Design and simulation of microstrip patch antenna with Inset feed for 2.4 GHZ frequency applications

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ABSTRACT

The design and implementation of a Rectangular microstrip patch antenna operating at 2.4 GHz frequency band. The antenna is designed using FR4 substrate with a thickness of 1.6 mm and relative permittivity of 4.4. The patch dimensions are optimized to achieve resonance at 2.4 GHz. A microstrip insert feed technique is used for feeding the patch. The antenna's performance is analyzed using CST simulation tools, and the results show a return loss of -10 dB, impedance bandwidth of 100 MHz, and a gain of 6.5 dbi. The design and simulation of patch antennas is widely used in mobile cellular phones today, and our emphasis in this work is on optimization of a 2.4 GHz rectangular Microstrip patch antenna. The return loss and the various gain plots have been studied along with the radiation patterns.

Keyword: - *Rectangular Microstrip patch antenna,* ***CST,*** *Insert feed, FR4 Substrate.*

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1. INTRODUCTION

Microstrip patch antennas (MSAs) have been widely researched and developed since their introduction in the 1950s. Their advantages, such as low profile, lightweight structure, and ease of fabrication, make them suitable for various wireless communication applications, including mobile networks, RFID, satellite communication, and high-frequency transmission systems. However, despite their numerous benefits, conventional MSAs face challenges related to bandwidth limitations, polarization control, radiation efficiency, and gain enhancement, necessitating continuous advancements in antenna design. To address these limitations, researchers have explored various techniques to improve the performance of MSAs. One approach focuses on achieving high isolation in multi-band and multi-mode antennas using slot-based designs, reducing feed coupling while maintaining a simple structure. Another method enhances circularly polarized (CP) antenna performance by employing stacked structures and parasitic elements, significantly improving the axial ratio bandwidth for applications like GSM and RFID. Additionally, the use of transparent conductive films (TCFs) in antenna design has gained traction for applications in solar panels and space-based systems, though these designs often suffer from low radiation efficiency. A novel curved microstrip patch antenna has been introduced to mitigate these efficiency issues, achieving improved gain and radiation performance. Lastly, for applications requiring high gain, a periodic microstrip rampart line structure has been proposed, effectively enhancing the gain of traditional patch antennas while maintaining a compact design. The study aims to guide future developments in microstrip antenna technology, ensuring optimal performance for next-generation communication systems.

2. MICROSTRIP PATCH ANTENNA WITH INSERT FEEDING TECHNIQUE: DESCRIPTION AND DESIGN PRINCIPLE

Microstrip patch antennas possess a very high antenna quality factor (Q) which represents the losses associated with the antenna where a large Q would lead to a narrow bandwidth and low efficiency. The factor Q can be reduced by increasing the thickness of the dielectric substrate but as the thickness will increase there will be a simultaneous increase in the fraction of the total power delivered by the source into a surface wave which can be effectively considered as an unwanted power loss since it is ultimately scattered at the dielectric bends and causes degradation of the antenna characteristics. Other problems such as lower gain and lower power handling capacity can be overcome by using an array configuration for the elements which is a collection of homogeneous antennas oriented similarly to get greater directivity and gain in a desired direction. The inset-fed microstrip antenna provides impedance control with a planar feed configuration.

The structure of the Micro strip patch antenna consists of a thin square patch on one side of a dielectric substrate and the other side having a plane to the ground. In its most fundamental form, a Micro strip antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on other side as shown in the figure below. The patch is generally made of conducting material such as copper or gold. The basic antenna element is a strip conductor of length L and width W, on a dielectric substrate. The thickness of the patch being h with a height and thickness t is supported by a ground plane. The rectangular patch antenna is designed so that it can operate at the resonance frequency.

3. FEEDING TECHNIQUE

A feedline is used to excite the antenna for making radiation by direct or indirect contact. Microstrip patch antennas can be fed by a variety of methods. Mainly these methods are classified into two groups contacting. Some popular feeding techniques are m line feed, coaxial probe feed, inset feed/ notch feed/cut feed, aperture coupling, proximity coupling, coupled (indirect) fed etc. The selection of feeding technique for a microstrip patch antenna is an important decision because it directly affects the bandwidth, return loss, VSWR [6]. We chose Inset feed technique because it can be easily fabricated and simplicity in modeling as well as impedance matching [7]. The fig.1 shows the layout of inset feed rectangular microstrip patch antenna with require dimensions. Where, Wp= width of patch, Wf= Width of feeder, Lf = Length of feeder, d = inset depth, g= notch width / inset width/gap width and L feeder from the left edge of the patch.

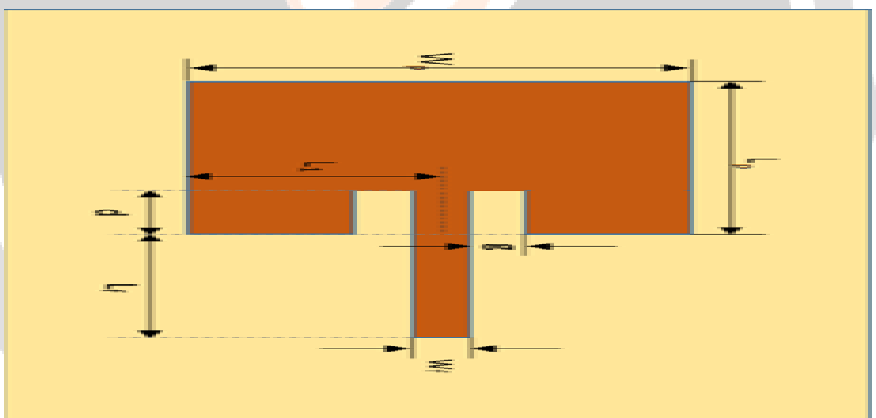

Fig -1 Inset feed rectangular microstrip patch antenna layout

To validate the simulated results, each antenna design underwent experimental verification through fabrication and testing. The microstrip patch antenna with a periodic microstrip rampart line was fabricated using a double-layer dielectric substrate with a periodic microstrip rampart line embedded in the middle layer. The prototype was tested using a vector network analyser (VNA) to measure its S-parameters (S11), and an anechoic chamber was used to evaluate the radiation pattern and gain.

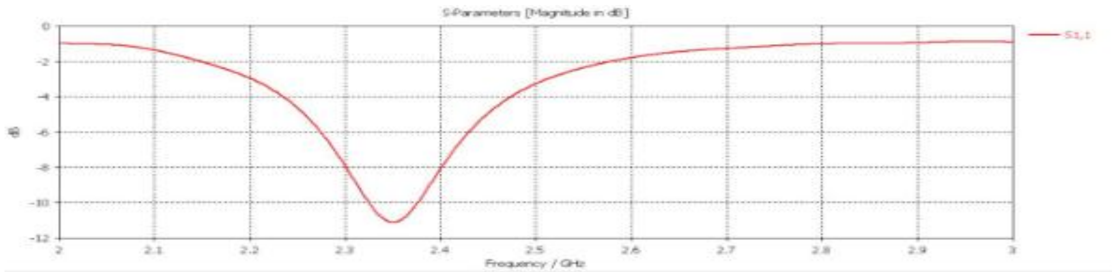

Fig -2 Graph showing the return loss

Similarly, the curved microstrip patch antenna designed from transparent conductive films (TCFs) as fabricated using PET film coated with transparent conductive materials, supported by a3D-printed PETG frame. The fabricated prototype was tested in an anechoic chamber, where its radiation efficiency and gain were measured. The experimental results demonstrated a realized gain of 5.3 dbi and a radiation efficiency of 72.3%, aligning well with the simulation data. This confirmed the effectiveness of the curved design in compensating for the lower conductivity of TCFs, achieving a4x improvement in efficiency over a flat transparent patch antenna*.

For the microstrip patch antenna for GSM applications, the fabricated prototype was tested using a spectrum analyser and an antenna measurement system (AMS-A) to measure return loss, impedance bandwidth, and axial ratio bandwidth. The antenna achieved resonant frequencies of 900 MHz and 1890 MHz, covering the bands 725–990 MHz and 1800–1920 MHz, with an axial ratio bandwidth of 17.14% and 10.98%. The measured gain of 6.7 dbi and radiation efficiency of 84 closely matched the simulation results, confirming the antenna's suitability for GSM applications.

Overall, the experimental verification of all three antennas demonstrated strong agreement between simulated and measured results. The microstrip patch antenna successfully improved gain, the curved transparent antenna optimized radiation efficiency while maintaining transparency, and the dual-band GSM antenna achieved enhanced circular polarization with stable bandwidth. These results validate the proposed designs for practical applications.

4. CONCLUSION

In this study, three distinct microstrip patch antenna designs were analyzed, simulated, fabricated, and experimentally verified for their respective applications. The microstrip patch antenna with a periodic microstrip rampart line successfully demonstrated a 2.55 dB gain improvement, making it an effective solution for high-gain applications. The microstrip patch antenna designed with transparent conductive films (TCFs)proved to be an innovative approach for lightweight and transparent antenna structures, achieving radiation efficiency of 72.3% and a realized gain of 5.3 di, offering significant improvements over traditional flat transparent antennas. The microstrip patch antenna for GSM applications provided a wider axial ratio bandwidth, ensuring better circular polarization performance,

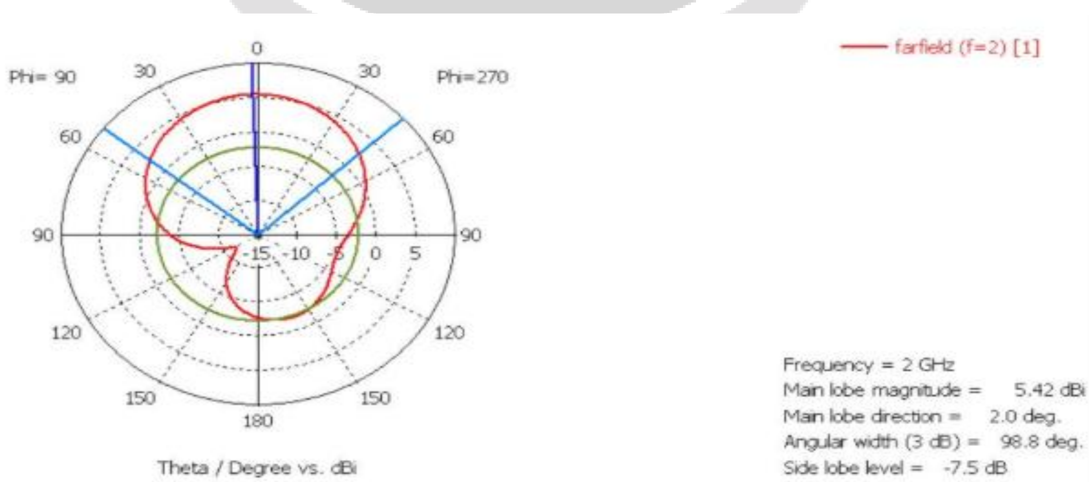

Fig -3 2D radiation pattern of designed antenna

with a gain of 6.7 dbi and radiation efficiency of 84%, making it suitable for GSM communication. Experimental validation confirmed strong agreement with simulations, proving the reliability of the proposed designs.

5. RESULT

For future work, the microstrip antenna could be further optimized by exploring Meta surface-based design or multi-layer configurations to achieve even higher gain and directivity. The transparent curved antenna can be improved by incorporating advanced conductive materials such as graphene or silver nanowires to enhance conductivity while maintaining transparency. Additionally, research can be conducted to integrate this design into solar panel applications for CubeSats and IoT devices. The microstrip patch antenna could be extended to support multi-band and wideband applications, improving its versatility for 5G and IoT networks. Moreover, integrating reconfigurable or tunable elements, such as PIN diodes or varactors, could enable dynamic frequency adaptability, making these antennas more suitable for emerging wireless communication technologies.

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