DESIGN CONSIDERATIONS FOR A SIMPLE 5 GHz PATCH ANTENNA

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Abstract

Patch antennas have many advantages for different applications, such as their small size and compatibility with modern communication systems and devices. However, there is a lack of theoretical understanding of how the geometry of these antennas affects their performance. Previous studies have tried various shapes and sizes of the patches, ground planes and feed methods, but they often achieved good results at the cost of complexity and without clear explanations. This gap in knowledge is a common problem and needs to be addressed to improve the design and understanding of patch antennas. This article reveals the physical principles behind the optimal geometry tuning (VSWR 1.05) for a 5GHz patch antenna. It also shows how geometry tuning can enable other features, such as beam steering (Up to 25 degrees). It provides useful insights for tuning patch antennas that can help researchers and engineers in this field. Therefore, the simulation and analysis of a 5GHz antenna presented in this article is a significant contribution to the patch antenna design literature.

Key Words: 5GHz Antennas, Patch Antenna, optimal geometry tuning, Beam steering of Pach Antenna

1. Introduction

Antenna theory and design is a vast and dynamic field that encompasses various aspects of electromagnetic radiation, propagation, and reception. Among the different types of antennas, patch antennas are one of the most popular and widely used in modern wireless communication systems. Patch antennas are low-profile, planar structures that consist of a metallic patch over a grounded substrate [1]. They offer several advantages such as low cost, easy fabrication, conformability, and integration with microwave integrated circuits (MICs) and monolithic microwave integrated circuits (MMICs). However, they also suffer from some drawbacks such as narrow bandwidth, low efficiency, and limited gain. Therefore, many researchers have devoted their efforts to improve the performance of patch antennas by using various techniques such as modifying the patch shape, adding slots or parasitic elements, using metamaterials or frequency selective surfaces [2], [3].

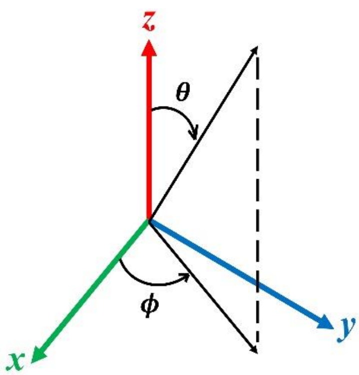
Recently, artificial intelligence (AI) and machine learning (ML) techniques have emerged as powerful tools for solving complex and challenging problems in various domains, including antenna design. ML techniques have been applied to antenna design for various purposes, such as optimization, synthesis, analysis, modeling, characterization, diagnosis, etc. However, most of these techniques have difficulty dealing with the geometry-complexity of the antenna, which makes it hard to connect the results with the theory. Although ML techniques overcame some issues regarding complexity and accuracy by adopting novel techniques [4], [5], [6], still the theoretical explanation for the antenna geometry and performance is missing.

This paper aims to explain the basic physics that make the main concepts, such as matching and maximum power transfer, easier to understand for designing the patch antenna. The paper also shows how this simplicity can lead to big advantages, such as radiation steering, and suggests some other potential benefits for future research. The paper is organized as follows: Section 2 describes the *methodology*, or the tool used in this study. Section 3 presents the simulation *results and discussion*. Section 4 *concludes* the paper and outlines some *future work*.

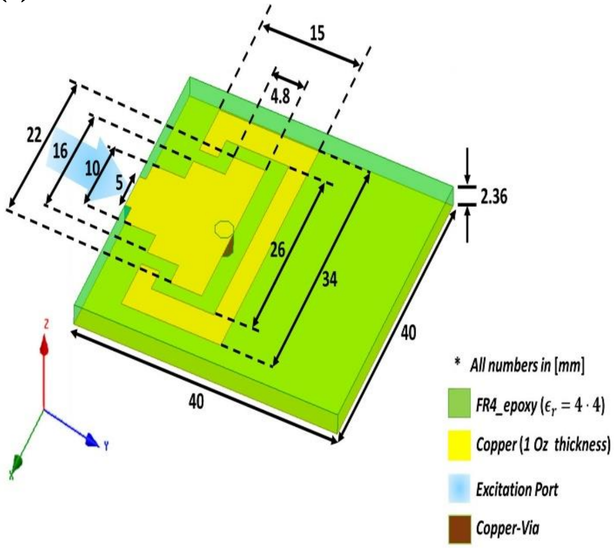
2. Methodology

Patch antennas are a type of microstrip antennas, which are composed of a metallic patch on a grounded substrate. The theoretical design of patch antennas can be based on mathematical equations that describe the microstrip lines. However, simulation techniques are more practical and convenient for antenna design. One can not enclose the design simulators into one software, several softwares are adopted to design such sort of antenna. For example, *Advanced Design System* (ADS) and *Applied Wave Research* (AWR) are both software packages that can be used for designing and simulating patch antennas and other microwave components [3], [7]. In this study, we use Ansys packages which is well known for wide range of engineering. Either Electrical, Mechanical, or Civil engineering, Ansys has capabilities to models, simulates, optimizes, and analyzes complex data and structures beside the validation with experimental results [8], [9]. Ansys HFSS, also known as Ansys Electronic desktop (EDT), is a software tool that can simulate high-frequency and high-speed electronic devices, such as antennas, filters, connectors, ICs, and PCBs in frequency ranges up to infrared [10], [11], [12], [13], [14], [15], [16]. It uses the finite element method (FEM), and it can also perform analysis, optimization, and tuning of the designs based on different parameters.

Ansys HFSS is good for antenna design because it can simulate the performance of antennas in various scenarios, such as free space, near or far fields, installed on platforms, or integrated with other components. Ansys HFSS employs a spherical coordinate system to analyze the near or far fields of the antenna, as shown in Fig. 1(a). The spherical grid has infinite points, each representing the direction of the radiated field from the center of the sphere. By using Ansys-HFSS, we can model the antenna as shown in figure 1(b) and simplify the design process without relying on mathematical equations. However, we still need to tune the matching of the antenna, to achieve maximum power transfer, according to the theory.



(a)

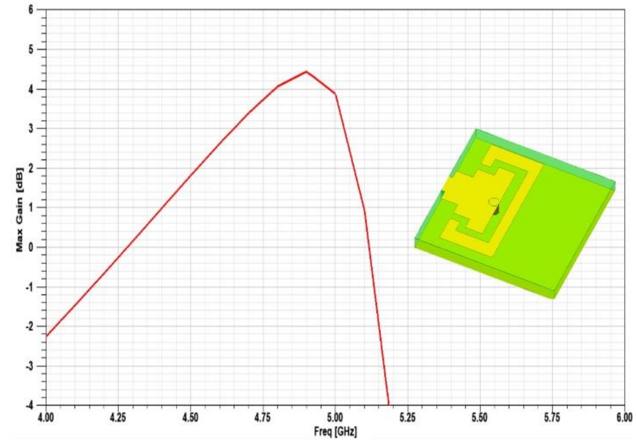


(b)

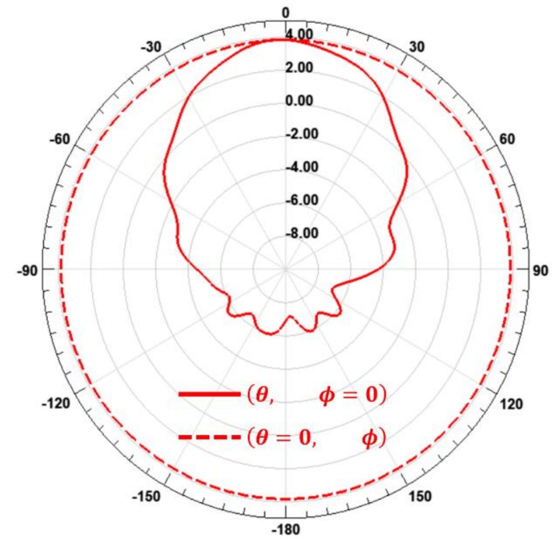
Figure 1; (a). HFSS coordinate System. (b). A simple design for 5GHz patch antenna.

3. Results and Discussion

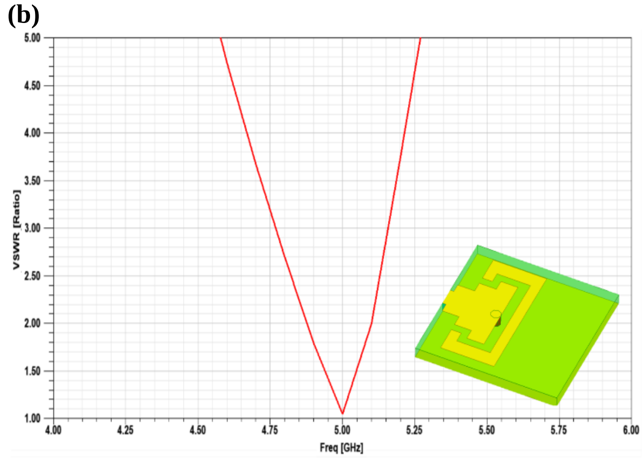
The following results in Fig. 2 are related to the model depicted in Fig. 1(b).



(a)



(b)



(c)

Figure 2; (a). Maximum Gain (regardless of orientation) as function of Frequency. (b). Elevational (solid-curve) and Azimuthal (dashed-curve) gain [in dB]. (c). Standing wave Ratio (SWR) Vs. Frequency.

The radiated part in the model includes a graded triangle surrounded by a squared open ring. Also, there is a ground plane (40mm X 40mm) and a via that connects the radiating part to the ground plane. The via plays a significant role in the tuning process by lowering the capacitance between the patch and the ground.

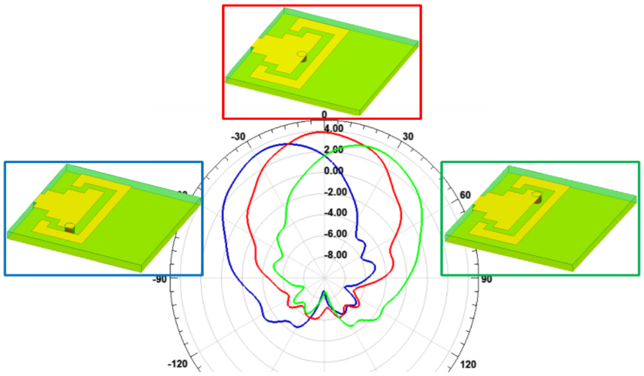


Figure 3. Effect of Via-position in steering the radiation pattern.

Furthermore, the position of the via can steer the radiation pattern as shown in Fig. 3 where the three different radiations are corresponding to the three different positions for the Via. The three cases are distinguished by colors accordingly. Therefore, it is important to investigate how much this effect is caused by the via.

The analysis of the antenna impedance shows that the Via is not the only factor that contributes to the good matching, as seen in the VSWR-result, Fig. 2(c). The rectangular ring around the grounded patch also has a dual function. This ring introduces a capacitive (C) impedance ($Z = -j1/(\omega C)\ \Omega$) due to the gap between the ring and the patch, and an inductive (L) impedance ($Z = j\omega L\ \Omega$) as a microstrip line where ($\omega = 2\pi * Frequency$). The following three Smith Chart results explain this concept of tuning based on the introduced reactance (capacitive or inductive) impedance.

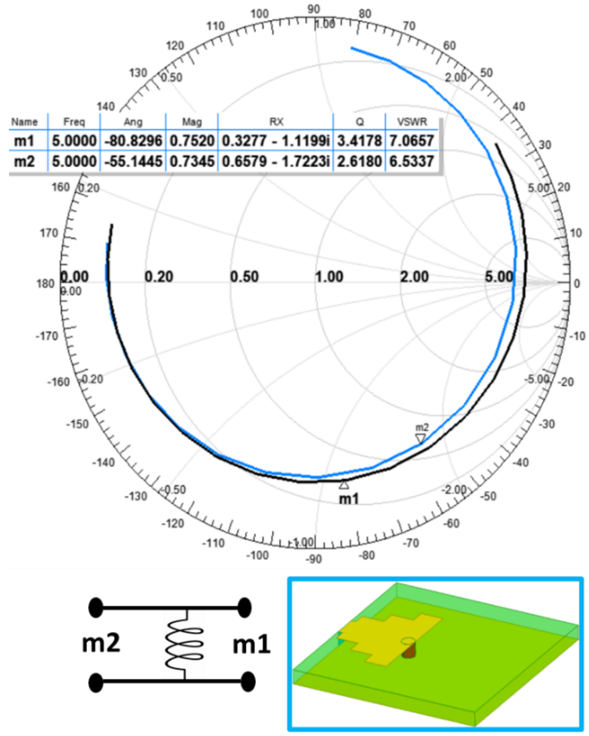


Figure 4. Smith chart for the patch only (black curve), and the patch with Via (blue curve). Tabulated results, equivalent lumped circuit, and the model are insets.

Fig. 4 shows the smith chart (or Z-chart) that illustrates how the Via affects the matching by reducing the capacitive touchscreen reactance between the radiating patch and the ground plane. This effect is similar to adding a shunt coil that shifts the antenna impedance (on Y-chart) from markers m1 to m2. The table in Fig. 4 also indicates a slight improvement in matching by lowering the VSWR from 7.0657 to 6.5337. The table also presents other data such as polar S11 values (Mag and Ang), normalised impedances (Rx), and quality factor (Q) within the smith chart.

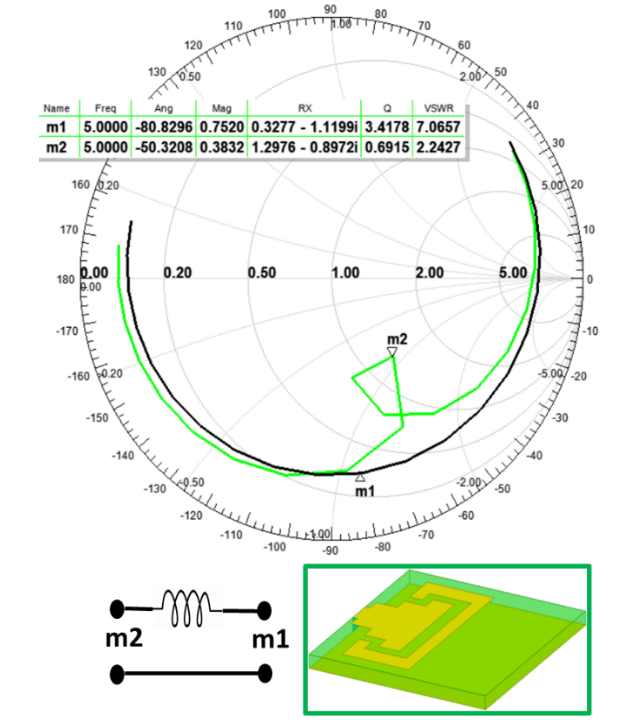


Figure 5. Smith chart for the patch only (black curve), and the patch with squared ring (green curve). Insets like the past figure are included.

Next, Fig. 5 demonstrates how a square ring influences the matching. The change in matching (from m1 to m2) is more significant than the previous one by the Via, as the VSWR is reduced by 68% as shown in Fig. 5.

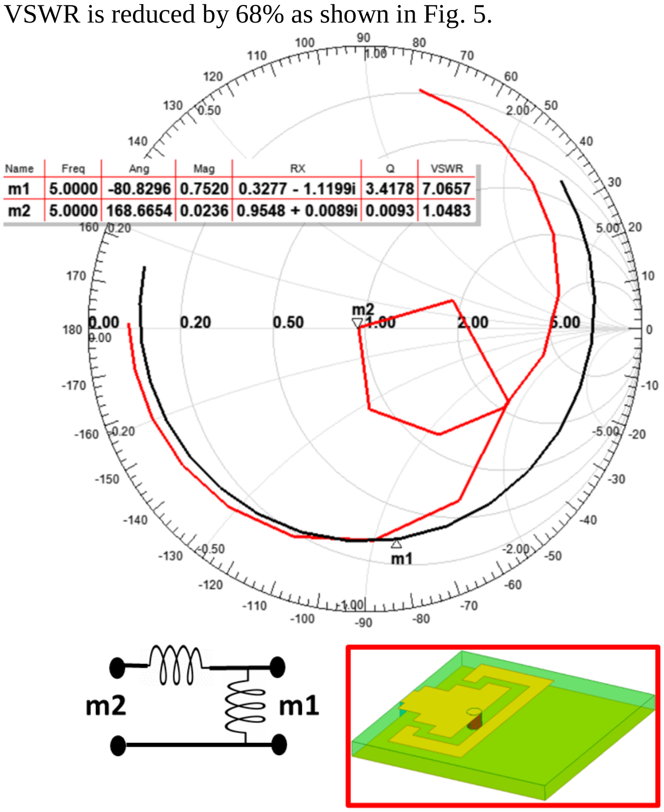


Figure 6. Smith chart for the patch only (black curve), and the patch with squared ring and Via (red curve).

Furthermore, the square ring introduces a small capacitive tuning due to the gap between the ring and the patch, which moves m2 slightly in a similar way to the effect in Fig. 4, and the large change in tuning is equivalent to a series inductive impedance as seen in the circuit diagram in Fig. 5. Finally, by combining the Via and the square ring with the radiating patch, an ideal matching can be achieved. Fig. 6 depicts this matching where the complex impedance is tuned from (16.4 – j56 Ω) to (47.7 + j0.45 Ω).

Finally, Presenting the matching on smith chart with VSWR instead of presenting the return loss, as several designing studies, is essential to understand matching process for any antenna design. The conventional antenna design studies show the return-, coupling-, or insertion-loss to define how good or bad the tuning is, but the smith chart is more informative in terms of matching.

4. Conclusion

Based on the presented results and discussion, it has been proved that simple concepts of tuning, like the projection of shunt and serial coils, are linked to design geometry. That is very helpful to understand the physical meaning for any geometry. However, the study did not include any complex antenna geometry because simplicity and defining the basics are the main goals. Also, the study highlights how other benefits like radiation steering can be gained along with such investigation of theory-model bridging.

For future suggested works, improve some of antenna features like its gain can be done by using array and tune the excitation of this array.

References

[1] Stutzman, Warren L., and Gary A. Thiele. Antenna theory and design. John Wiley & Sons, 2012.

[2] Nawaz, Muhammad Imran, Zhao Huiling, Muhammad Sabir Sultan Nawaz, Khalid Zakim, Shah Zamin, and Aurangzeb Khan. "A review on wideband microstrip patch antenna design techniques." In 2013 International Conference on Aerospace Science & Engineering (ICASE), pp. 1-8. IEEE, 2013.

[3] Esseid, Ali Giuma F. "A Novel Design of Broadband Antennas with a Defected Radiating Patch Structure for Wireless Communication Systems." PhD diss., Florida Institute of Technology, 2020.

[4] Hmouda, Eljilani. "A Validity-based Approach for Feature Selection in Systems." PhD diss., Nova Southeastern University, 2022.

[5] El Misilmani, Hilal M., and Tarek Naous. "Machine learning in antenna design: An overview on machine learning concept and algorithms." In 2019 International Conference on High Performance Computing & Simulation (HPCS), pp. 600-607. IEEE, 2019.

[6] Hmouda, Eljilani, and Wei Li. "Detection and prevention of attacks in MANETs by improving the EAACK protocol." In SoutheastCon 2018, pp. 1-7. IEEE, 2018.

[7] Almuzwghi, Ali Esseid, and Lail Brian. "Broad band microstrip patch antenna

based on foam-filled and one open slot on backward of radiating layer." Journal of Computer and Communications 7, no. 6 (2019): 15-28.

[8] Eissa, Taleb Eissa Ali. "Effect of Industry Clusters and Commodity Flow Characteristics on the Selection of Freight Transportation Modes in the United States with Advanced Econometric Approaches." PhD diss., Florida Institute of Technology, 2019.

[9] Wtaife, S., Alsabbagh, A., Eissa, T., Alshammari, E., Shaban, A., & Suksawang, N (2020). Effect of Polypropylene Fibers on Serviceability and Ultimate Limit States on Fiber Reinforced Concrete Behavior.

[10] Kyamo, M. J., A. A. Alsalhin, N. Premkumar, S. Miao, and B. A. Lail. "Ultrahigh mid-infrared electric field enhancement via nanoantenna plasmonic resonance coupled to a novel hyperbolic metalens." Journal of Modern Optics 68, no. 7 (2021): 394-402.

[11] Alsalhin, Abdelgader A., and Brian A. Lail. "A Systematic Investigation of Coupling Between Dark and Bright Polaritons for Infrared Sensing Design." IEEE Sensors Journal 21, no. 13 (2021): 14899-14905.

[12] Kyamo, Mohamed, Navaneeth Premkumar, Abdelgader Alsalhin, and Brian A. Lail. "A Novel Mid-Infrared Metalens Using a Hyperbolic Metamaterial." In 2019 International Applied Computational Electromagnetics Society Symposium (ACES), pp. 1-2. IEEE, 2019.

[13] Kyamo, Mohamed J., and Brian A. Lail. "A novel near-infrared metalens using type I hyperbolic metamaterial." In Image Sensing Technologies: Materials, Devices, Systems, and Applications VI, vol. 10980, pp. 296-301. SPIE, 2019.

[14] Alsalhin, Abdelgader A., Michael F. Finch, and Brian A. Lail. "Coupling between metallic structure and phonon polaritons for sensing applications." In Metamaterials, Metadevices, and Metasystems 2018, vol. 10719, pp. 84-93. SPIE, 2018.

[15] Jera, Elforjani S., Hussin K. Ragb, Mohammed J. Kyamo, Omar M. Darwish, and Nagi Buaossa. "Spin-Orbital Angular Momentum Conversion Under High NA Focusing of Vertically Polarized Vortex Beam." In NAECON 2021-IEEE National Aerospace and Electronics Conference, pp. 150-153. IEEE, 2021.

[16] Alsalhin, Abdelgader, and Brian Lail. "Determining the dispersive features of nanophotonic structures based on hybrid fem/tmm technique." In 2019 International Applied Computational Electromagnetics Society Symposium (ACES), pp. 1-2. IEEE, 2019.