Defence Science Journal, Vol. 70, No. 5, September 2020, pp. 486-492, DOI : 10.14429/dsj.70.15155

Dual Frequency Electronically Controlled Radiation Beam Reconfigurable slotted Antenna for Detection of a Stationary or Nonstationary Target

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ABSTRACT

A dual-frequency and radiation pattern reconfigurable microstrip patch antenna for detecting a stationary as well as a non-stationary target is described. Six angular patches, that collectively form a circular shape, are used. All the six patches radiate one by one after a fixed interval of time and their feed controlling is done by six PIN diodes. The switching of PIN diodes is controlled by an embedded biasing network. This antenna provides radiation beam scanning characteristics. It gives the main lobe scanning at every 60° clockwise (or anticlockwise) continuously by applying a signal to patches one by one. The purpose of introducing the slot is to get the radiation pattern in the desired direction since by changing the length, width, and position of the slot, the direction of the radiation pattern can be controlled. The slotted antenna operates in a C band with two frequencies 4.21 GHz and 4.82 GHz and provides a radiation pattern, 90° apart from each other. The scanning rate of 0.6 deg/ms is obtained; however, the scanning rate can be changed with the help of ATMEGA 2560 microcontroller. This compact Microstrip patch antenna can be widely used for short-range applications i.e. ground surveillance radar, missile control, mobile battlefield surveillance for military and many other applications in a modern wireless communication system. The designed antenna along with the switching application will be able to track the stationary as well as a non-stationary target.

Keywords: Radiation pattern reconfigurable antenna; Beam scanning; Non-stationary target; PIN diode; Embedded biasing network

1. INTRODUCTION

Reconfigurable antennas is very popular in modern wireless communication because it provides variety in antenna performance to satisfy diverse communication requirements[1]. There are four types of reconfigurable antennas, frequency reconfigurable antenna, polarisation reconfigurable antenna, radiation pattern reconfigurable antenna and combination of these three[2]. It is a challenge to scan a non-stationary object. Various techniques have been proposed for scanning the non-stationary target. In most of these, the authors have presented patch antenna arrays for beam scanning. In this type of patch antenna arrays, they have used multi-feeding techniques which are very difficult to mount and require more area[3].

A frequency beam-scanning array antenna operating at Y band (220-325 GHz) has been proposed[4]. It is a travelling wave antenna with meandered rectangular waveguide for frequency beam scanning. Beam steering may also be accomplished by switching the antenna elements or by changing the relative phases of the RF signals used for driving the elements[5]. The beam-scanning method is applied when all the patches are mutually synchronised, which is only possible when all patches are of the same size. The direction of the target may be determined by the directivity of the antenna[6]. Physical sensors can be integrated with a reconfigurable antenna to build it as a reconfigurable sensing antenna (RSA)[7]. Automotive radar is a current technology for ensuring the safety of the driver in the future[8]. For the automotive UBW radar sensor, a grid antenna array with 33 radiating elements has been proposed[9]. A distance measurement method for a short-range radar system by using a direct sequence ultra wideband system has been proposed[10]. An ultra-wideband antenna (3.1 GHz to 10.6 GHz) with two notched characteristics at WiMAX and WLAN (3.4/3.5 GHz) using two nested C slots on the patch and CPW transmission line was proposed[12]. Multi-beam antennas have been studied extensively and realised using diverse techniques.

Very few research papers are currently available on a microcontroller-based electronic beam steering system for the detection of stationary as well as a nonstationary target. This motivates us to design and develop a microstrip antenna with a rotating radiation pattern. The rotation of the radiation pattern is based on six microstrip patches, six PIN diodes and a micro-controller based driver circuit. This circuit uses ATMEGA 2560 microcontroller for controlling the switching of 6 PIN diodes. A microcontroller-controlled embedded biasing network (EBN) has been used to control the PIN diodes and varactor diodes for achieving a frequency reconfigurable behavior in multi-band microstrip antenna by Romputtal[13], *et al.*

In this paper, the authors present a pattern reconfigurable antenna to track a non-stationary object with the help of RF

Received : 25 September 2019, Revised : 05 July 2020
Accepted : 31 July 2020, Online published : 08 October 2020

PIN diode switching. In this work, a beam-steering radiation pattern is achieved with the help of six PIN diodes. Switching positions of these diodes is controlled by a microcontroller-based embedded biasing network. By using the microcontroller-based EBN, there is no need for passive elements for biasing and this embedded biasing network can be integrated with Microstrip antenna on a single PCB. As the target enters into radiation beam of the antenna, the echo signal is detected. The patch radiating at that instant provides information about the direction of the target as shown in Fig. 1(a). When the target enters the radiation pattern, the amplitude of the received echo is very small. When the target penetrates deeper into the radiation pattern, the amplitude of the received echo is large as shown in Fig. 1(b). Thus with the knowledge of amplitude and time interval between two consecutive echoes, speed and distance of the target can be calculated.

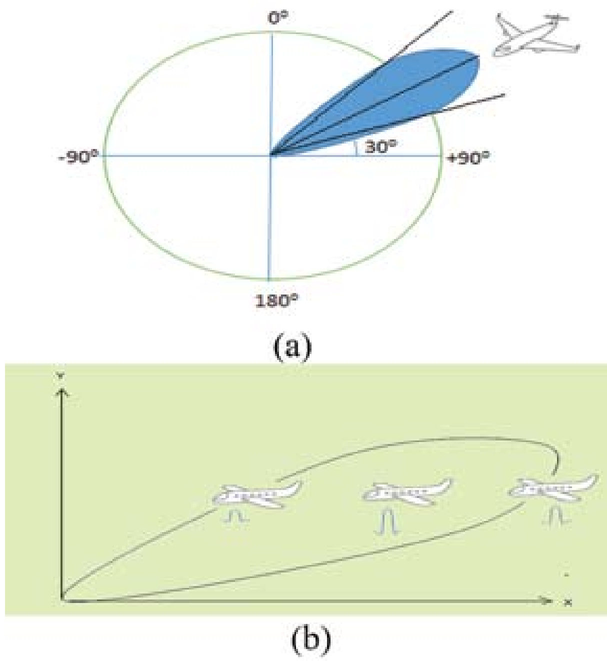

Figure 1. Application of beam scanning antenna (a) Direction and (b) Speed/distance detection.

2. ANTENNA DESIGN CONSIDERATION

This section is divided into two parts. Discussion about the design of an antenna is covered in the first part. The methodology of achieving reconfigurable behaviour in the radiation pattern is discussed in the second part. In this design, it is kept in mind that resonant frequency will remain the same for every radiating patch, and only radiation direction (angle) will change. For the above condition, an angular patch is designed. Authors have used the sectoral microstrip patch antenna design formulae for calculating the radius R_3 of the patch[14]. The radius (R_3) of the patch is optimised for better results and is found to be 31 mm. Similar six angular patches of angular width 50° are designed. All six small patches of angular width 50° are kept 10° apart from each other as shown in Fig. 2(a). The feed circle radius (R_1) is optimised for better results and is found to be 4.2 mm. A 50-ohm coaxial probe is used for exciting the feed circle. Six PIN diodes are used for connecting six patches with feed circle as shown in Fig. 2(a). When an individual patch is excited, the corresponding PIN diode is turned ON and rest five PIN diodes are turned OFF. The ON-OFF controlling of these diodes is done by a microcontroller with the help of a program that provides a 100ms delay between switching of two consecutive PIN diodes. Since switching time is negligible, each patch will radiate for 100 ms. Two designs of the patch are proposed ,one without a rectangular slot and other with a rectangular slot.

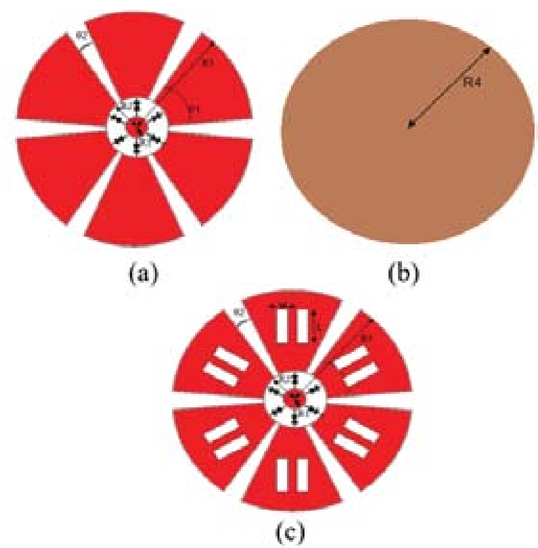

Figure 2. Antenna design: (a) Patch without slot, (b) Ground plane, and (c) Slotted patch.

Figures 2(a) - 2(c) show the design of the simple patch, ground plane, and slotted patch respectively of the proposed antenna. All dimensions of the antenna are given in Table 1. The designed antenna is fabricated and tested. The fabricated antenna is shown in Fig. 3. Two small rectangular slots are fabricated on every patch as shown in Fig. 2(c) to achieve antenna radiation in the desired direction. Apart from this, it also provides a new resonant frequency. The length and width of the slot are optimised to ensure that radiation remains between the X-axis and the Y-axis. And the radiation of the antenna is obtained orthogonal to each other at both received resonant frequencies.

Table 1. Dimensions of the proposed antenna

Radius /angle	mm/degree
R_1	4.2 mm
R_2	6 mm
R_3	31 mm
R_4	25 mm
L (slot length)	10 mm
W (slot width)	3 mm
θ_1	50 degree
θ_2	10 degree

This antenna can be used for dual frequency band operation to achieve the requirements of modern communication. Rectangular slot performs as a series resonant circuit, so that the total impedance of the patch is changed[15]. Due to changes

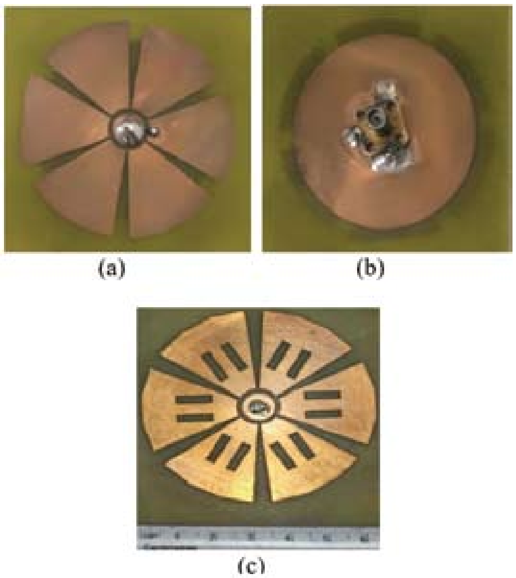

Figure 3. Fabricated antenna: (a) Patch without slot, (b) Ground plane, and (c) Slotted patch.

in impedance, another current flow on the patch and antenna resonates at other frequencies.

3. EMBEDDED BIASING NETWORK

The microcontroller-based embedded biasing network (EBN) is used as a driving circuit that works on DC supply, it may get damaged if an AC signal reaches its terminals. The antenna is used to radiate the AC (high frequency) electrical signal coming from the AC source and to receive EM waves. The AC source and antenna needs to be protected from the DC signal. So there must be a separation between AC signals from antenna or AC source and DC signal from embedded biasing network. The authors have used the circuit made up of capacitors and inductors as shown in Fig. 4 which will separate the AC and DC signal and avoid the hazards. Here, two capacitors C_{b1} and C_{b2} of values 0.1uF are used to block the DC signal coming from EBN and protect the AC source and antenna. Similarly Two R.F. coils of values 6.8 nH are used to block the AC signal from source or antenna and protect the Embedded biasing network.

The ON and OFF timing of a PIN diode can be controlled by using a microcontroller (ATMEGA 2560). The circuit consists of ATMEGA 2560 microcontroller, Signal conditioning circuit, and AC-DC separator circuit as shown in Fig. 5. The port '0' of the microcontroller is used as an output port which

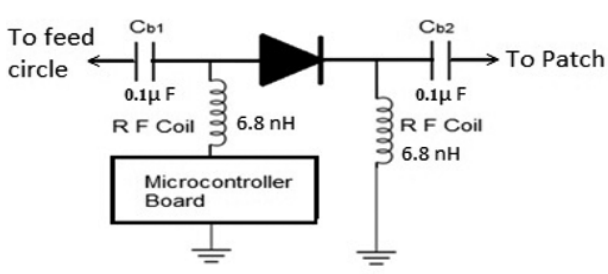

Figure 4. DC biasing circuit of a PIN diode using embedded biasing network.

sends the DC signal through a signal conditioning circuit to turn PIN diodes ON and OFF. This circuit also overcomes various problems like cost, weight, and complexity[11]. The microcontroller unit sends the DC signal in a required fashion to turn PIN diodes ON and OFF, whose logic configuration is given in Table 2.

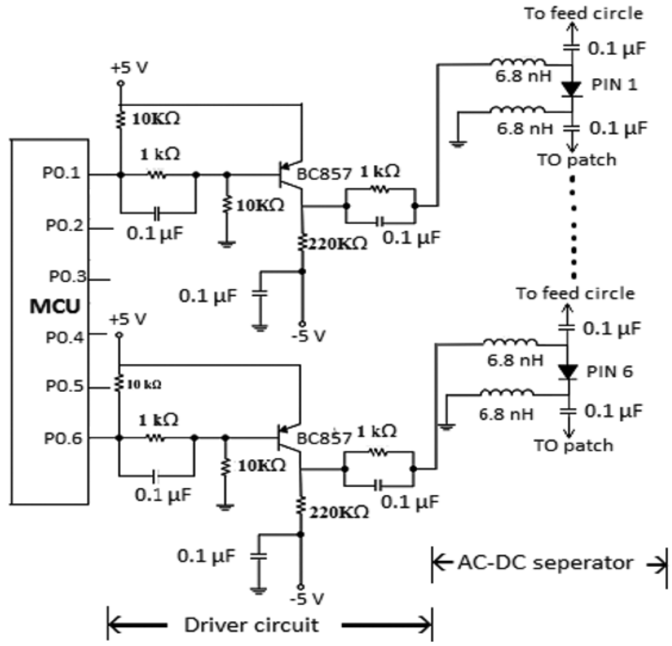

Figure 5. Embedded biasing network using ATMEGA 2560 microcontroller.

Table 2. Switching combinations of PIN diodes

PIN1	PIN2	PIN3	PIN4	PIN5	PIN6
ON	OFF	OFF	OFF	OFF	OFF
OFF	ON	OFF	OFF	OFF	OFF
OFF	OFF	ON	OFF	OFF	OFF
OFF	OFF	OFF	ON	OFF	OFF
OFF	OFF	OFF	OFF	ON	OFF
OFF	OFF	OFF	OFF	OFF	ON

4. RESULTS AND DISCUSSION

HFSS software is used for designing and simulation purposes. The simulated and measured return loss for a design 1 (simple patch) and design 2 (slotted patch) of the proposed antenna are shown in Figs. 6(a) and 6(b). Figure 6 shows that the proposed antenna resonates at a single frequency with design 1 while it resonates at two frequencies with design 2. Table 3 shows the value of simulated and measured return loss for both designs. The simulated and measured resonant frequencies remain the same for all six patches.

This resonant frequency depends on the radius of the patch under consideration. Figure 7 shows the relationship between the radius of the patch and resonant frequency. It is observed from the graph, if the radius of the patch is decreased then resonant frequency is increased. The radius of the excited patch (in mm) and the corresponding resonant frequency in GHz are shown in Table 4. The authors have varied the radius of the patch from 28 mm to 33 mm and observed the resonant

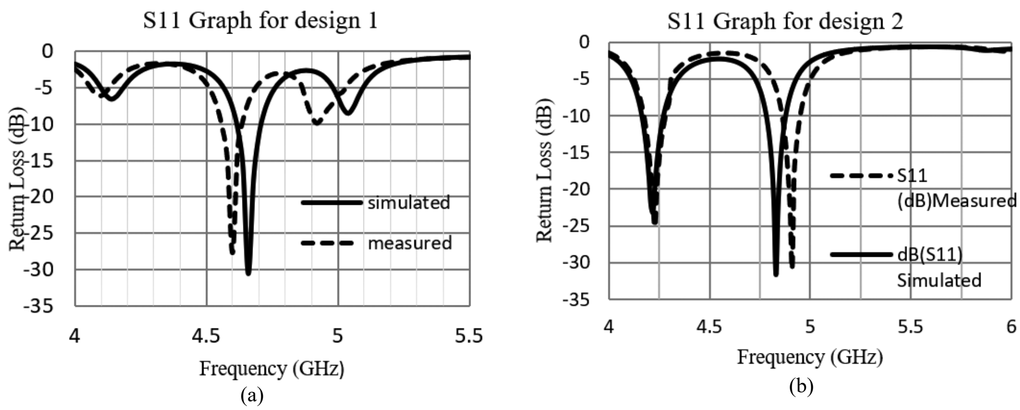

Figure 6. The simulated and measured return losses of the antenna with (a) design1 (patch without slot), (b) design 2 (slotted patch).

Table 3. Resonant frequencies and corresponding return losses

Type of Design	Parameters	Simulated		Measured	
Design 1 (patch without slot)	Resonant Frequency (GHz)	4.66		4.6	
	Return Loss (dB)	-30.5		-28	
Design 2 (patch with slot)	Resonant Frequency (GHz)	4.21	4.82	4.23	4.91
	Return Loss (dB)	-22.2	-31.6	-25.16	-30.9

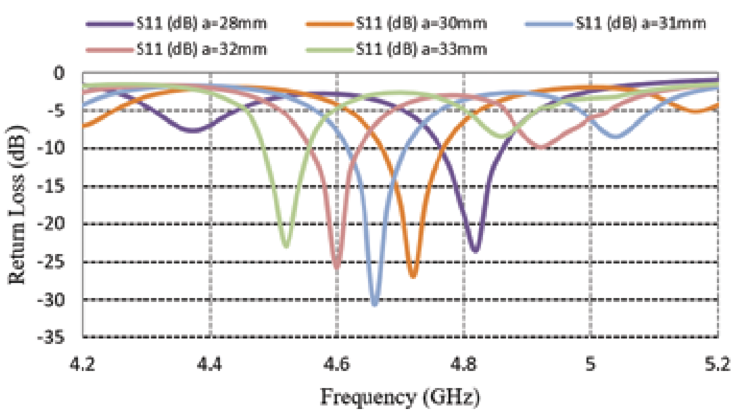

Figure 7. Return loss at different values of patch radius.

frequency from 4.82 GHz to 4.52 GHz respectively as listed in Table 3. The authors observed that return loss is better than -23 dB at resonant frequency throughout the range as shown in Fig.7.

Table 4. The resonant frequency and return loss on different radius of the excited patch.

The radius of the patch (mm)	Resonant frequency (GHz)	S_{11}(dB)
33	4.52	-23
32	4.60	-25.7
31	4.66	-30.5
30	4.72	-26.8
29	4.76	-25
28	4.82	-23.5

The best return loss -30.5 dB is obtained at patch radius 31mm which is radiating at 4.66 GHz. This is considered for further discussion.

As we provide the input to the single antenna element without slots, the antenna will radiate in the direction 70° to 90° from the ground. This will not address the issue as an antenna is required that can radiate in between vertical (broadside) and the horizontal axis. By the introduction of slots, the path of the current changes (circulates around the slot) that changes the direction of magnetic field intensity, this variable magnetic field intensity generates variable electric field intensity and propagation of wave gets changed according to the direction of **E** and **H** fields. By changing the dimensions and position of slots we can control the direction of propagation. We have chosen the dimensions and position of slot such that its radiation is around 40°-70° from the ground. Also if all the six elements are feeded simultaneously then it will radiate in broadside direction which will cover the rest 70°-90° from the horizontal (ground).

Figure 8 shows 3D radiation patterns for design 2 (slotted patch) where PIN diodes are turned ON successively. When PIN 1 turns ON, Pach 1 (φ= 90°) radiates in the direction of φ=0° as shown in Fig. 8(a). Similarly, when PIN 2 turns ON, Patch 2 (φ=150°) radiates in the direction of φ=60° as shown in Fig. 8(b) and so on. Table 5 shows the direction of the exciting patch and the direction of maximum radiation respectively. The radiation pattern is getting rotated by 60° for change in the excitation of the consecutive patch. Figure 9 is the two-dimensional radiation pattern of design1 (without slot patch) in the X-Y plane which clearly shows that the Radiation pattern is getting rotated by 60° for change in the excitation of the consecutive patch. Similarly, two-dimensional radiation patterns (simulated and measured) for the slotted patch at both frequencies are shown in Fig. 10. It is clear from Figs. 10(a) to 10 f) that radiation of both frequencies is perpendicular to each other. When PIN 1 turns ON, patch (φ=90°) radiates in the direction of φ= 0° at the frequency of 4.82 GHz and in the direction of φ= 90° at the frequency of 4.21 GHz.

The radiation beam of design 2 is also moved at 60° with the excitation of the next patch and it is similar to design 1.

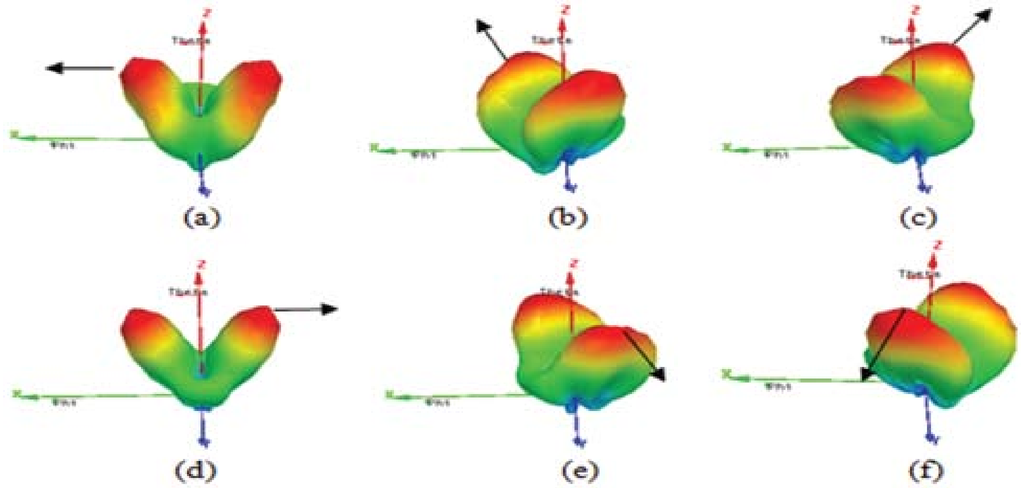

Figure 8. 3D Radiation Patterns for design 2 (slotted patch) of proposed antenna when (a) PIN1 ON, (b) PIN 2 ON, (c) PIN 3 ON, (d) PIN 4 ON, (e) PIN 5 ON, and (f) PIN 6 ON.

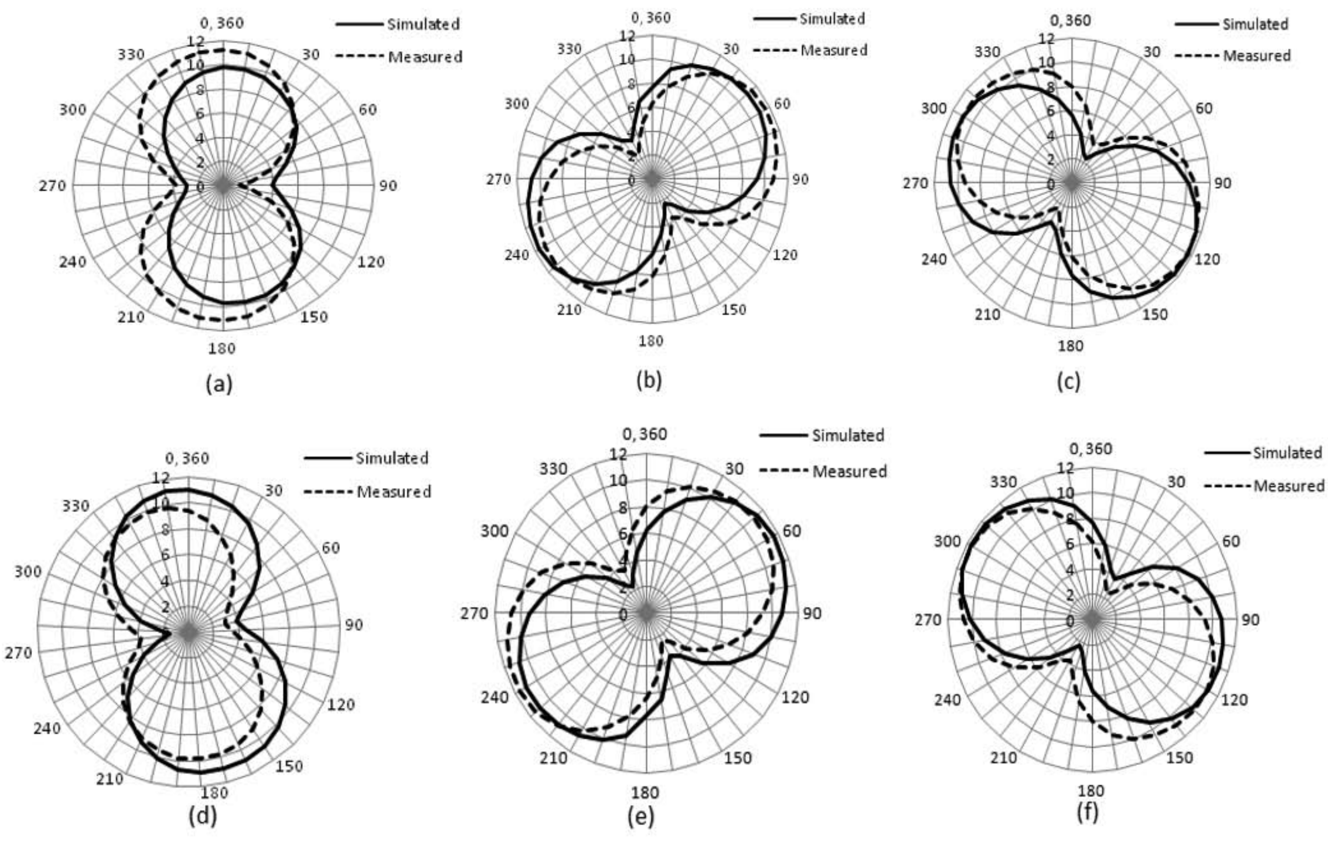

Figure 9. 2D radiation patterns (simulated and measured) of the antenna (patch without slot) when (a) PIN1 ON, (b) PIN 2 ON, (c) PIN 3 ON, (d) PIN 4 ON, (e) PIN 5 ON, and (f) PIN 6 ON.

The direction of the exciting patch and their radiations in terms of angle φ corresponding to PIN diode configuration is shown in Table 5. As the radiating patch is rotated by 60^o in a clockwise direction (Radiating patch indicates that the corresponding PIN diode is ON and other PIN diodes are OFF) Radiation pattern also rotates by 60^o in a clockwise direction. The proposed work gives more reliable and accurate results compared with work carried out by previous researchers. In the given work, the electronic switch which is controlled by the microcontroller is used for generating a rotating radiation beam. The proposed method is much better than all previously given research works where either mechanical switch or antenna array or manually controlled switches are used to obtain the rotating beam. Where electronic switching is used for rotating beams, the direction of the radiated beam is adjusted by cutting two parallel slots in the radiating patch. Both these methods give novelty to the proposed work and make it different from the earlier ones.

Table 5. The direction of the exciting patch and its maximum radiation

Patch Excited	PIN diode configuration	The direction of the Excited patch (φ in degrees)	Design -1	Design -2	
			The direction of maximum radiation at a frequency (4.66GHz) (φ in degrees)	The direction of maximum radiation at a frequency (4.21GHz) (φ in degrees)	The direction of maximum radiation at a frequency (4.82 GHz) (φ in degrees)
Patch 1	PIN 1 ON	90°	0°	90°	0°
Patch 2	PIN 2 ON	150°	60°	150°	60°
Patch 3	PIN 3 ON	210°	120°	210°	120°
Patch 4	PIN 4 ON	270°	180°	270°	180°
Patch 5	PIN 5 ON	330°	240°	330°	240°
Patch 6	PIN 6 ON	30°	300°	30°	300°

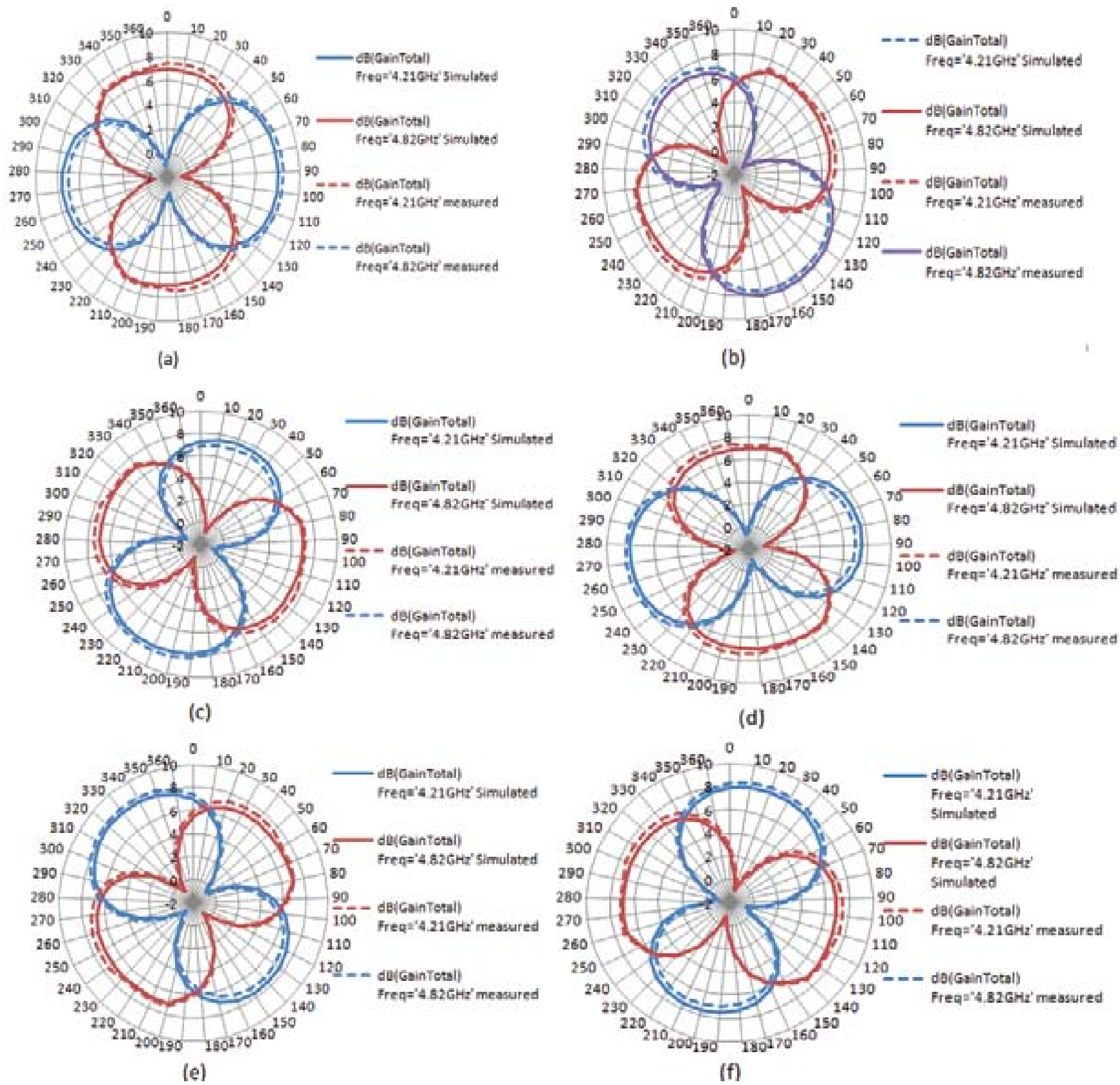

Figure 10. 2D radiation patterns (simulated and measured) of the slotted patch antenna when (a) PIN1 ON, (b) PIN 2 ON, (c) PIN 3 ON, (d) PIN 4 ON, (e) PIN 5 ON, and (f) PIN 6 ON.

5. CONCLUSION

A Dual-band electronically controlled beam-steering slotted antenna is successfully designed, simulated and tested. The simulated and measured results are in good agreement. This antenna radiates in C-band (4-8 GHz) on two frequencies 4.21 GHz and 4.82 GHz with radiation pattern 90° away from each other. The proposed antenna can be used for short-range radar ground surveillance, missile control, mobile battlefield surveillance for military.

Since the beam is controlled electronically ,so no mechanical movements are required unlike in the case of conventional radar systems. In this novel design, a single patch provides two radiation beams 180o apart simultaneously.Thus it's scanning rate will be doubled to the switching rate. The proposed future work is to increase the range of the antenna by increasing its gain so that it can be used for long-range radar applications.

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ACKNOWLEDGMENT

Authors would like to thank the Department of Electronics and Communication Engineering, JIIT Noida and AIT New Delhi for providing the necessary facilities to measure the antenna.

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Contribution in the current study, she has supervised the overall research work presented in the current paper by providing ideas and guidance and writing the manuscript in a systematic way.

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In the current study, he is involved in the formulation and conceptualisation of the problem and carrying out the experimental work. He wrote the first draft of the paper and improved it several times.