International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:12, No:1, 2018

PIN-Diode Based Slotted Reconfigurable Multiband Antenna Array for Vehicular Communication

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Abstract**—**In this paper, a patch antenna array design is proposed for vehicular communication. The antenna consists of 2-element patch array. The antenna array is operating at multiple frequency bands. The multiband operation is achieved by use of slots at proper locations at the patch. The array is made reconfigurable by use of two PIN-diodes. The antenna is simulated and measured in four states of diodes i.e. ON-ON, ON-OFF, OFF-ON, and OFF-OFF. In ON-ON state of diodes, the resonant frequencies are 4.62-4.96, 6.50-6.75, 6.90-7.01, 7.34-8.22, 8.89-9.09 GHz. In ON-OFF state of diodes, the measured resonant frequencies are 4.63-4.93, 6.50-6.70 and 7.81-7.91 GHz. In OFF-ON states of diodes the resonant frequencies are 1.24-1.46, 3.40-3.75, 5.07-5.25 and 6.90-7.20 GHz and in the OFF-OFF state of diodes 4.49-4.75 and 5.61-5.98 GHz. The maximum bandwidth of the proposed antenna is 16.29%. The peak gain of the antenna is 3.4 dB at 5.9 GHz, which makes it suitable for vehicular communication.

Keywords**—**Antenna, array, reconfigurable, vehicular.

I. Introduction

IN vehicular communication systems, antenna with high gain and good bandwidth are desirable to accommodate fluctuations caused by vehicular mobility that can be in the form of power loss and Doppler shift. Vehicle–to–vehicle (V2V) and vehicle–to–infrastructure (V2I) communications are main aspects in vehicular communication systems to increase safety and ease of transportation. A vehicle is required to support both V2V and V2I simultaneously. Therefore, multiband reconfigurable antenna is needed to meet the stringent requirement of modern vehicular communication systems with high performance and compact size. A fairly high performance of antenna can be obtained by using antenna array instead of a single antenna. So design and development of a high performance antenna array is a challenging and popular issue in antenna research. Sayeed [1] et al. reported maximizing multiple input multiple output (MIMO) capacity in sparse multipath with reconfigurable antenna arrays. Piazza [2] et al. reported a reconfigurable antenna array for MIMO systems. The antenna system contains two printed dipoles separated by a distance of a quarter wavelengths. The dipoles can be reconfigured in length using PIN–diodes. Fertas [4] et al. reported multiband antenna array for modern communication systems. Byford [5] et al. reported a frequency reconfigurable patch antenna array. The array contains planar radiating elements. Radiating elements may be interconnected through switches to obtained larger elements radiating at frequencies lower than the resonant frequency of the individual elements. Row [6] et al. reported pattern reconfigurable antenna array. The reported antenna consists of four–sector antenna configuration, and each sector element can generate unidirectional radiation with circular polarization. Senanayake [7] et al. reported performance analysis of reconfigurable antenna array. Zhao [8] reported a frequency and pattern reconfigurable antenna array based on liquid crystal (LC) technology. The antenna contains two parts; one is microstip patch array and other is a phase shifter using the inverted microstrip line (IMSL). For controlling the resonance frequency response, the LC substrate is used while IMSL phase shifter is implemented to tune the transmission phase by changing the effective dielectric constant of the LC.

This paper is divided in following sections: Section II gives the antenna design specifications. Results and discussion are covered in Section III. Section IV concludes the vitals of the current proposed design.

II. Antenna Design and Specification

The schematic structure of the proposed 2-element multiband reconfigurable array antenna is shown in Fig. 1. The proposed antenna consists of reconfigurable rectangular slotted patch array. In this design all parameters are investigated, and a parametric structure is designed in order to design compact size antenna. The total length of the proposed antenna is $W \times L$. Two rectangular patches with size of $l_1 \times w_1$ are designed. The patches are slotted with the dimension of w_2, l_2, l_5, w_5, and w_8.

For reconfigurability the antenna is loaded with two PIN-diodes. Two PIN-diode BAR64-02 are loaded between patch and feed line as shown in Fig. 1. In "ON" state the resistance value is 0.85 Ω and in "OFF" state the capacitance value is 0.23 *pF*. A 50 Ω microstrip feedline feed is attached to microstrip patch antenna.

TABLE I
Dimensions of the Proposed Antenna in mm

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
L	50	l_3	9	l_6	27
W	50	w_3	2	w_6	11.6
l_1	22	$l4$	18	w_7	3
w_1	24	w_4	1	w_8	1
l_2	14	l_5	3	w_9	2
w_2	l_2	w_5	0.5		

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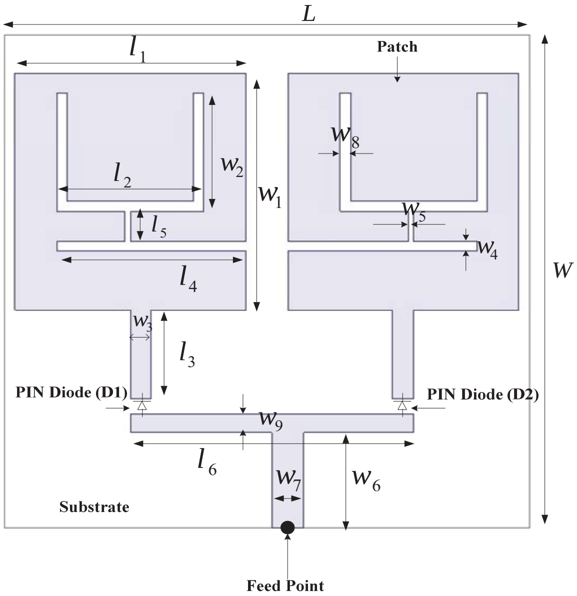


Fig. 1 Schematic structure of the 2-element patch array antenna

The proposed antenna structure is fabricated using substrate Rogers/rtduroid 5880 having dielectric constant 2.2 and thickness 1.57 mm. The fabricated antenna is measured using vector network analyzer (VNA) (Rohde & Schwarz). The radiation pattern is measured in anechoic chamber.

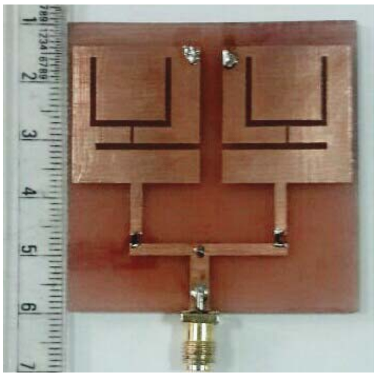


Fig. 2 Hardware structure of proposed antenna

III. Results and Discussion

The proposed antenna is simulated using HFSS v15 [9]. The antenna is simulated and measured in four states of PIN-diodes (D1, D2): ON-ON, ON-OFF, OFF-ON and OFF-OFF.

A. When Both Diodes (D1, D2) Are in "ON" State

When both diodes (D1, D2) are in "ON" state the measured and simulated reflection coefficients versus frequency plot is shown in Fig. 3. In this state, the measured resonant frequencies are F1 = 4.79 GHz, F2 = 6.625GHz, F3= 6.98GHz, F4 = 7.78 GHz, and F5 = 8.99 GHz with return loss (S11) -27.23 dB, -33.56 dB, -15.65 dB, - 11.5dB and -12.6 dB with the respective bandwidth of 340 MHz, 250 MHz, 110 MHz, 880 MHz, and 200 MHz respectively. The black line shows the simulated data and red lime shows measured data. The result shows a good matching between measured and simulated results of S11 in "ON" state.

B. When Diode D1 Is "ON" and Diode D2 Is "OFF" State

When diode D1 is "ON" and diode D2 is "OFF" state, the measured and simulated results between |S11| and frequency are shown in Fig. 4. The measured resonant frequencies are F1= 4.78 GHz, F2= 6.6 GHz and F3= 7.86 GHz with maximum return loss |S11| -44, -30.57, and -11.5 dB with bandwidth of 300 MHz, 200 MHz, and 1000 MHz respectively. The result shows good agreement between measured and simulated results.

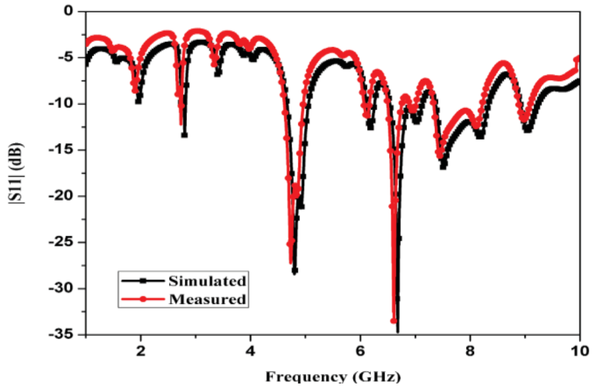


Fig. 3 Reflection coefficient |S11| versus frequency, when both diodes are in "ON" state

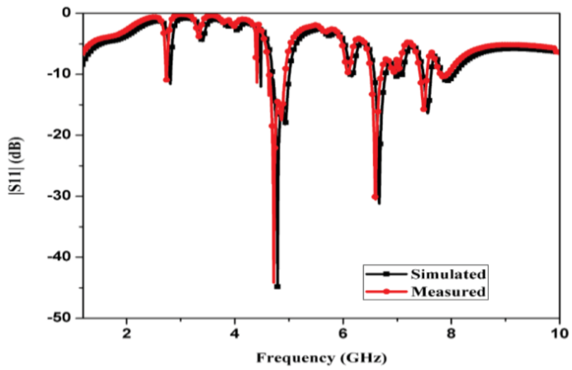


Fig. 4 Reflection coefficient |S11| versus frequency, when D1 is "ON" and D2 is "OFF"

C. When Diode D1"OFF" and Diode D2 is "ON" State

Fig. 5 shows the measured and simulated results, when diode D1 is "OFF" and diode D2 is in "ON" state. In this condition the results show that the return loss |S11| is maximum at the center frequency F1= (1.24 GHz – 1.46 GHz), F2= (3.4 GHz – 3.75 GHz), F3= (5.07 GHz – 5.25 GHz), and F4= (6.9 GHz – 7.2 GHz) with maximum return loss – 18.21, – 24.4, – 23.97, and – 26.36 dB with the bandwidth of 220 MHz, 350 MHz, 180 MHz and 300 MHz. The measured and simulated results are very close to each other.

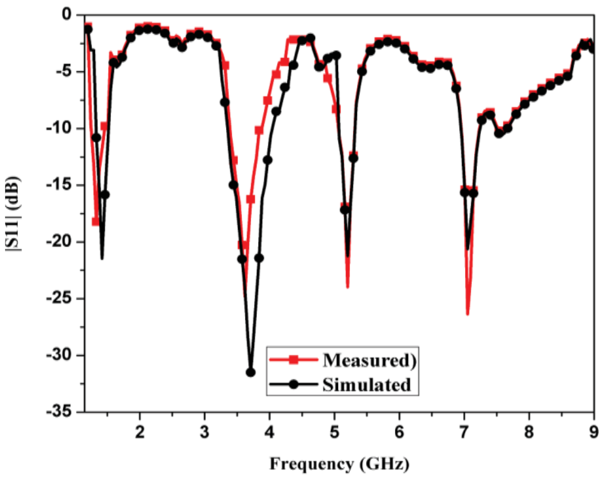


Fig. 5 Reflection coefficient |S11| versus frequency, when D1 is "OFF" and D2 is "ON"

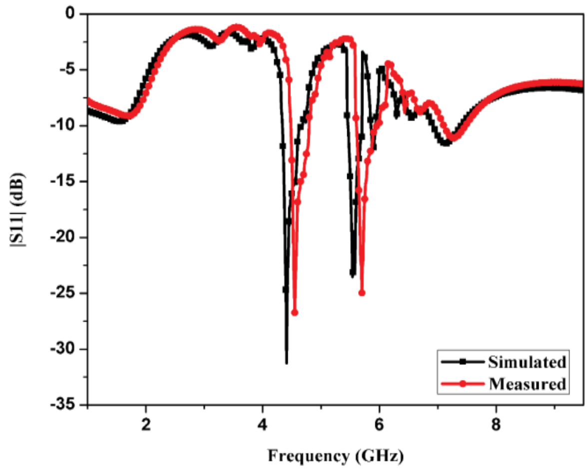


Fig. 6 Reflection coefficient |S11| versus frequency, when D1 is "OFF" and D2 is "ON"

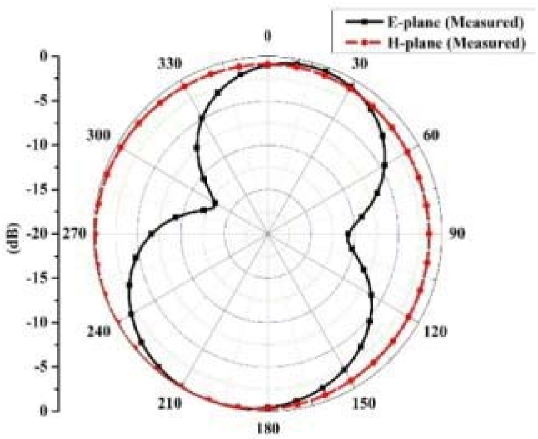
D.When Both Diodes (D1, D2) Are in "OFF" State

The simulated and measured results of the antenna are shown in Fig. 6, when both diodes are in "OFF" state. In this state of diodes, the results shows that the two resonant frequency occur at 4.62 (4.49 – 4.75) GHz and 5.79 (5.61 – 5.98) GHz. The maximum return loss at 4.62 GHz is -26 dB and -24.6 dB at 5.79 GHz. The bandwidth for center frequency is 460 MHz at 4.62 GHz and 370 MHz at 5.79 GHz. The simulation and measured results are very close to one another, but measured results not exactly match with simulation results. This is due to the use of cable in measurement of antenna parameters and in simulation there is no cable connection is used for measurement of antenna parameters.

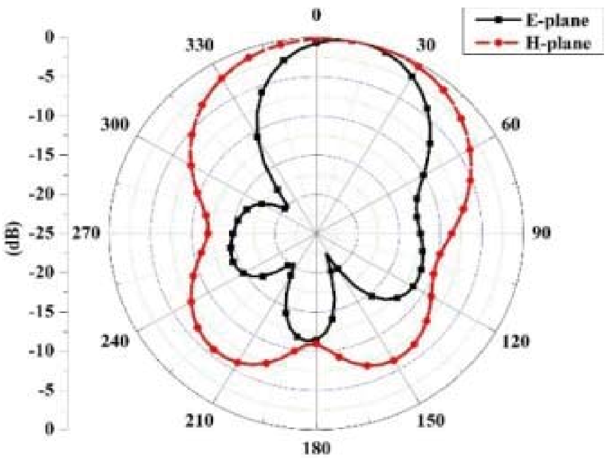
TABLE II
MEASURED RESULTS OF PROPOSED ANTENNA IN DIFFERENT-DIFFERENT STATE OF DIODES

Diode	Diode state	Frequency range (GHz)	Return loss |S11| (dB)
D1 and D2	ON-ON	(4.62 – 4.96) GHz	–27.23
		(6.50 – 6.75) GHz	–33.56
		(6.90 – 7.01) GHz	–15.65
		(7.34 – 8.22) GHz	–11.50
		(8.89 – 9.09) GHz	–12.6
D1 and D2	ON-OFF	(4.63 – 4.93) GHz	– 44
		(6.50 – 6.70) GHz	– 30.57
		(7.81 – 7.91) GHz	–11
D1 and D2	OFF-ON	(1.24 – 1.46) GHz	– 18.21
		(3.40 – 3.75) GHz	– 24.4
		(5.07 – 5.25) GHz	– 23.97
		(6.90 – 7.20) GHz	– 26.36
D1 and D2	OFF-OFF	(4.49 – 4.75) GHz	– 26
		(5.61 – 5.98) GHz	– 24.6

The far-field radiation pattern of proposed antenna is shown in Fig. 7. The far-field radiation pattern of the antenna shows that the antenna radiates in omnidirectional. Fig. 8 shows the current distribution of proposed antenna. The peak gain of the antenna is 3.4 dB at 5.9 GHz.



(a)



(b)

Fig. 7 Measured radiation pattern at (a) 1.2 GHz (b) 5.9 GHz

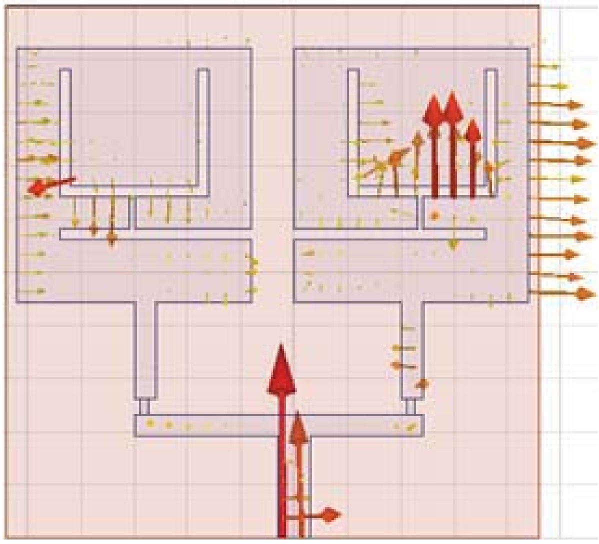


Fig. 8 Current distribution of proposed antenna array

TABLE III
COMPARISON OF RECENTLY PUBLISHED WORK WITH PROPOSED WORK

Sl. No.	Reference	No. of switch	Antenna size (mm)	Resonant Frequencies	Bandwidth
1.	[3]	4	95×60	2.05 GHz-2.18 GHz	6.1%
2.	[5]	-	68×68	2 GHz, 5 GHz	-
3.	[6]	5	-	1.9 GHz-2.3 GHz	19%
4.	Proposed work	2	50×50	4.79 GHz, 6.625 GHz, 6.95 GHz, 7.78 GHz, 8.99 GHz, 1.35 GHz, 3.75 GHz, 5.16 GHz, 5.79 GHz	7%, 3.7%, 1.5%, 11.18%, 2.22%, 1.20%, 16.29%, 3.40%, 6.3%

IV. CONCLUSION

A compact 2-element multiband reconfigurable array antenna is designed and fabricated. Two PIN-diodes are used as switch. The antenna is fabricated and experimentally tested. The patch is slotted for achieving multiband behavior. Two PIN-diodes are loaded for reconfigurability. The antenna is simulated and measured in four states of diodes. In ON-ON state of diodes the resonant frequencies are (4.62 – 4.96) GHz, (6.50 – 6.75) GHz, (6.90 – 7.01) GHz, (7.34 – 8.22) GHz, (8.89 – 9.09) GHz. In ON-OFF state of diodes the measured resonant frequencies are (4.63 – 4.93) GHz, (6.50 – 6.70) GHz and (7.81 – 7.91) GHz. In OFF-ON states of diodes the resonant frequencies are (1.24 – 1.46) GHz, (3.40 – 3.75) GHz, (5.07 – 5.25) GHz and (6.90 – 7.20) GHz and in OFF-OFF state of diodes (4.49 – 4.75) GHz and (5.61 – 5.98) GHz. The antenna is suitable for GPS, WLAN, WiMAX, DSRC, and other wireless applications in vehicular communication.

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