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Frequency Reconfigurable Multiband Patch Antenna Using PIN-Diode for ITS Applications

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Abstract**—**A frequency reconfigurable multiband antenna for intelligent transportation system (ITS) applications is proposed in this paper. A PIN-diode is used for reconfigurability. Centre frequencies are 1.38, 1.98, 2.89, 3.86, and 4.34 GHz in "ON" state of Diode and 1.56, 2.16, 2.88, 3.91 and 4.45 GHz in "OFF" state. Achieved maximum bandwidth is 18%. The maximum gain of the proposed antenna is 2.7 dBi in "ON" state and 3.95 dBi in "OFF" state of the diode. The antenna is simulated, fabricated, and tested in the lab. Measured and simulated results are in good confirmation.

Keywords**—**ITS, multiband antenna, PIN-diode, reconfigurable.

I. Introduction

CURRENTLY, due to the rapid development of wireless communication, many applications are integrated in ITS. Users require many applications in a single device. For ITS application, the antenna is one of the essential components whose function is to interface with the propagating medium. Intelligent transportation systems demands antennas to be compact in size and be easily integrated into the system. In addition, they need to support different communications standards for various applications. Antenna can be made reconfigurable by use of different types of switches. In many proposals multiple switches are used to achieve frequency reconfigurability. But with the increments of switches, the complexity of the circuit also increases. That is why in this paper only one switch is used to cover many frequency bands. For multiband communications, many techniques were proposed for the designing antenna. Reference [1] investigated the slot excitation in various shapes with the help of numerical modeling of coplanar waveguide (CPW)-fed patch antenna. Lim et al. [2] presented a reconfigurable PIFA antenna design with PIN-diode and tunable varactor for the application of WCDMA, WLAN, m-WiMAX, and USPCS. Luxey et al. [3] reported a dual band CPW-fed antenna operation, using PIN-diodes. Mansour et al. [4] presented a switchable multiband microstrip patch antenna. Abutarboush et al. [5] reported reconfigurable wideband and multiband antenna for compact wireless devices using dual-patch. Yang et al. [6] presented a reconfigurable antenna with four polarization states using dual feed. Borhani et al. [7] reported a printed microstrip slot antenna for switchable multiband. Upadhyay et al. [8] reported switchable multiband microstrip patch antenna using the dual port.

In this paper, a compact single fed multiband reconfigurable antenna is designed and fabricated for ITS application. The antenna is loaded with the PIN-diode for the reconfigurability. The proposed antenna is small in size and it can be easily manufactured and used in ITS application.

This paper is divided into following sections. Antenna design is covered in Section II. Section III covers results and discussion. The vitals of the current proposed design are concluded in Section IV.

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II. Antenna Design and Parameters

The schematic structure of the multiband reconfigurable proposed antenna is shown in Fig. 2. FR4_epoxy is used as a substrate with relative permittivity (ε_r) = 4.36 with thickness (h) = 1 mm and loss tangent of (tanδ) = 0.002. The dimensions of proposed design are, length (L) of 17 mm and width (W) of 26 mm and ground plane have 29.6 mm (L)× 26 mm (W) and the width of feed line is 2.8 mm and length of 32 mm to gain 50Ω impedance, and a PIN-diode 0.4 mm × 0.4 mm is loaded between top view of two patches.

In this paper, the design of antenna cluster integrated the RF switch (PIN-diode). A BAR64-05 PIN-diode is used to control the antenna's electrical length to allow for operation at different frequency band while the physical dimension of antenna remained unchanged. The equivalent circuit of PIN-diode is shown in Fig. 1. PIN-diode has two states: "ON" and "OFF" state. The diode allows current flow when in "ON" state, but not in the other when it is in "OFF" state, it blocks RF energy. In the simulation, PIN-diode is loaded by using the RLC boundary sheet. In the "ON" state, PIN-diode is modelled as a series combination of resistance (R_f) and inductance (L_f). The value of resistance is 0.85 ohm (Ω) and inductance is 1.4 nH and in "OFF" state the capacitance value is 0.23 pF.

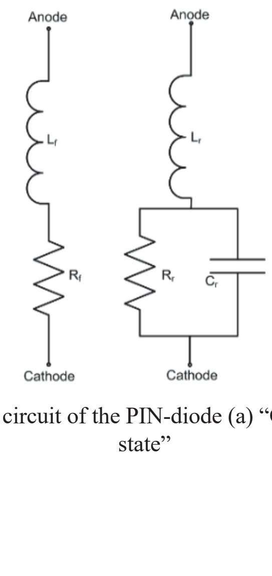
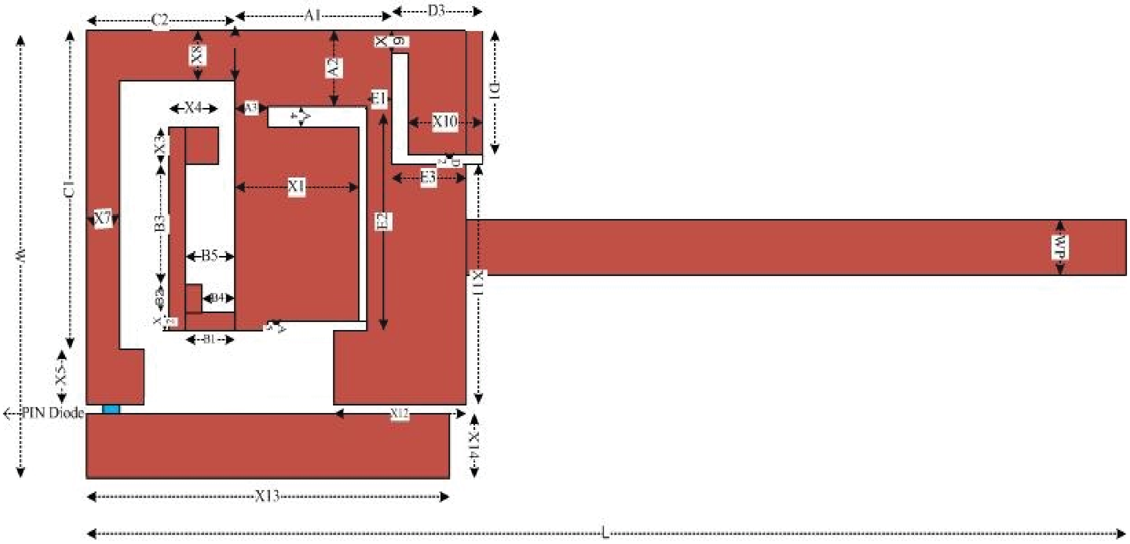
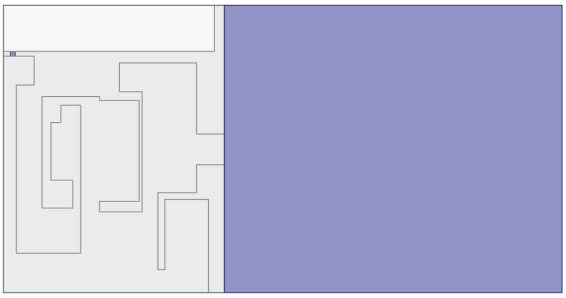


Fig. 1 Equivalent circuit of the PIN-diode (a) "ON" state (b) "OFF state"



(a)



(b)

Fig. 2 Proposed multiband reconfigurable antenna (a) top view (b) bottom view

The L-shape slot, inverted L-shape slot and G-shape slots in the proposed antenna facilitate the multiband characteristics and PIN-diode feed's capability. Due to the cut of slots from the patch the density of currents change and the different resonant frequencies are achieved. The PIN-diode is used to change in frequency bands.

The proposed antenna is fabricated using substrate FR4_epoxy material having thickness 1 mm. A PIN-diode is loaded between the patch as shown in Fig. 3. A connector is connected for the measurements of antenna parameters.

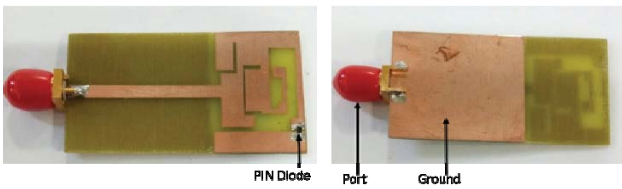


Fig. 3 Fabrication of proposed antenna

III. Results And Discussion

The proposed structure is designed and simulated using High Frequency Structure Simulator (HFSS v15) [11]. Return loss and radiation pattern of the proposed antenna are experimentally calculated. The PIN-diode is loaded in the slot between the patch as a perfect conductor in "ON" state.

TABLE I
VALUES OF THE PARAMETERS (IN MM)

Parameter	X1	X5	X9	X13	A3	B2	C1
Value	4.8	2.6	2.1	16.5	1.7	1.6	18.8
Parameter	X2	X6	X10	X14	A4	B3	C2
Value	6.8	2.7	3.7	4	1.0	5.2	6.8
Parameter	X3	X7	X11	A1	A5	B4	D1
Value	2.5	1.2	11.7	6.8	0.5	1.7	18.8
Parameter	X4	X8	X12	A2	B1	B5	D2
Value	2.7	3.6	6.8	7.3	3.4	2.6	0.6
Parameter	E4	W	L	D3	E1	E2	E3
Value	1.7	26	49	4.4	6.8	10.9	3.4

A. PIN-Diode in "ON" State

In "ON" state of diode, the proposed antenna resonates at multiple frequency bands. Fig. 4 shows the measured and simulated return loss of the proposed antenna. The return loss is observed to be below -10 dB and it is -29.81 dB, -25 dB, -29.47 dB, -23.53 dB and, -27.81 dB at resonating frequencies of 1.38 (1.25 GHz - 1.5 GHz), 1.98 (1.88 GHz - 2.1 GHz), 2.89 (2.77 GHz - 3 GHz), 3.86 (3.75 GHz - 3.97 GHz), 4.33 (4.33 GHz - 4.47 GHz), and 5.84 (5.675 GHz – 6.0 GHz), with bandwidth of 250 MHz, 530 MHz, 230 MHz, 220 MHz, 140 MHz, and 325 MHz respectively.

B. PIN-Diode in "OFF" State

In "OFF" state PIN-diode has a value of capacitance (C) = 0.23 pf. The proposed antenna resonates at 1.56 (1.52 GHz - 1.6 GHz), 2.16 (2.1 GHz - 2.22 GHz), 2.88 (2.75 GHz - 3 GHz), 3.91 (3.82 GHz - 4 GHz) and 4.45 (4.25 GHz - 4.65 GHz). The return losses is observed to be below -10 dB and it is -20.47 dB, -16.94 dB, -34.68 dB, -20.33 dB and -36.55 dB with the bandwidth of 80 MHz, 120 MHz, 250 MHz, 180 MHz and 400 MHz respectively as shown in Fig. 5.

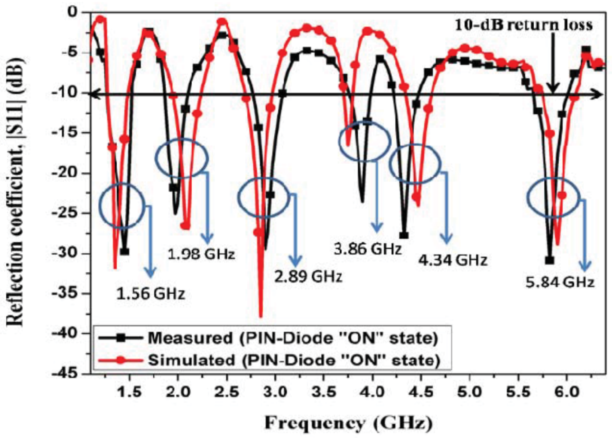


Fig. 4 Reflection coefficient |S11| versus frequency when PIN-diode in "ON" state

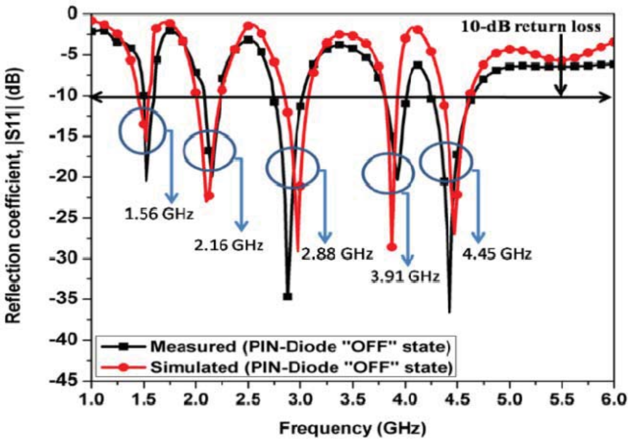


Fig. 5 Reflection coefficient |S11| versus frequency when PIN-diode in "OFF" state

The proposed antenna in "ON" state of diode resonates at six center frequency bands 1.38 GHz, 1.98 GHz, 2.89 GHz, 3.86 GHz, 4.34 GHz, and 5.84 GHz and in "OFF" state of diode five center frequency bands 1.56 GHz, 2.16 GHz, 2.88 GHz, 3.91 GHz and 4.45 GHz are obtained. Results show a good agreement in both simulated (red line) and measured (black line) results. There is small difference occurs between simulation and measurements results due to the feed line because no feeding cable is used in simulation. However, in measurements, a feeding cable is used to connect the antenna for measurements. The antenna is very useful for the ITS applications. A single antenna enables many frequency bands used in ITS applications.

The current distribution of the proposed antenna at all resonant frequencies in "ON" and "OFF" states of PIN-diode are shown in Fig. 6. For center frequency band 1.38 Fig. 6 (a) shows that the surface currents mainly distributed at the edges of patch. The current is mainly distributing at the edge of Inverted L-shape and edge of patch due to which the coupling between patch and inverting L-shape slot is very high, and the resonant frequencies occurs at 1.98 GHz, 2.16 GHz, 2.89 GHz, and 3.91 GHz frequency bands as shown in Figs. 6 (b), (g), (c), and (h). Fig. 6 (f) shows the current of 1.56 GHz frequency band the inverted L-shape, edge of patch, and at the point of diode mainly maximum currents distributes. 3.86 GHz frequency band occurs mainly due to Inverted L-shape slot and Figs. 6 (i), (e), and (j) frequency band currents distribution shows that the maximum currents flow at the patch and the slots due to which these frequency bands occur.

The radiation pattern of the proposed antenna at its operating frequencies for E-plane and H-plane are shown in Fig. 7. The radiation pattern of antenna at resonant frequencies are measured in anechoic chamber. The antenna is the almost omnidirectional antenna. The proposed antenna is radiating in broadside direction and has a good gain at the operating frequencies. The measured and simulated radiation pattern results of the antenna show that there is some distortion between measured and simulated results due to setup.

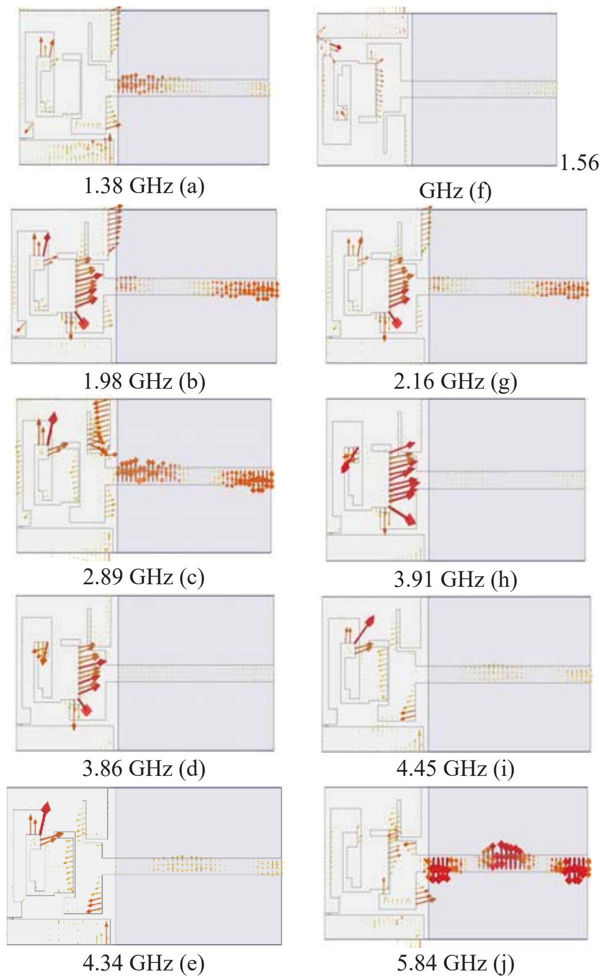


Fig. 6 Vector current distribution of antenna

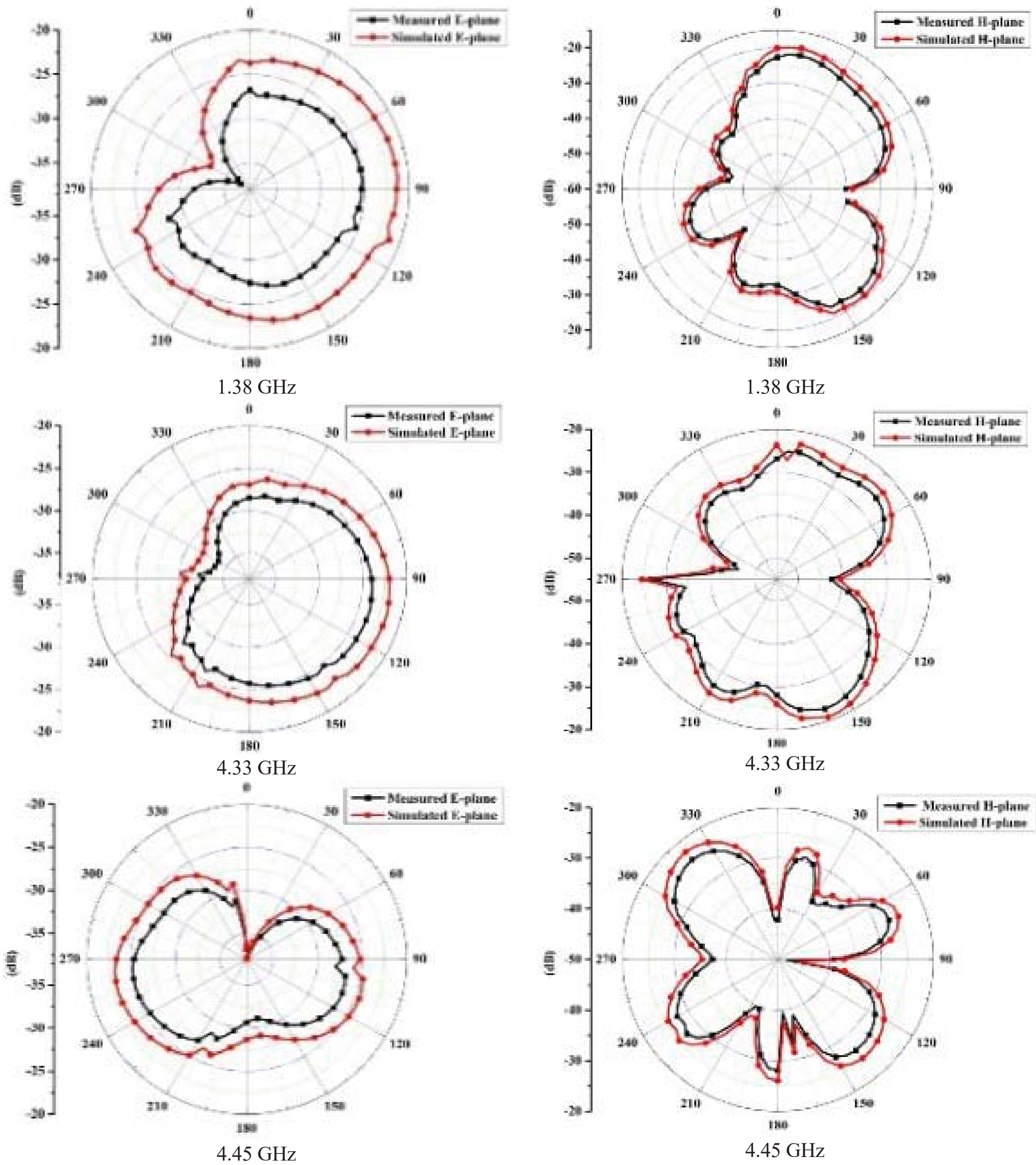


Fig. 7 Radiation pattern of the proposed antenna at center frequency 1.38 GHz, 4.33 GHz, and 4.45 GHz

TABLE II
COMPARISON OF PROPOSED ANTENNA WITH PREVIOUS WORK

Reference	Size (mm)	Diode state	Resonant Frequency (GHz)	Bandwidth	Peak Gain
[9]	40×15 mm^2	ON	2.64, 3.67, 4.94, 5.30	21.1 %	3.61 dBi
		OFF	2.45, 3, 3.69, 5.5	12.5 %	3.11 dBi
[7]	20×20 mm^2	OFF-OFF-OFF	2.4	8.7 %	0.85 dBi
		ON-ON-OFF	3.5	11.2 %	1.5 dBi
		ON-ON-ON	5.5	11 %	1.95 dBi
[10]	35×6.5 mm^2	ON	3.45, 5.46	19.5 %	4.64 dBi
		OFF	2.37, 3.42, 5.8	17.9 %	1.3 dBi
Proposed work	26×49 mm^2	ON	1.38, 1.98, 2.89, 3.86, 4.34, 5.84	18 %	5.7 dBi
		OFF	1.56, 2.16, 2.88, 3.91, 4.45	8.9 %	3.95 dBi

IV. CONCLUSION

In this paper, a multiband reconfigurable microstrip patch antenna is designed using PIN-diode for ITS application. Its frequency response can be efficiently switched by using a PIN-diode. In "ON" and "OFF" state of PIN-diode, the antenna resonates at different frequencies. In "ON" state of diode frequencies 1.38 GHz, 1.98 GHz, 2.89 GHz, 3.86 GHz, 4.34 GHz and 5.84 GHz which is suitable for the applications of GPS, Wi-Fi, WiMAX Radar and ITS applications. In "OFF" state antenna resonates multibands at the center frequencies of 1.56 GHz, 2.16 GHz, 2.88 GHz, 3.91 GHz and 4.45 GHz which is suitable for the application of WiMAX, Satellite communication, Public Safety Security and Personal Area Networks. The maximum gain of the antenna is 5.7 dBi at 4.3 GHz in "ON" state and 3.95 dBi in "OFF" state at 1.56 GHz. The simulated results give good radiation pattern which is omnidirectional in E-plane and H-plane and gain is also very good for ITS applications.

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