionality while maintaining good directivity and gain has been suggested. By applying this technique, the antenna's radiation pattern can be modified without affecting its other electrical properties. This approach will surely lead to better directional properties of the designed antenna, which consequently improves the reliability of modern wireless communication systems.

Several techniques can be used to achieve omnidirectional radiation patterns with circular polarization in patch antennas. One such technique involves wrapping an array of three or more Microstrip patch radiators around a small cylinder. Another approach is to use a linearly polarized antenna surrounded by a complex polarizer [6]. In addition, there are two planar omnidirectional circular polarization antennas that have been reported. The first antenna employs the zeroth-order resonance of an epsilon negative transmission line. In contrast, the second uses two back-to-back coupled truncated-corner patches fed by an orthogonal coplanar waveguide [8,10]. These techniques have successfully enhanced the performance of patch antennas, making them suitable for modern wireless communication systems.

One of the simplest techniques used for this purpose involves adding conductive vias within the dielectric substrate medium, as demonstrated in [6]. These vias consist of thin conductive wires connecting the ground plane on one side to the patch on the other side, as depicted in Figure 8. This simple approach has been shown to provide significant improvements in antenna performance, such as enhancing the bandwidth and gain while reducing return loss. This technique has the potential to revolutionize the design of patch antennas, making them more competitive in the wireless market.

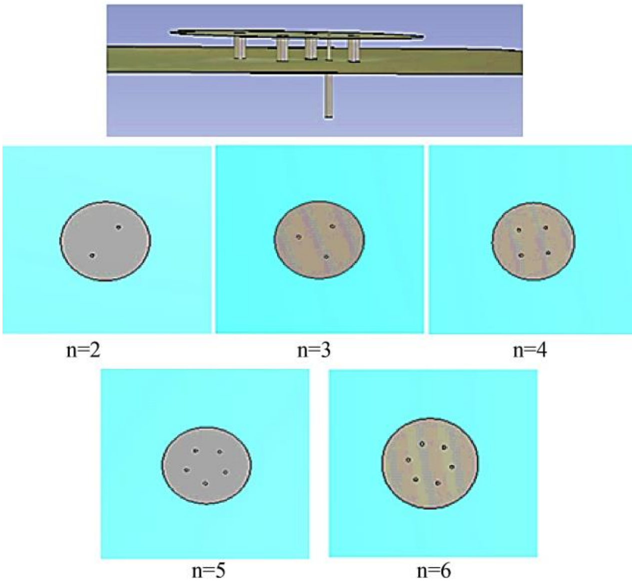


Fig. 8 Patch antenna with vias (Top and Side View)

Adding "n" conducting elements to the antenna affects the electromagnetic wave configuration within the dielectric substrate, like adding reactive elements such as L and C. As a result, the overall impedance of the patch antenna is affected. However, by selecting the appropriate number of vias, their radius, location, and orientation, one can obtain the desired results in terms of omnidirectionality and good impedance matching while maintaining good radiation efficiency. This technique has shown great potential in enhancing the performance of patch antennas.

Given the many degrees of freedom in terms of variables that can be adjusted, an optimization simulation process is essential in achieving the desired results. For instance, an optimization simulation process has been conducted to achieve an omnidirectional pattern with a good level of reflection loss at the operating frequency of f = 2.4 GHz. Through this process, we were able to identify the optimal values for the variables and achieve the desired performance in our patch antennas.

Through the manipulation of all the above-mentioned antenna variables, a desirable performance in terms of omnidirectionality, Axial Ratio Level, and Reflection Loss Level has been achieved. Specifically, adding four (n = 4) conductive vias with specific radii and locations within the dielectric substrate of the patch antenna, as depicted in Figures 9 and 10, would result in better impedance characteristics and acceptable values of AR and directivity.

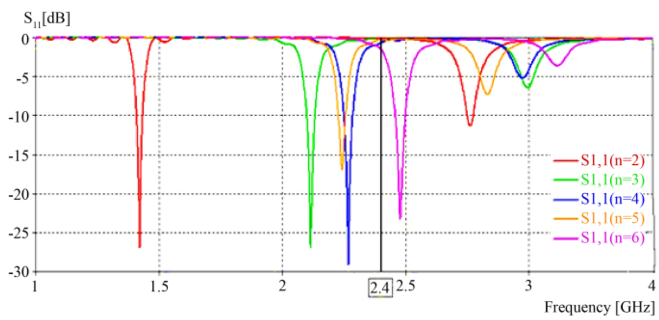


Fig. 9 Reflection loss vs frequency for various numbers of Vias "n"

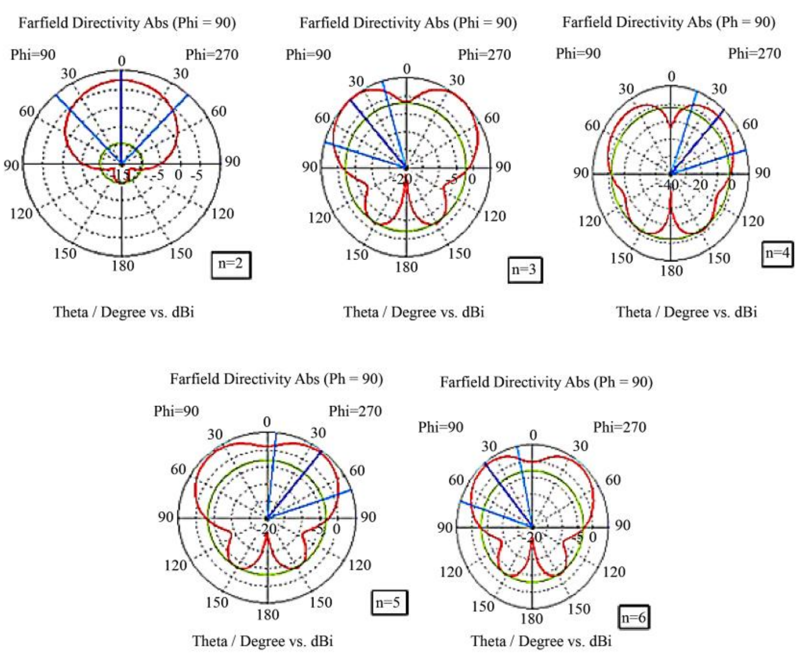


Fig. 10 Radiation pattern for various numbers of Vias "n"

As an additional step, and with a number of vias n = 4, some other parameters like radius and locations of vias with respect to the center point of the patch have been manipulated for more improvement in the S_{11} and radiation pattern. Large series of simulation results have led to providing acceptable performance that meets the stated objectives of this paper (See Fig. 11 and Fig.12).

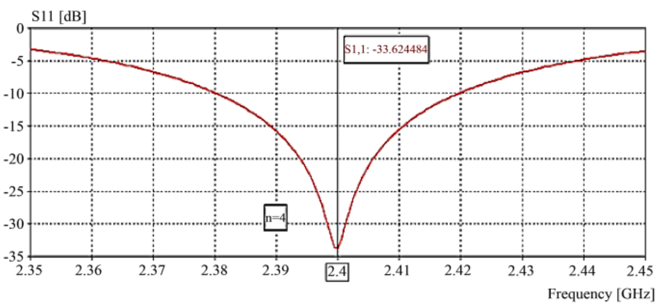


Fig. 11 Reflection loss for the optimum design

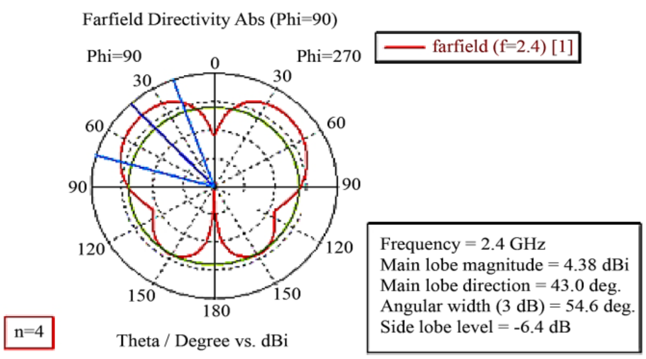
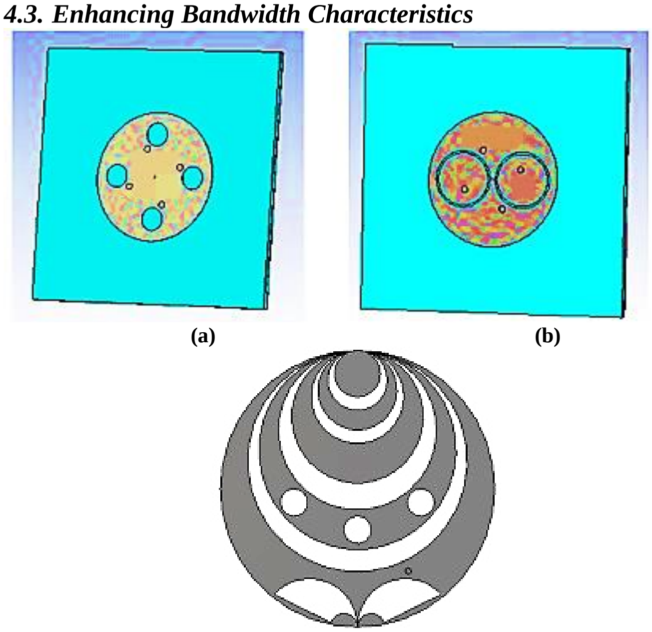


Fig. 12 Radiation Pattern for the optimum design

4.3. Enhancing Bandwidth Characteristics



(a) **(b)**

(c)

Fig. 13 Patch antenna with (a) circular slots, (b) Cylindrical ring slots, and (c) fractal slots

Among the many techniques available, one of the easiest and most cost-effective is cutting circular slots over the patch conducting surface. This technique creates a reactive load that generates extra resonances in the antenna. The size and shape of the slots within the patch conducting circular surface significantly influence the reflection loss, which in turn affects the bandwidth properties of the overall antenna system. Circular slots, cylindrical ring slots, and fractal slots inspired by the Smith Chart configuration are some of the highly suitable shapes for this approach. These slot geometries are covered extensively in [12,14] and are depicted in Figure 13. This technique can potentially revolutionize the design of patch antennas, making them more efficient and capable of resonating at multiple bands.

Fig.14, shown below, it is shown that when adding various forms and sizes of circular slots within the patch geometry would significantly impact the resonance properties of the designed antenna since adding such irregularities to the antenna is equivalent to adding reactive elements (L and C) which would impose additional resonances in the frequency band of interest. Simulation results have shown that new resonance frequencies have appeared in the S11 graph below by adding such slots.

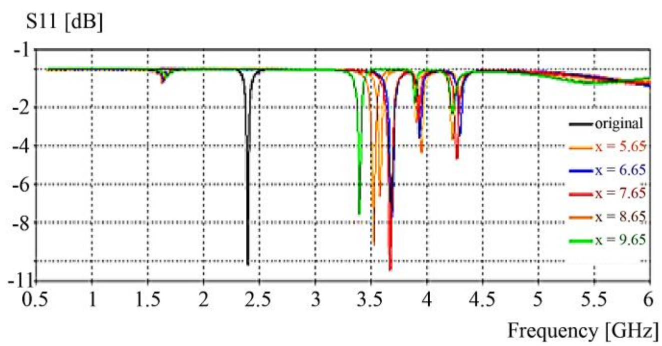


Fig. 14 Reflection Loss for different ring slots dimensions

It is obvious that by simply adjusting the radius of the slot (denoted as x), multiple resonances can appear in the reflection loss graph. This allows the antenna to operate at various frequencies. However, the optimization process of the bandwidth characteristics is left for future work. To optimize the bandwidth, several techniques can be adopted, such as adding different shapes and dimensions of slots within the patch geometry and modifying the substrate type and dimensions. These approaches have been employed on various types of printed patch antennas and have led to a significant improvement in their bandwidth characteristics [14,15].

5. Conclusion

In conclusion, the proposed study has resulted in the successful design of a compact and simple patch antenna capable of providing omnidirectional radiation with circular polarization at a predefined desired frequency. The designed antenna has achieved an average axial ratio of less than (3-5) dB and an efficiency ranging between 2 to 4 dB. While our study has yielded promising results, it is planned to extend this work in the future. Our goal is to develop an antenna that possesses the characteristics mentioned earlier at multiple frequencies or even within a certain large frequency band. The suggested extension of this study will have significant implications for the design of efficient patch antennas. It will inspire further research in this area and contribute to developing more sophisticated antenna designs that meet the needs of the wireless market.

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