IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Design and Analysis of a Self-Adaptive Tri-Band Thermal Reconfigurable Microstrip Patch Antenna for Defence Applications

Vikram S, Srijen T,
Sriram R, Santhoshkumar R
Department of Electronics and
Communication Engineering
K. Ramakrishnan College of Engineering
Trichy, India

Abstract — **In recent times, there has been a significant rise in the importance of adaptive communication systems owing to the unpredictable environment of wireless networks. This paper proposes the design and simulation of a thermal reconfigurable self-adaptive microstrip patch antenna around 2.4 GHz. The proposed antenna employs a thermal reconfigurable dielectric substrate with permittivity varying with respect to changes in temperature. This characteristic of the proposed antenna enables the automatic adjustment of the resonant frequency of the antenna without the need for any switching circuitry or biasing network. The design and simulations of the proposed antenna have been carried out in CST Studio Suite, while its performances have been evaluated based on S11 (Return Loss) and VSWR (Voltage Standing Wave Ratio). The results have shown that the proposed antenna yields S11 below -10 dB and VSWR near unity at the desired frequency.**

Keywords —Microstrip patch antenna, Star slot antenna, Multiband operation, CST Microwave Studio, Return loss, VSWR, C-band communication

I. INTRODUCTION

Wireless communication systems have come to be one of the most indispensable parts of our daily lives, and are widely used for applications like cellular communication, WiFi, IoT, satellite communication, and even for the development of smart objects. The growing need for increased data rate, improved reliability, and small-sized equipment has led to a lot of research in antennas. Various kinds of antennas have been developed; however, the microstrip patch antennas have become increasingly popular owing to their thin profile, light weight, easy construction, and compatibility with IC technology.

Even though there are many benefits to microstrip patch antennas, there are also some downsides. The most significant disadvantage is that it has a limited bandwidth and a predetermined frequency range. It can operate only within a fixed frequency range and cannot adjust according to any changes in its surroundings.

However, there have been several innovations within the last few years that promise to address the problem effectively. For instance, the material-oriented methods of reconfiguration involve the use of smart materials whose electrical properties depend upon environmental factors like temperature, light, and electric field. Thermal reconfiguration is one of them, which uses dielectrics whose dielectric constants vary according to temperature. The resonance frequency of the antenna can be automatically tuned by changing the value of the dielectric constant.

II. ANTENNA DESIGN

The proposed antenna is designed using a microstrip patch structure. It consists of a substrate layer, a radiating patch, a ground plane, and a microstrip feed line. The substrate is made of FR-4 along with a thermal-sensitive material region placed near the patch. The patch is designed in a modified rectangular shape with a circular region at the center, which acts as the thermal tuning element. This circular region is assigned a thermal material whose dielectric constant varies between 2.5 and 3.5.

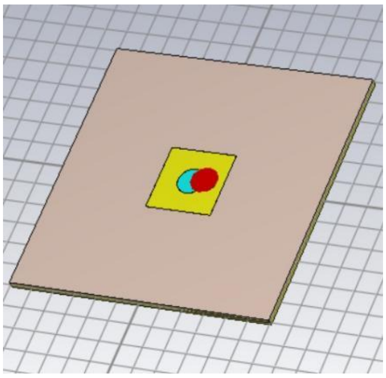


Fig.1. Antenna Design

The variation causes the effective length of the antenna to change, leading to the phenomenon of frequency tuning. The feed line is used to ensure that the impedance is correctly matched, while the ground plane is necessary for ensuring proper radiation properties. The antenna system is configured to function optimally at around 2.4 GHz. The thermal tuning technique makes it possible for the antenna to act as a self-configuring reconfigurable antenna.

III BLOCK DIAGRAM

As seen from (Fig.2) , the design flow of the proposed self-adaptive thermal reconfigurable microstrip patch antenna has been depicted using a block diagram. First of all, design specifications are obtained according to the range of frequency that needs to be covered by this antenna, which is between 1 and 5 GHz, and a suitable substrate material. FR-4 dielectric substrate is chosen for this particular antenna since it is inexpensive and exhibits good electrical properties. The antenna model is developed using CST Microwave Studio, where the patch antenna, ground plane, and microstrip feed are designed. Moreover, a thermal reconfigurable unit has been incorporated into the patch, using a temperature-sensitive material, to change its frequency of operation automatically.

Fig.2. System Block Diagram

A. Define Specification

The first step in designing the antenna is to decide the requirements based on where it will be used. In this project, a self-adaptive thermal reconfigurable microstrip patch antenna is designed to work in the frequency range of 1–5 GHz. This range is chosen because it supports different wireless communication applications.

B. Design Antenna Structure (CST)

The antenna is designed using CST Microwave Studio software. In this step, the basic structure of the antenna is created, including the patch, ground plane, and feed line. CST helps to simulate and analyze the antenna performance before actual fabrication, which reduces errors and improves accuracy.

C. Add Substrate Layer

A substrate layer is placed between the patch and the ground plane. Here, FR-4 material is used with a dielectric constant of 4.4 and thickness of 1.6 mm. The substrate provides support and also affects important parameters like frequency, bandwidth, and efficiency of the antenna.

D. *Design Ground Plane*

The ground plane is designed below the substrate. It acts as a reference layer and helps in improving the radiation characteristics and stability of the antenna. It helps reflect the radiated waves in the desired direction, which improves radiation efficiency and ensures stable overall performance.

E. Design Patch Structure

The patch is placed on top of the substrate using copper material because of its good conductivity. A slot is introduced in the patch to change the current flow. This increases the electrical path length and helps the antenna to operate at multiple frequencies. It also improves impedance matching compared to a normal patch.

F. Create Circular Slot

A circular slot is made at the center of the patch by cutting a cylindrical shape. This helps in controlling the resonance and supports multiband operation. It also improves the bandwidth of the antenna. It changes the way current flows on the patch, making it travel around the slot instead of straight across.

G. Insert Thermal Reconfigurable Material

A special material that changes its properties with temperature is placed inside the slot. Due to this, the antenna can automatically adjust its frequency when the temperature changes. This makes the antenna self-adaptive without using external switches like PIN diodes or MEMS.

H. Apply Discrete Port Feed

A discrete port with 50 Ω impedance is used to feed the antenna. This ensures proper matching and efficient power transfer. The port is placed between the patch and the ground for accurate simulation results.

I. Apply Boolean Subtraction

The circular slot is created by subtracting a cylindrical shape from the patch using a Boolean operation. This changes the current path, increases the electrical length, and helps achieve multiband operation. It also improves overall antenna performance.

J. 5G / WLAN / IoT Applications

This antenna can be used in applications like 5G, WLAN, and IoT. These systems require antennas that are compact and can work at multiple frequencies. Unlike traditional antennas, this design can adapt its frequency automatically and support different communication needs, making it more flexible and efficient. This antenna can be used in applications such as 5G, WLAN, and IoT, where compact size and multiband operation are essential. Unlike conventional antennas, it can automatically adjust its frequency based on conditions, making it more flexible and efficient for handling different communication requirements.

Parameter	Value
Substrate Material	FR-4
Substrate Size	80 mm × 60 mm
Substrate Thickness	1.6 mm
Ground Plane Size	80 mm × 60 mm
Patch Size	30 mm × 30 mm
Patch Material	Copper
Patch Shape	Thermal cylinder with slot
Feed Type	Microstrip Line Feed
Operating Frequency	1-5 GHz

Fig.3. Dimensions

III. EVOLUTION OF THE PROPOSED ANTENNA STRUCTURE

A. *Stage 1 – Substrate Design*

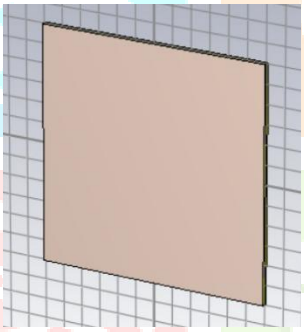


Fig. 4. Substrate of the Proposed Antenna

The substrate forms the base of the antenna and strongly influences its overall electrical performance. In this work, FR-4 (εr ≈ 4.4) is selected due to its low cost and suitability for microwave applications. It is modeled in CST with dimensions of 120 mm × 120 mm and a thickness of 1.6 mm, ensuring both structural support and proper propagation of electromagnetic waves. The substrate also facilitates interaction between the patch and ground plane, which directly affects key parameters such as resonant frequency and bandwidth. Hence, it plays a vital role in maintaining stable and efficient antenna operation.

B. Stage 2 – Ground Plane Design

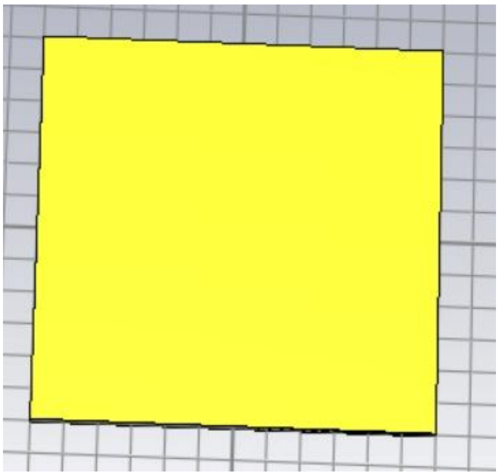


Fig. 5. Ground plane structure

A copper ground plane is placed beneath the substrate, serving as a reference conductor. Its dimensions are kept consistent with the substrate (80 mm × 60 mm) with a thickness of 5 mm. The ground plane reflects electromagnetic waves generated by the patch, thereby improving radiation efficiency. It also contributes to stable simulation results and enhances the overall performance of the antenna.

C. Stage 3 – Patch Layer Formation

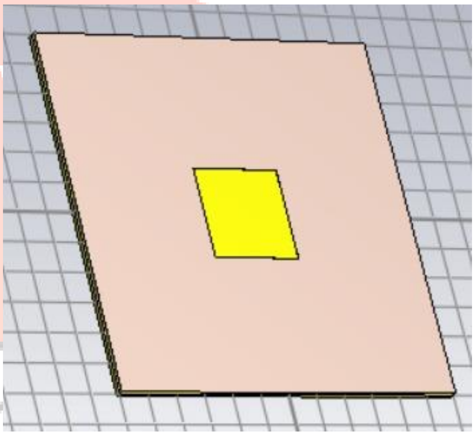


Fig. 6. Patch layer of the Proposed Antenna

The radiating patch is responsible for transmitting electromagnetic waves. A rectangular copper patch is designed on top of the FR-4 substrate, taking advantage of copper’s high conductivity and low loss characteristics. The patch size is approximately 30 mm × 30 mm, selected to operate within the 1–5 GHz frequency range. This configuration forms a standard microstrip antenna structure, where the patch primarily determines the resonant frequency and radiation behavior.

D. Stage 4 – Circular Slot Geometry Creation

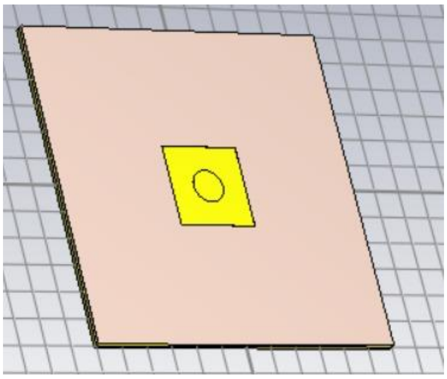


Fig. 7. Circular Slot Geometry Creation

To enable multiband and reconfigurable operation, a circular slot structure is introduced. Initially, a cylindrical shape is created in CST and positioned at the center of the patch (X = 0, Y = 0) to maintain symmetry in current distribution. The radius of the cylinder is about 6 mm, aligned along the Z-axis to match the patch thickness. At this stage, it acts as a reference geometry for the slot that will be formed later.

E. Stage 5 –Boolean Operation for Slot Formation

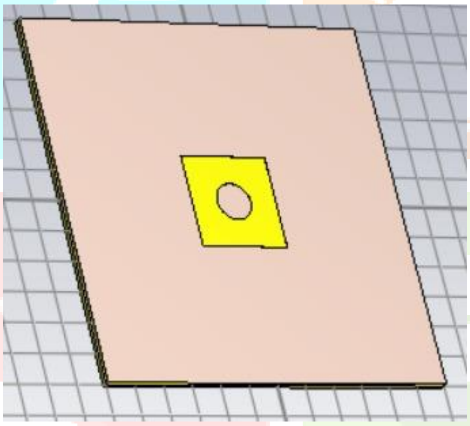


Fig. 8. Boolean Operation for Slot Formation

The cylindrical structure is then removed from the patch using the Boolean "Subtract" operation, forming a precise circular slot. This modification alters the surface current path, forcing it to flow around the slot and effectively increasing its length. As a result, impedance matching improves, and the antenna characteristics can be controlled more efficiently by adjusting the slot dimensions.

F. Stage 6 – Thermal Material Definition

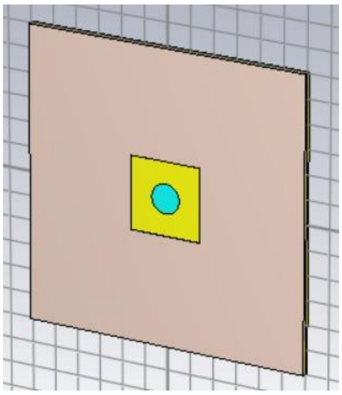
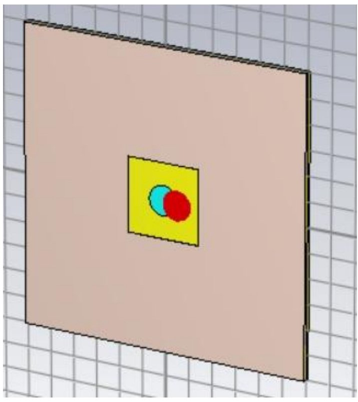


Fig. 9. Thermal Material Definition

To achieve self-adaptive reconfigurability, a custom material named "ThermalMaterial" is defined in CST. Its electrical properties, such as permittivity and conductivity, are configured to vary with temperature. This material is applied within the slot region, where it significantly influences current distribution and resonant behavior. Due to this property, the antenna can automatically adjust its operating frequency without relying on external switching components.

G. Stage 7 – Feeding Mechanism Using Discrete Port



s

Fig. 10. Feeding Mechanism Using Discrete Port

The antenna is excited using a discrete port, providing a simple and effective feeding technique. The port is placed between the patch and ground plane to ensure proper signal input. A characteristic impedance of 50 Ω is selected to achieve good impedance matching and minimize reflection losses. This excitation generates surface currents on the patch, enabling radiation and interaction with the slot and thermal material. It also supports accurate evaluation of S-parameters while keeping the simulation process simple and reliable.

IV. SIMULATION SETUP

The proposed self-adaptive thermal reconfigurable microstrip patch antenna is designed and analyzed using CST Microwave Studio, which is a full-wave electromagnetic simulation tool. The antenna is implemented on an FR-4 substrate having a relative permittivity of approximately 4.4 and a thickness of 1.6 mm. The substrate dimensions are selected as 80 mm × 60 mm to maintain stable radiation behavior and to reduce unwanted edge effects.

Copper (annealed) is used for both the radiating patch and the ground plane because of its high electrical conductivity, which helps in minimizing conduction losses. A full ground plane is placed below the substrate, while the patch is positioned on the top surface, forming a conventional microstrip antenna structure. For excitation, a microstrip line feed is employed, designed to provide a characteristic impedance of 50 Ω, ensuring proper impedance matching and efficient power transfer.

The antenna is simulated over a frequency range from 1 GHz to 5 GHz. Its performance is analyzed using parameters such as return loss (S_{11}), voltage standing wave ratio (VSWR), and radiation characteristics in the far field. A frequency-domain solver is used to obtain accurate results across the entire operating range. To enable reconfigurable behavior, a temperature-dependent thermal material is integrated into the patch in the form of a cylindrical structure, allowing variation in antenna characteristics based on temperature changes.

V. RESULTS AND DISCUSSION

The performance of the proposed self-adaptive thermal reconfigurable microstrip patch antenna is analyzed using CST Microwave Studio, and the simulation results confirm its effective multiband behavior. The return loss (S_{11}) response shows that the antenna operates at multiple resonant frequencies within the desired range, particularly around 2.8 GHz, 4.2 GHz, and 5.3 GHz. At these frequencies, the return loss values are below −10 dB, which indicates good impedance matching and low signal reflection. In addition, the VSWR values are observed to be close to unity, confirming efficient power transfer between the feed and the antenna.

The inclusion of the thermal reconfigurable element significantly influences the antenna's performance by altering the current distribution and the effective electrical length of the patch. As the temperature changes, the electrical properties of the material also vary, resulting in a shift in resonant frequencies. This enables dynamic frequency tuning without the need for external switching components, making the antenna more adaptable to different operating conditions.

The use of an FR-4 substrate provides a cost-effective solution while still maintaining acceptable performance levels. Although FR-4 may introduce some dielectric losses, the optimized antenna structure and proper feeding technique help in achieving satisfactory results. Based on the obtained characteristics, the antenna is suitable for applications such as RF communication, WLAN, Wi-Fi, and C-band systems. Overall, the results demonstrate that the proposed antenna achieves a compact structure, multiband operation, and self-adaptive functionality. This combination makes it a strong candidate for modern wireless applications, including 5G, WLAN, and IoT systems. The design effectively balances performance, simplicity, and practicality, highlighting its potential for real-world implementation.

A. *S11 (Return Loss)*

Return loss (S_{11}) is a key parameter used to assess antenna performance, as it represents the amount of power reflected back due to impedance mismatch. A more negative return loss value indicates better matching between the antenna and the transmission line, which leads to more efficient radiation of electromagnetic energy.

From the simulated S_{11} results, the proposed antenna clearly shows multiband operation within the 1–5 GHz frequency range. The antenna exhibits distinct resonances around 1.98 GHz, 4.29 GHz, and 4.80 GHz, with return loss values of approximately −11.42 dB, −11.94 dB, and −19.22 dB, respectively. Since all these values are below −10 dB, it confirms that the antenna achieves good impedance matching at these frequencies.

The strongest performance is observed near 4.80 GHz, where the return loss reaches about −19 dB, indicating very low reflection and efficient power transfer. The occurrence of multiple resonant frequencies is mainly due to the presence of the circular slot and the thermal reconfigurable element, both of which modify the surface current distribution and effective electrical length of the patch.Overall, the return loss characteristics confirm that the antenna provides efficient impedance matching along with stable multiband operation, making it suitable for modern wireless communication applications.

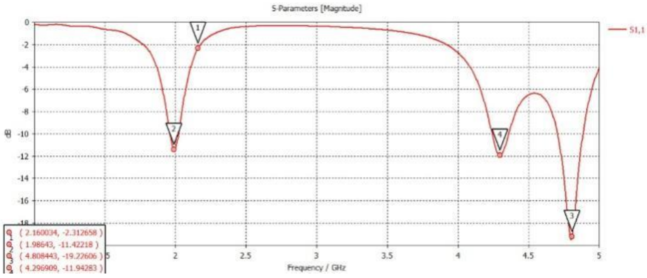


Fig.11. S11 Parameter

S.No	Resonant Frequency (GHz)	Return Loss (dB)	VSWR
1	2.0 GHz	−11.42 dB	1.79
2	4.3 GHz	−11. 89dB	1.83
3	4.8 GHz	−19.37dB	2.00

Table 1: Resonant Frequencies with S11 and VSWR Values

B. *VSWR (Voltage Standing Wave Ratio)*

The Voltage Standing Wave Ratio (VSWR) is an important parameter used to evaluate how well the antenna is matched with the transmission line. It represents the ratio between the maximum and minimum voltage along the line and is closely related to return loss. Ideally, a VSWR value of 1 indicates perfect impedance matching, while in practical antenna systems, values below 2 are generally considered acceptable.

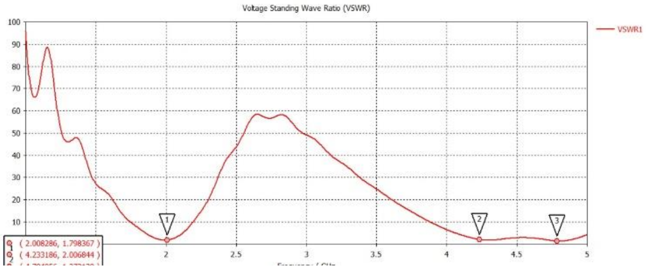


Fig.12. VSWR

In a well-designed antenna, the VSWR should remain close to unity at the operating frequencies, indicating efficient power transfer. If the value exceeds 2, it suggests the presence of impedance mismatch, which can lead to power reflection and reduced performance. Therefore, VSWR serves as a reliable measure to verify whether the antenna is properly matched with the feed line.

From the simulated VSWR results of the proposed antenna, it is observed that the values at the resonant frequencies fall within the acceptable range. Around 2.00 GHz, the VSWR is approximately 1.79, indicating good matching. At about 4.23 GHz, the value is close to 2.00, which is still within permissible limits. At higher frequencies near 4.7–4.8 GHz, the VSWR further improves to around 1.5, showing better impedance matching and efficient power transfer.

C. *Far-Field Radiation patterm*

The far-field characteristics of the proposed self-adaptive thermal reconfigurable microstrip patch antenna are studied to understand its radiation behavior at large distances. In the far-field region, electromagnetic waves propagate as plane waves, and the radiation pattern becomes independent of distance.

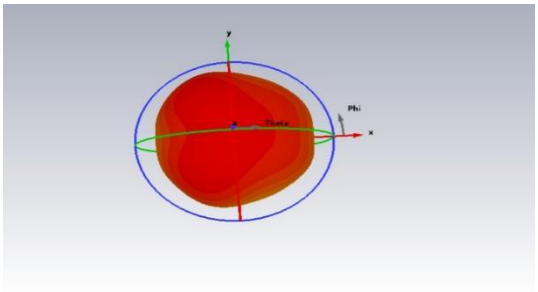


Fig.6. far-field

The radiation is analyzed using spherical coordinates defined by the angles theta (θ) and phi (φ). The variation of radiation intensity with respect to these angles shows that the antenna provides good coverage in both elevation and azimuth directions. A well-defined main lobe is observed, indicating that most of the radiated power is directed toward the desired region. At the same time, the side lobes remain relatively small, which helps reduce unwanted radiation.

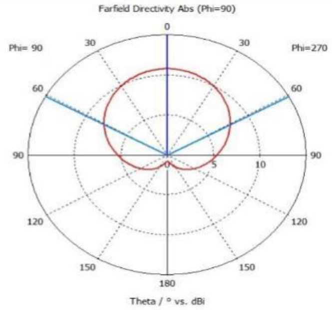


Fig.13. Radiation pattern

The radiation pattern is further examined using both 2D polar plots and 3D representations obtained from simulation. The 2D polar plot (far-field directivity at φ = 90°) indicates that the antenna exhibits a nearly omnidirectional pattern in the azimuth plane. However, slight variations in the pattern are observed due to the presence of the circular slot and thermal reconfigurable element, which influence the surface current distribution on the patch.

VI. CONCLUSION

This work presents the design and analysis of a self-adaptive tri-band thermal reconfigurable microstrip patch antenna intended for defense-related applications. The antenna operates within the 1–5 GHz frequency range and integrates a modified circular slot along with a temperature-dependent material to achieve reconfigurability. Overall, the antenna offers a compact design with multiband and self-adaptive capabilities. This makes it suitable for defense systems and modern wireless applications such as 5G, WLAN, and IoT.

Reference	**Frequency (GHz)**	**S11(dB)**	**VSWR**	**Patch Shape**
[1]	1.98	−11.42	1.79	Microstrip Array
[5]	4.3	−19.22	2.00	Fractal Slot
[7]	4.9	−11.94	1.08	Rectangular
Proposed Work	1.98 / 4.3 / 4.8	-11.42 / -19.22 / -11.94	1.79 / 2.00 / 1.08	Circular Slot

Acknowledgement

The authors sincerely thank the faculty members of the Department of Electronics and Communication Engineering for their continuous guidance and support throughout this work. They also acknowledge the lab staff for their assistance and for providing the required facilities during the design and simulation process. Special appreciation is extended for the use of CST Microwave Studio in carrying out the antenna simulations. The overall support from the institution has been instrumental in successfully completing this work.

REFERENCES

1. M. T. Islam *et al.*, “A Compact Multiband Microstrip Patch Antenna for Wireless Applications,” *Progress In Electromagnetics Research*, vol. 98, pp. 267–283, 2009.
2. D. M. Pozar, “Microstrip Antennas,” *Proceedings of the IEEE*, vol. 80, no. 1, pp. 79–91, 1992.
3. C. A. Balanis, *Antenna Theory: Analysis and Design*, 4th ed., Wiley, 2016.
4. R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon, *Microstrip Antenna Design Handbook*, Artech House, 2001.
5. A. K. Gautam and S. Yadav, “Slot Loaded Microstrip Patch Antenna for Multiband Applications,” *International Journal of Electronics and Communications*, 2015.
6. J. Costantine, Y. Tawk, S. E. Barbin, and C. G. Christodoulou, “Reconfigurable Antennas: Design and Applications,” *Proceedings of the IEEE*, vol. 103, no. 3, pp. 424–437, 2015.
7. F. Yang and Y. Rahmat-Samii, “Patch Antennas with Switchable Slots for Reconfigurable Designs,” *IEEE Transactions on Antennas and Propagation*, 2008.
8. N. Behdad and K. Sarabandi, “A Varactor-Tuned Dual-Band Slot Antenna,” *IEEE Transactions on Antennas and Propagation*, vol. 54, no. 2, pp. 401–408, 2006.
9. M. Ali, M. Okoniewski, and M. A. Stuchly, “Dual-Frequency Microstrip Patch Antenna Using Slot Techniques,” *IEEE Transactions on Antennas and Propagation*, vol. 55, no. 5, pp. 1427–1432, 2007.
10. S. Nikolaou *et al.*, “Pattern and Frequency Reconfigurable Annular Slot Antenna Using PIN

Diodes," *IEEE Transactions on Antennas and Propagation*, vol. 54, no. 2, pp. 439–448, 2006.