Journal of Data Acquisition and Processing
ISSN: 1004-9037
https://sjcjycl.cn/
DOI: 10.5281/zenodo.7763398

A NOVEL DESIGN OF RECONFIGURABLE MICROSTRIP PATCH WITH INVERTED U-SLOT FOR MULTIBAND WIRELESS APPLICATIONS

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ABSTRACT: This paper presents a novel design for reconfigurable microstrip patch antenna capable of operating at multiple frequencies, specifically at 7.5, 10.7, 11.7, 16.5 GHz and 6.9, 13, 16.7 GHz. The antenna design consists of a modified patch entrust with rectangular and elliptical patch and two PIN diode for frequency tuning. The proposed antenna is fabricated on a low-cost FR-4 substrate with a dielectric constant of 4.4 and a thickness of 1.6 mm. The simulated results show that the antenna can achieve frequency tuning by changing the DC bias voltage applied to the PIN diodes. The proposed antenna shows good performance in terms of return loss, radiation pattern, and gain. The results indicate that the proposed reconfigurable microstrip patch antenna is a promising candidate for future communication systems that require frequency agility and reconfigurability.

KEYWORDS: Reconfigurable, return loss, PIN diode, multiband, frequency agility

I. INTRODUCTION:

With the ever-increasing demand for high-speed data communication and the emergence of various wireless communication systems, there is a growing need for agility and reconfigurable antenna that can operate at multiple frequency bands [1, 2]. Reconfigurable microstrip patch antennas have become a subject of increasing interest in recent years due to their potential to adapt to different operating conditions and improve the overall performance of wireless communication systems [3, 4] .These antennas are fabricated using modification in the physical design by disconnecting and connecting different part of radiating element through a switching device that gives a modification in distribution of current within the radiator [5, 6]. There are various types of on and off switches are applied to get redistribution of current in the radiator circuit [7, 8]. The switching can be getting using a PIN diode, RF MEMS or Varactor diode, lumped elements, or capacitance switches. Varactor and PIN diode can perform faster and can be a replacement for the RFMEMS [9, 10]. The switching speed of the PIN diode is 1-100 ns. It has a more dynamic ability to get a reconfigurable antenna [11, 12]. The reference articles present many reconfigurable antennas for different wireless applications. Frequency and pattern reconfigurability with the help of PIN diode and Vector diode is presented in the reconfigurable antenna [13-15]. These antennas are also designed using parasitic elements and beam steering techniques [16, 17]. In the field of biomedical application reconfigurable antennas with multiple polarization using pin diode and is analyzed and tested [17-20]. In the presented antenna design it has been found that when rectangular shape with an inverted U-slot is combine with an elliptical shaped patch, it gives a novel deign and antenna give better radiation pattern, good return loss and gain, good directivity and when it entrust with PIN diode it reconfigured the design and antenna operate multiple useful frequency bands. The performance of the presented antenna is compared with some other design as presented in table 2.

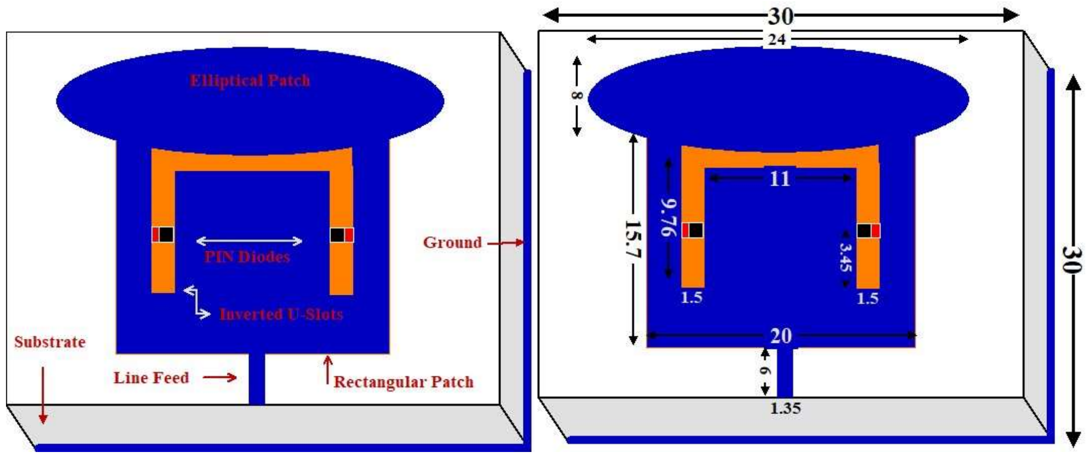


Fig.1: Presented Antenna design and dimensions

II. EVOLUTION OF ANTENNA DESIGN:

The proposed design obtains through the multiple stages of optimization as shown in fig.1. At the beginning a rectangular shaped FR4 substrate of size $32 \times 32 \times 1.6\ mm^3$ used as base of the antenna. A conducting rectangular shaped patch of dimension $20 \times 15.7\ mm^2$etched on that substrate. The rectangular shaped patch can be design as follow-

$$w = \frac{C}{2f}\sqrt{\frac{2}{\varepsilon_r+1}}\ ,\ \varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{2h}{w}}}\right),\ L_{eff} = \frac{C}{2f_r\sqrt{\varepsilon_r}}$$

The optimization of the radiating patch is done through the introduction of an inverted U slot and an additional elliptical shaped path joint to the rectangular patch. The position and dimensions are of the slot and the additional elliptical patch is obtained through the multiple steps of optimization and shown in Fig1. The inverted U slot produce lower order band of frequency and elliptical patch produce higher order resonance frequency. The antenna contains a plain ground structure. Proposed design the fed using a strip line feed of size $1.5 \times 6\ mm^2$.

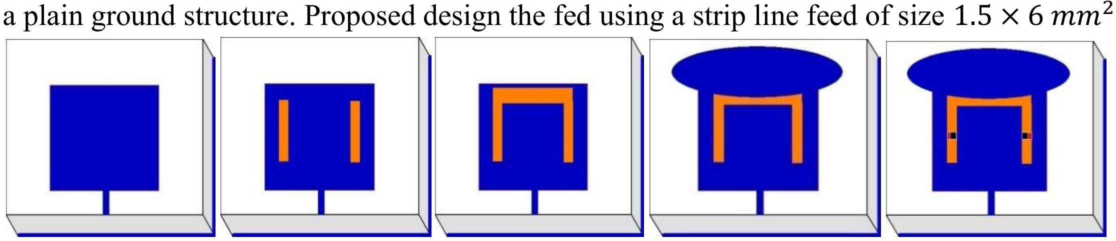


Fig.2: Evolution of proposed Antenna Design

The antenna design is reconfigured through PIN diode connected across the inverted U slot. The PIN diodes are operated and reconfigure the antenna geometry and thus the overall radiation characteristics.

The antenna that has evolved can operate in two modes. The first mode is when both PIN diodes are turned off. In this mode, the current in the radiating patch is distributed along with the patch, and the slots cause discontinuity which leads to resonance at multiple frequencies.. The continuous patch structure provides high gain at the resonance frequency, while maintaining VSWR within a specific range. The patch resonate four useful frequency when switches are off and three frequencies when diode switched off.

III. PARAMETRIC ANALYSIS:

The effect of the inverted U slot and the impact of the insertion of elliptical patch on the rectangular patch antenna performance can be analysed with the help of their equivalent circuits. The inverted U slot can be divided into the three individual rectangular slot and the effects of each slot and their equivalent circuit element on the performance of the antenna are discussed as follow. The equivalent circuit for a horizontal slot can be draws as follow.

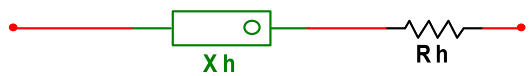


Fig.3. Equivalent circuit for rectangular slots

The total impedance of a horizontal slot is given as-

$$Z_H = R_H + X_H$$

As shown in Figure, the resonant frequency decreases as the slot width increases.

The patch can be treated as combination of rectangular patch and elliptical patch. The equivalent circuit and resonant frequency for rectangular patch can be represent and calculate as multiple reactance connected in parallel.

$$f_{mn} = \frac{c}{2\sqrt{\varepsilon_e}}[\left(\frac{m}{L_e}\right)^2 + \left(\frac{n}{W_e}\right)^2]$$

$$L_e = L + 2\Delta L$$

In an elliptical patch antenna, the semi-major axis, semi minor axis and effective semi-major axis are designated as a, b and $aeff$ respectively. The polarized frequencies are produced at two orthogonal modes, known as even and odd modes, using a single feed along a line inclined at 450 to the semi-major axis. Determination of dual resonance frequency can be carried out using the approximated Mathieu function as given below

$$a_{eff} = a\left[1 + \frac{2h}{\pi\varepsilon_r\, a}\ln\left(\frac{a}{2h}\right) + (1.41\,\varepsilon_r + 1.71) + ha\,0.268\,\varepsilon_r + 1.65\ 12\ (1)\right.$$

$$f_{11e,0} = \left(\frac{15}{\pi e a_{ff}}\right)\left(\frac{Q_{11e,0}}{\varepsilon_r}\right)^{\frac{1}{2}}$$

$$q_{11e} = -0.0049e + 3.7888e^2 - 0.7278e^3 + 2.314e^4$$

$$q_{110} = -0.0063e + 3.8316e^2 - 1.1351e^3 + 5.2229e^4$$

Where, a = length of semi-major axis;

h = height of dielectric substrate;

a_{eff} = effective length of semi-major axis;

ε_r =permittivity of dielectric substrate;

e = eccentricity of elliptical patch;

$f_{11\ ,0}$ = dual resonance frequency;

$q_{11e,0}$ = approximated Mathieu function of the dominant TM11 e.o mode.

The impact of fringe field between the edge of the patch and the dielectric substrate are considered in the following formula. An ellipse with semi major axis a and b the foci situated at ±c, where

$c = \sqrt{a^2 - b^2}, a = \frac{p}{f\sqrt{\mu\varepsilon}}, p = 0.275$ and the eccetricity of the ellipse is $E_c = \frac{c}{a}$

The equivalent circuit of the combination of rectangular patch and elliptical patch is as follow

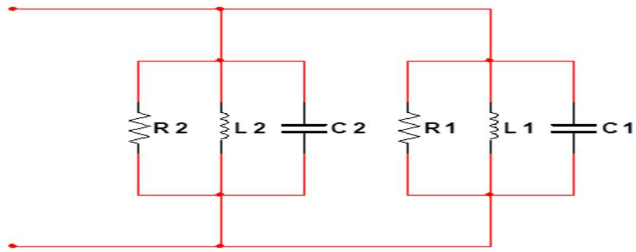


Fig.4. Equivalent circuit for combination of rectangular and elliptical patch

The equivalent circuit of whole antenna design loaded with rectangular and elliptical path and inverted U-slot is shown in the Fig.5. Based on cavity model it is considered as a parallel combination of elliptical and rectangular patch and inverted U-slot, reactance with resistance, capacitance and inductance of the circular patch.

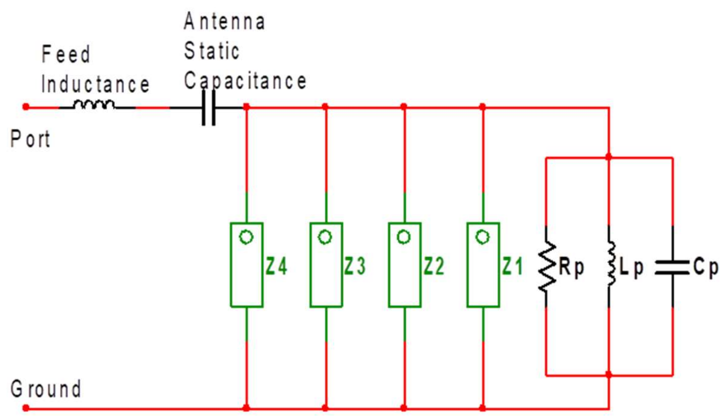


Fig.5. Equivalent circuit of proposed Antenna

Total impedance of patch without slot:

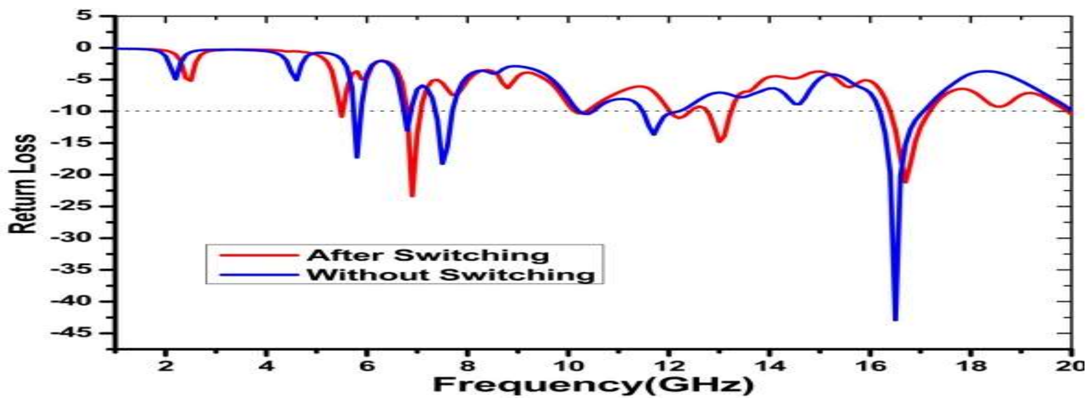
$$Z_p = \frac{1}{\frac{1}{R_1} + j\omega C_1 + \frac{1}{j\omega L_1}}$$

The total input impedance of the slot with all three slots is as follow:

$$Z_T = \frac{Z_{H_1} Z_{H_2} Z_e}{Z_{H_2} Z_e + Z_{H_1} Z_e + Z_{H_1} Z_{H_2}}$$

IV. RESULT AND DISCUSSION

A new antenna design for multiband wireless applications has been proposed. This design uses a simulated PIN diode (specifically the BAR64-03WE6327) to switch the entire band of frequencies. The diode's constant capacitance (CT) and reverse resistance (Rp) of about 100kΩ, which depend on the reverse voltage (up to -40V), allow for this switching. The antenna prototype was fabricated using the dimensions provided in Figures 4 and 5, incorporating two PIN diodes and having two states of operation. The simulated values of the antenna parameters, including return loss (S11), bandwidth, and voltage standing wave ratio (VSWR), are presented



in various figures.

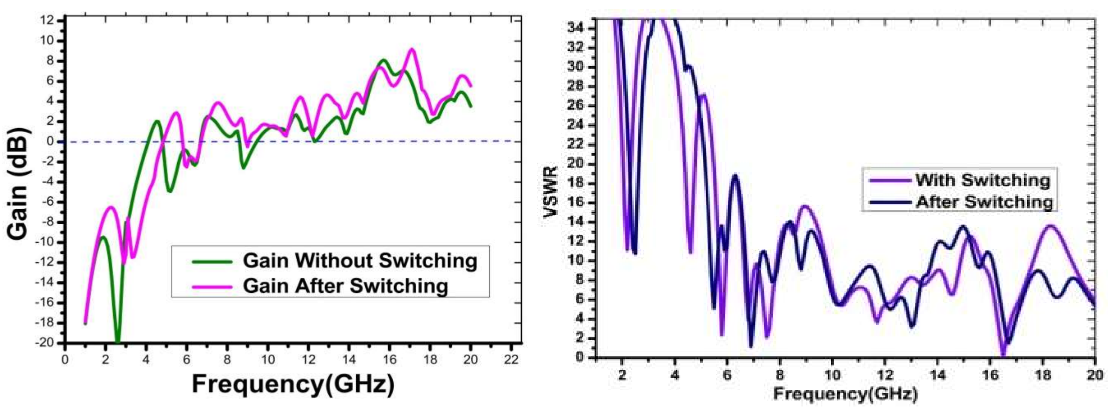


Fig.6: The Return Loss, Antenna Gain, and VSWR

When both diodes are switched off, the antenna acts as an open circuit in the current path over the radiating patch, polarizing four frequencies as 7.5, 10.7, 11.7, 16.5GHz. In contrast, when both diodes are in the ON state, the antenna works as a short circuit in the path of current flow and redistributes the current over the patch, polarizing three major frequencies as 6.9, 13, 16.7 GHz. The simulated result shows that these resonant frequencies have wide range applications with good gain and radiation pattern over the range.

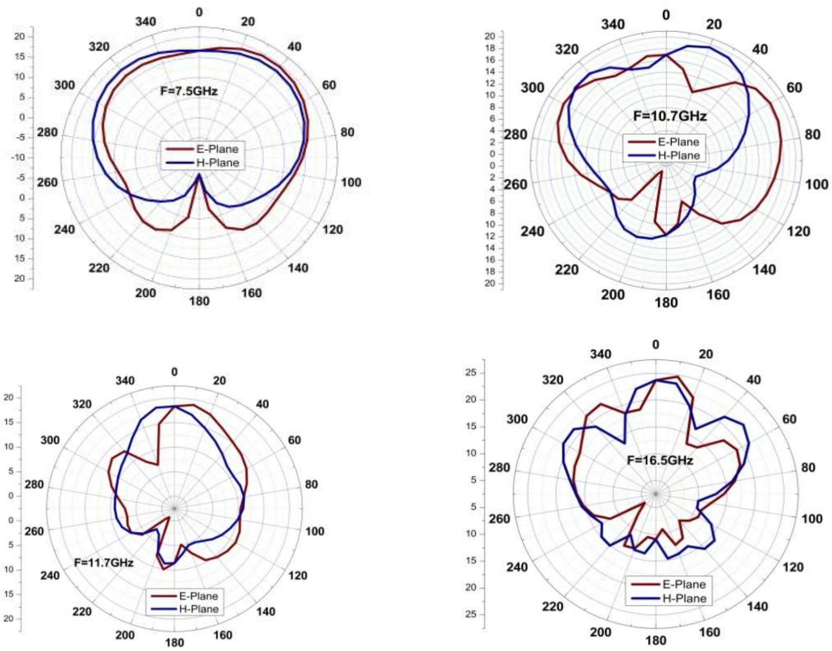


Fig.7: Radiation Patterns before switching

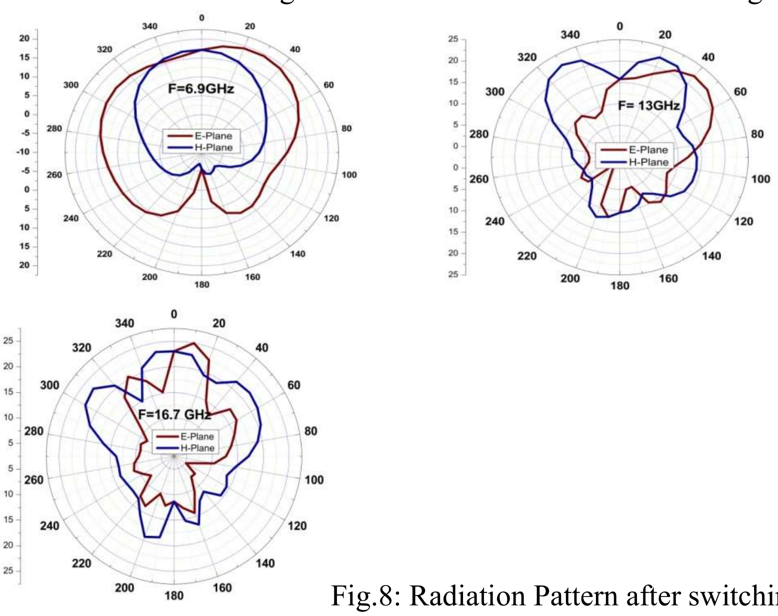


Fig.8: Radiation Pattern after switching

Position of switch	Resistance	Capacitance(pf)	Inductance(nH)	Supply (V)
OFF	R_{OFF} = 10 kΩ	C_{OFF} = 0.17	L_S = 0.4	0
ON	R_{on} = 4.7 Ω	--	L_S = 0.4	5

Table: 1 Characteristics of PIN Diode

Ref.	No of pin diode	No of band	Antenna size	Highest Bandwidth(GHz)	Max antenna gain (dB)	VSWR
[13]	3	6	30×30×1.6	3.54	3.96	1.11
[14]	3	3	20×20×1.57	0.6	2.72	NR
[15]	3	6	27×25×0.8	0.4	2.8	NR
[16]	2	1	70×70×1.6	0.14	2.0	NR
[17]	4	2	40×30×1.6	0.6	2.8	NR
Proposed	2	7	32×32×1.6	0.9	6.8	1.2

Table: 2 Comparison Table

V. CONCLUSION

The article introduces a novel antenna design that combines a rectangular and elliptical slot with an inverted U-slot, offering reconfigurable properties. The proposed design can change its behaviour across multiple bands in a unique combination of an elliptical patch, inverted U-slot, and switches while maintaining a small size and less complexity. This design has potential applications in unlicensed Wi-Fi and vehicular communication, satellite communication, 5G communication, RADAR, and more.

VI. ACKNOWLEDGEMENT

The authors express their gratitude to the members of the JK Institute of Applied Physics and Technology at the University of Allahabad, India, India, for providing lab facilities to simulate and evaluate the proposed antenna prototype.

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