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# Design and Simulation of a Circular Microstrip Patch Antenna at 2.4 GHz using HFSS

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**ABSTRACT:** The accelerating demand for compact, efficient, and cost-effective antennas in modern wireless communication systems, particularly for Wi-Fi/WLAN applications, necessitates continuous research into microstrip patch design. This paper presents the design and simulation analysis of a circular microstrip patch antenna optimized for the standard 2.4 GHz Industrial, Scientific, and Medical (ISM) band. The antenna is constructed on an economical FR-4 epoxy substrate with a dielectric constant of 4.4 and substrate height of 1.6 mm, utilizing a microstrip feed line for excitation. The design methodology prioritizes achieving a low profile, ensuring ease of integration into portable and Internet of Things (IoT) devices, while concurrently maximizing performance parameters. Simulation results obtained using HFSS demonstrate promising characteristics at the desired operating frequency including low VSWR, excellent return loss, good antenna gain, and suitable radiation pattern.

**KEYWORDS:** Microstrip patch antenna, Circular patch, Return loss, VSWR, 2.4 GHz, HFSS

## I, INTRODUCTION

The antenna stands as a critical component in any modern wireless communication system, including the rapidly expanding Internet of Things (IoT) environment. Microstrip patch antennas have become particularly significant due to their inherent advantages, such as small size, low profile, light weight, ease of manufacture using printed circuit technology, and low cost. These features make them highly desirable for integration into portable and compact devices. The rapid growth in controlling numerous hardware devices through IoT necessitates large bandwidth for local area network communication, driving the development of these antennas.

The 2.4 GHz frequency band is a standard and essential spectrum for various wireless services, including Wi-Fi (WLAN) and Bluetooth. In designing microstrip patches, various shapes like rectangular, square, and triangular are available, but the circular patch antenna is often preferred for its simplicity in design, as it only has one degree of freedom (the radius) to control, unlike the rectangular patch which has two. Additionally, circular patch antennas can be approximately 16% smaller than rectangular versions at the same operating frequency.

## II. OBJECTIVE

The primary objective of this work is to develop and analyze a microstrip circular patch antenna specifically tuned for operation at the 2.4 GHz resonant frequency, making it suitable for modern Wi-Fi and wireless communication

applications. The goals of this research include designing a robust antenna to improve performance metrics, achieving high antenna gain, minimizing return loss to ensure better impedance matching, and maintaining low VSWR for efficient power transfer.

#### Antenna Design Theory and Specifications

A microstrip patch antenna fundamentally consists of a radiating patch, a dielectric sub substrate layer, and a ground plane. The radiating patch is placed on top of the dielectric substrate, which is in turn placed above the ground plane. For the circular patch geometry, the theoretical radius is calculated using cavity model theory to ensure resonance at the desired frequency.

The factor  $F$  is calculated as:

$$F = 8.791 \times 10^9$$

$$f_r^2 \epsilon_r$$

The actual radius of the circular patch is then determined by:

$$a = F$$

$$\sqrt{1 + \frac{2h}{\pi \epsilon_r F}}$$

$$\ln \frac{\pi F}{2h}$$

$$+ 1.7726 \frac{1}{2}$$

Where  $f_r$  is the resonant frequency,  $\epsilon_r$  is the dielectric constant of the substrate, and  $h$  is the substrate height. The design specifications adopted for this work include an operating frequency of 2.4 GHz, dielectric constant of 4.4, substrate height of 1.6 mm, and circular patch radius of approximately 17 mm using FR-4 epoxy material.

### III. METHODOLOGY

ANSYS HFSS software is used to design and simulate the circular microstrip patch antenna. The design process begins with substrate modeling using FR-4 epoxy material. A rectangular copper ground plane is placed on the bottom face of the substrate to act as the reference plane. A circular copper patch of radius 17 mm is placed on the top face of the substrate, and an inset-fed microstrip feed line is connected to excite the patch.

Radiation boundaries are applied using an air box surrounding the antenna, and a lumped port is assigned at the feed point to provide excitation. A frequency sweep is performed from 1 GHz to 3 GHz to analyze antenna performance. Parameters such as return loss, VSWR, radiation pattern, and gain are observed.

### IV. EXPERIMENTAL RESULTS

The proposed circular microstrip patch antenna was designed and simulated using ANSYS HFSS and subsequently fabricated on an FR-4 substrate. Both simulation and hardware results were analyzed to validate the antenna performance at 2.4 GHz.

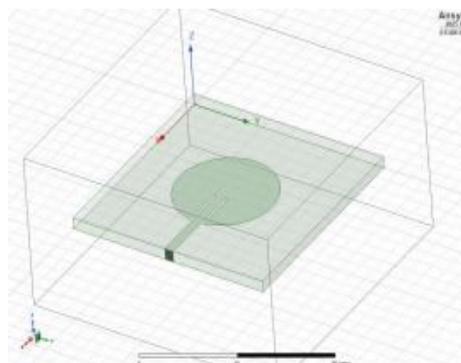


Fig. 2. 3D HFSS model of circular microstrip patch antenna (Front View)

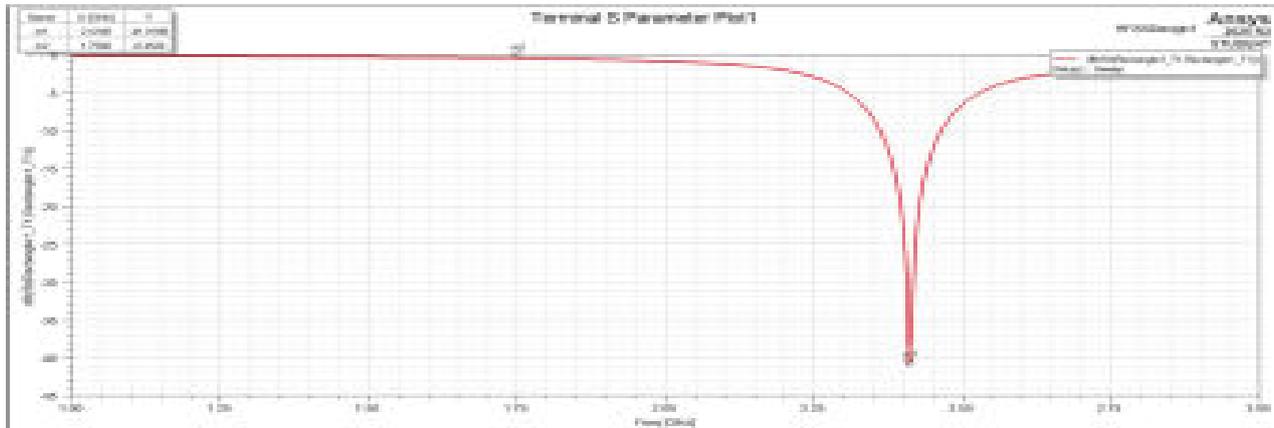


Fig. 3. S-Parameter (Return Loss) plot showing resonance at 2.4 GHz

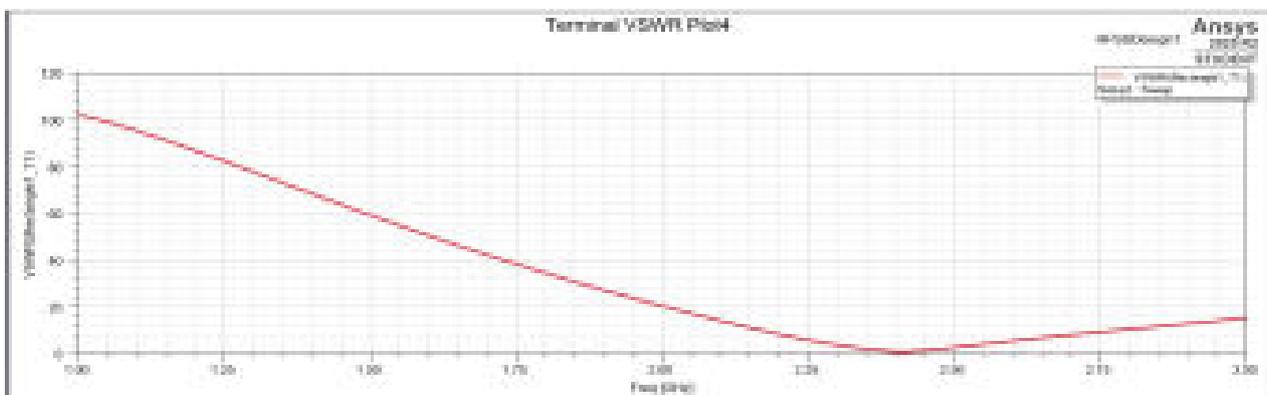


Fig. 4. VSWR plot of the circular microstrip patch antenna

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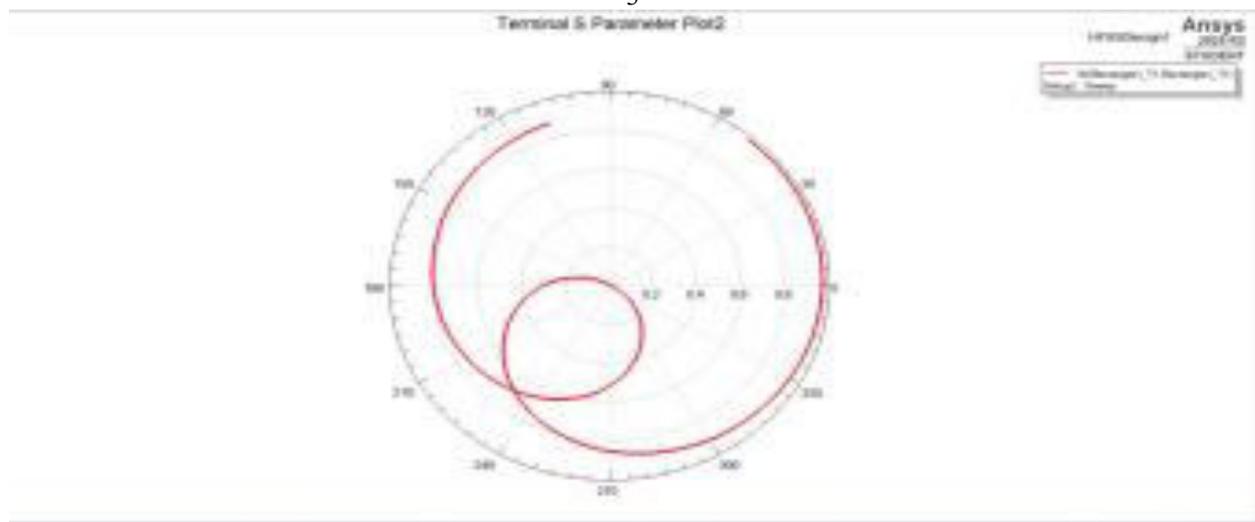


Fig. 5. Polar radiation pattern of the circular microstrip patch antenna

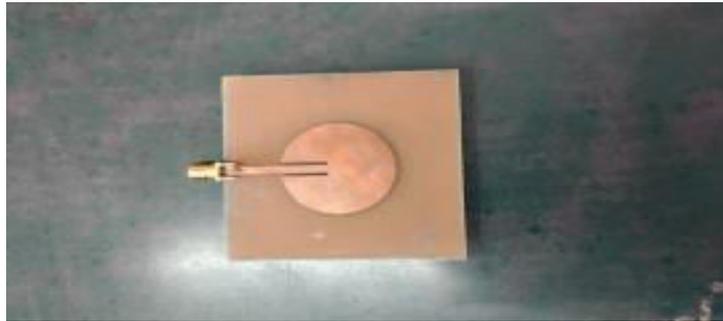


Fig. 6. Fabricated circular microstrip patch antenna (Top view showing patch and feed line)



Fig. 7. Fabricated antenna ground plane (Bottom view)

The S-parameter plot indicates a deep resonance at 2.4 GHz with a return loss of approximately -41 dB, confirming excellent impedance matching. The VSWR value is well below 2, indicating efficient power transfer. The polar plot shows a stable radiation pattern suitable for WLAN and IoT applications.

The fabricated antenna consists of a circular copper patch on the top layer and a full copper ground plane on the bottom layer of the FR-4 substrate. An SMA connector is used to feed the antenna, with the center pin connected to the microstrip feed line and the outer conductor soldered to the ground plane. The close agreement between simulation and hardware results validates the effectiveness of the proposed antenna design.

## V. CONCLUSION

In this paper, a circular microstrip patch antenna operating at 2.4 GHz has been successfully designed, simulated, and fabricated. The antenna demonstrates excellent performance in terms of return loss, VSWR, gain, and radiation pattern. Due to its compact size, low profile, and ease of fabrication, the proposed antenna is highly suitable for Wi-Fi, WLAN, and IoT applications.

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