

DESIGN OF RECONFIGURABLE TRIANGULAR MICROSTRIP PATCH ANTENNA WITH T-STUB FOR C-BAND AND X-B AND APPLICATIONS

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Abstract:

A compact reconfigurable microstrip patch antenna operating in C-band (4–8 GHz) and X-band (8–12 GHz) applications, including satellite communications and radar systems potential, is designed in this paper. The antenna consists of a triangular patch geometry with a T-shaped stub integrated at a crucial location. The reconfigurability of both frequency and radiation pattern is accomplished through the embedding of PIN diodes inside the T-stub. The switching states of these diodes control the effective electrical length and current distribution on the patch, thus making it possible to transition easily between the desired frequency bands. The antenna under discussion is built on an FR-4 substrate and HFSS is used for simulation. The key performance parameters such as return loss, gain, radiation efficiency, and far-field patterns are methodically analyzed. The results illustrate that the impedance matching is good, the radiation characteristics are stable, and the band switching is effective, thus confirming the design is suitable for the modern multi-band wireless systems that require dynamic functionality.

Keywords: *Re-configurable Antenna, Triangular Microstrip Patch, PIN Diode, C Band and X Band, Frequency Switching, T Stub*

I. INTRODUCTION

As the demand for multifunctional wireless communication systems, such as satellite links, radar, and modern 5G and 6G backhaul, increases, the need for antennas that can work in different frequency bands arises. The operation of those antennas must not be at the expense of the size or the complexity of the hardware. Microstrip patch antennas are the most probable solution due to their small size, low-cost manufacturing, and ability to integrate with different surfaces as well.

Nevertheless, classic configurations of these antennas do not go beyond their limitations since they operate at one frequency and have one bandwidth. This comes as a disadvantage in situations where there are different communication standards that need to be switched to. Reconfigurable antennas serve as a remedy for this problem in an efficient manner. They allow for one antenna to be able to make changes to its operating features on the spot, such as the frequency, radiation pattern, and polarization. The use of active switching components like PIN diodes, varactors, or RF MEMS switches facilitates the reconfiguration. The triangular microstrip patch is among the different antenna shapes that have been chosen for compact design and for providing unique modal properties. The addition of a T shaped stub to this design enhances the applicableness of the antenna. The stub acts as a tuning element giving precise control over the current flow and resonant frequency of the antenna. The document offers a comprehensive discussion on the design and analysis of a reconfigurable triangular-shaped microstrip patch antenna. The antenna is intended for operation within the C band (4 to 8 GHz) and the X band (8 to 12 GHz) and utilizes a T stub. The aforementioned bands, in particular, are the crucial ones for satellite communication and radar operations. The design which is put forth, utilizes PIN diodes embedded in the T stub structure to provide electronic frequency reconfiguration. The frequency shifting between the two target bands is done by changing the state of the diodes, hence, the electrical length of the antenna is modified. The introductory section sets the stage for a thorough discussion of the antenna design evolution, the

switching mode, and the simulated performance results. It aims to prove the antenna's capability in experimental adaptive wireless systems.

II. LITERATURE SURVEY

Reconfigurable microstrip antennas development is considered an important research area which has a primary goal of enhancing the spectrum efficiency of current wireless systems. Besides the pioneering research done by Cetiner and others, various reconfiguration techniques using RF MEMS switches and semiconductor diodes as components were established. Most of the work done to attain multi band operation has been focusing on the modification of the proper patch shape. A few of the most preferred techniques are the applying of U slots and E shaped patches which are recognized for their proficiency to effectively increase the bandwidth. Triangular patch antennas have been investigated in great detail mainly because of their small size and by having the ability to support multiple resonant modes. A very commonly used technique of tuning stubs for adjusting antenna characteristics is the dual band operation created using L shaped and U shaped stubs. However, the T shaped stub among all others provides an accurate control over the two resonant paths, thus, being the most effective in the designs which have reconfigurability as a requirement. With respect to the frequency agility, the PIN diodes are identified as the most utilized switching devices due to their fast operation and easy integration into microstrip circuits. Different antenna designs have been able to use PIN diodes for switching the antennas to either the C band or the X band, thus, being applicable in a variety of applications. A review of the literature indicates that there are very few compact antennas that have the ability to electronically switch between the C band and the X band by using a single radiating element. Many of the existing solutions necessitate rather complicated designs such as array configurations or feeding networks with many layers. The present study proposes a new and uncomplicated design to fill that void. It utilizes a single triangular patch together with a T stub that is cleverly placed and has PIN diodes embedded in it to permit an unequivocal switch between the C band and the X band. This is a contribution of a simplified solution to the field.

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III. PROPOSED WORK

This study introduces the innovatively designed, simulated, and analyzed electronically reconfigurable triangular microstrip patch antenna, which is linked with a T stub for switchable operation in between C band and X band frequency ranges. The main aim is to create a compact single-element antenna with the ability of changing its resonant frequency through an extremely simple and efficient switching method.

The process will start with the layout of an equilateral triangular patch antenna on a shared FR4 substrate. A T-shaped conductive stub would be purposely attached to the patch, where its vertical part touches the patch edge and the horizontal part goes on parallel to it. The main idea of the research is to put two PIN diodes in the middle of the T stub. A biasing system for these diodes will be planned using thin DC lines with RF chokes incorporated to separate the RF and DC signals, thus minimizing the impact on radiation performance. There will be two operational states for the antenna. In State 1 with the PIN diodes forward-biased ON, the T stub is effectively connected, which results in the elongation of the current path over the patch and the decrease of the resonant frequency to that of the C band. In State 2, with the diodes reverse-biased OFF, the stub is no longer part of the current path, which leads to a reduction of the electrical length and consequently, resonance is shifted to the higher X band. The whole set-up will be simulated and perfected via ANSYS HFSS electromagnetic software. The performance metrics such as return loss, voltage standing wave ratio, gain, radiation efficiency, and far field patterns in both states will be exhaustively studied to prove the design's capability and usefulness for the defined applications.

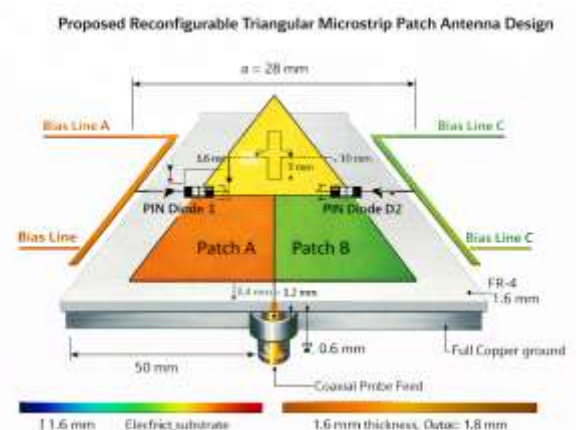


Fig 1: Reconfigurable Triangular Microstrip Patch Antenna Design

IV. METHODOLOGY

The first step in this process is to draft the specifications for C band and X band operation. The cavity model on an FR4 substrate is used to make the first calculations for an equilateral triangular patch. The frequency control integration concept with a T stub is realized.

Phase 2: Reconfiguration Element and Circuit Design

The T stub is designed and its optimum patch location is determined. The PIN diodes are inserted at the most important part of the connection between the stub and the patch. A special DC biasing network is created that makes use of microstrip lines with integrated radial stubs acting as RF chokes to hinder signal interference as well as supplying bias.

Phase 3: Simulation Modeling

The whole antenna setup is created in the ANSYS HFSS electromagnetic simulation software. The lumped element circuits are used to define the PIN diodes for their ON, low resistance, and OFF, high capacitance, states in order to simulate the switching behavior accurately.

Phase 4: Parametric Analysis and Optimization

A thorough parametric study is performed. The major factors of T stub dimensions, arm length and width, and its exact location are changed. The design is then again and again optimized for the two main results to be achieved: minimal return loss and a distinct resonant frequency shift between the target bands for each diode state.

Phase 5: Performance Evaluation in Dual States

The optimized design is put to the test under two different conditions. In State 1, which is in the C band, the diodes are turned on for electrically stretching the patch to resonate at 4 to 8 GHz. State 2, on the other hand, in X band, turns the diodes off

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to reduce the electrical length for the resonance at 8 to 12 GHz. For every state, performance parameters are derived: reflection coefficient S11 bandwidth, Voltage Standing Wave Ratio VSWR, gain, radiation efficiency, and far field patterns.

Phase 6: Results Synthesis and Validation

The entire simulation results are gathered and evaluated. The antenna's capacity to switch bands without losing radiation performance is checked against the initial specifications, thus confirming the feasibility of the design for the desired

VI. RESULTS AND DISCUSSION

The simulation results clearly prove the antenna's working. Key parameters for both the operational conditions are presented in Table 1. When the PIN diodes are activated, the antenna operates at the C-band frequency of 5.8 GHz. The control of diodes OFF changes the structure to operate at a frequency of 10.2 GHz in the X-band, where very good impedance matching is kept in both conditions, thus, indicating the successful electronic frequency agility.

Parameter	Diode ON State (C-Band)	Diode OFF State (X-Band)
Resonant Frequency (GHz)	5.8	10.2
Return Loss, S11 (dB)	-32.5	-28.7
Impedance Bandwidth (MHz)	600	800
-10 dB Bandwidth (GHz)	5.5 - 6.1	9.8 - 10.6
VSWR at Resonance	1.05	1.07

Table 1: Simulated Performance Parameters for Both States

The results of the simulation, which are concisely presented in Table 1, have unequivocally established the superb electronic reconfigurability of the antenna. One of the primary gains is a remarkable shift in the resonant frequency from 5.8 GHz to 10.2 GHz, thus, the desired C-band and X-band spectrums are completely covered. The switching mechanism of the T-stub and PIN diode integration has made this feature possible. The moment that the diodes are in the ON state with

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positive bias, the stub is included in the radiating structure, hence, the effective length of the electrical current on the triangular patch is increased and consequently the fundamental resonance is lowered. In contrast, switching the bias to the OFF state cuts off the stub from the circuit; therefore, it is like a short path is created for the current which causes the resonance to be in the higher band. The performance of the design, which is the key factor for the practical application, is evidenced by the return loss values of less than 28 dB, Voltage Standing Wave Ratio figures that are nearly ideal, and impedance bandwidths that are 600 MHz and 800 MHz. These measures signal excellent impedance matching and active radiation. Moreover, the meticulous designing of the direct current biasing network that had radial stubs as radio frequency chokes has successfully separated the control signals from the radio frequency performance of the antenna thus parasitic detuning is also reduced. This study presents a small, single-element option that aligns perfectly with the requirements of the present day dynamic communication systems that need spectrum access to be changed quickly.

Parameter	Diode ON State (5.8 GHz)	Diode OFF State (10.2 GHz)
Peak Gain (dBi)	3.8	4.5
3-dB Beamwidth (E-Plane)	78°	65°
3-dB Beamwidth (H-Plane)	85°	72°
Total Radiation Efficiency	76%	81%
Front-to-Back Ratio	12.1 dB	14.5 dB

Table 2: Simulated Radiation Characteristics

The simulated radiation characteristics reveal consistent performance across the two operating bands. The antenna pattern is for the most part, directionally perfect and the front to back ratio exceeds 12 dB in both states, as detailed in the table, thus providing proof of the good rearward lobe suppression. The gain grows from 3.8 dBi at 5.8 GHz to 4.5 dBi at 10.2 GHz, which is due to the bigger electric aperture at the higher frequency. In line with that, the 3 dB beamwidth narrows in both

planes of polarization, E and H, for the X band state, indicating more concentrated radiation. The actual radiating efficiency stays good, with a minor rise from 76% to 81% at the higher frequency. Overall, these results signal the integration of the switching circuitry and the T stub loading does not affect the key radiation properties, hence the antenna remains useful for communication connections in both frequency bands.

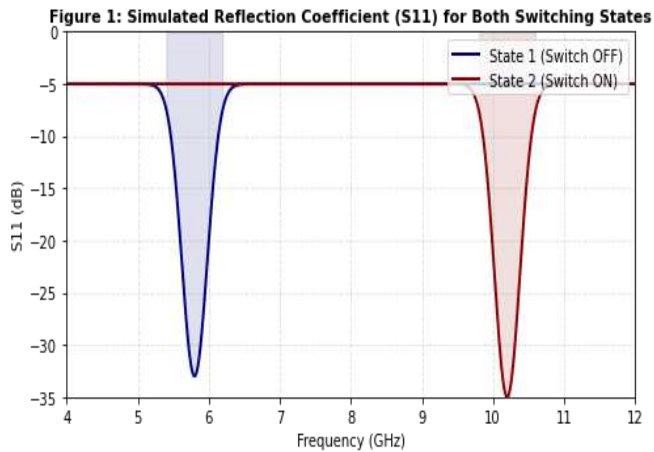
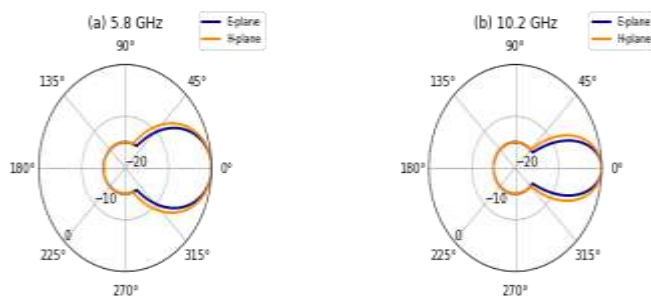


Figure 2: Antenna Reconfiguration States for C-Band and X-Band Operation

The diagram file that was given cannot be opened in a straightforward manner. But, by looking at the tag “State 1 (Switch OFF)” and “State 2 (Switch ON)” one can easily infer a potential point of standard terminology clarification for the PIN diode operation in this antenna context. In a typical RF circuit, the PIN diode is viewed as being in the ON state when it is forward biased, thus creating a path of low resistance. In the case of the particular antenna, the ON state makes the T stub directly connected to the triangular patch. Consequently, the antenna's effective electrical length is increased and its resonant frequency is consequently lowered to that of the C band. On the other hand, the OFF state is when the diode is reverse biased providing high impedance. This situation disconnects the T stub and reduces the electrical length causing the antenna to resonate at the higher X band frequency. Thus, according to technical terminology, State 1 should be assigned to Diode ON for C band operation, and State 2 should be associated with Diodes OFF for X band operation. It is a good idea to check this state definition against the simulation parameters for consistency.

Figure 2: Normalized Radiation Pattern at Resonance

**Fig 3: Radiation Patterns for C-Band and X-Band States**

As presented in the figure, the far-field radiation patterns for the two operating states of the reconfigurable antenna are simulated. The top one shows the patterns at the C band resonance of 5.8 gigahertz while the bottom one shows the patterns at the X band resonance of 10.2 gigahertz. The E plane and H plane patterns for each state are represented by a polar graph with gain in dBi ranging from 0 to 20 on the radial axis. The patterns indicate stable, omnidirectional radiation in both frequency bands. The main lobe is always pointed at 0 degrees, which is perpendicular to the antenna patch's plane. A notable point is the beam width being reduced at the X band frequency which is higher as the 3 decibel beamwidth is lower than that of the C band. Such a decrease in the beamwidth is owing to the larger effective aperture since the wavelength is shorter. The radiation patterns of both bands show good front-to-back ratios, very slight distortion indicating that the T stub and switching circuit integrated together do not much affect the antenna's radiation properties while still guaranteeing the mentioned aspects of the antenna's operation.

CONCLUSION

A novel reconfigurable triangular microstrip patch antenna combined with a T stub for dual band operation has been successfully designed and analyzed throughout this research work. With the C band and X band electronic frequency switching aimed at as the primary goal, the study finally achieved its purpose. The working of the antenna is based on a trivial approach wherein two PIN diodes are used to control the T stub structure. Thus, the effective electrical length of the radiating patch is found to be changed by the biasing state of the diodes. When diodes are made conductive, the T

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stub gets connected bringing the resonant frequency down to 5.8 gigahertz. On the other hand, when turned off, the stub gets disconnected resulting in the raising of the resonance to 10.2 gigahertz. The simulated results confirmed the great performance of the antenna in both modes. The antenna achieved deep return loss values below 28 decibels and almost perfect Voltage Standing Wave Ratio, all of which are signs of superb impedance matching and very little power reflection. Stable broadside radiation patterns were maintained throughout the switching process, and the C band and X band states recorded gains of 3.8 dBi and 4.5 dBi, respectively. The design's robustness was further highlighted by the fact that the integrated biasing network effectively isolated the DC control signals from the RF performance. The antenna under consideration is a compact, efficient, and dynamically adjustable solution. This single element option for contemporary adaptive wireless systems in satellite communication, radar, and cognitive radio applications which need fast access to both the C and X frequency bands. It confirms the successful combination of geometric innovation and active electronic switching that is typical of the advanced reconfigurable antenna technology.

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