Rotating Radiation Beam Slotted Antenna with Two Orthogonal Frequencies for 5G Applications

Dr. Manoj Kumar Garg
Department of Electronics and Communication, IEC College of Engineering and Technology, Greater Noida
manojgarg.ece@ieccollege.com

Abstract--**A rotating radiation beam C-band microstrip antenna for 5G applications is proposed.Two orthogonal resonant frequencies radiated at 4.21 GHz and 4.82 GHz provide a scanning beam that can rotate clockwise or anti-clockwise at every 60^{O}. Two slots on every patch provide two orthogonal radiation beams. Direction of beam can be adjusted by changing dimensions of slots. Six patches are used to cover six directions. For exciting patches, six p-i-n diodes are integrated with the antenna.They are turned on one-by-one with the help of an ATMEGA 2560 microcontroller. The scanning rate of 0.36 deg/ms is obtained, which can be changed by means of microcontroller.**

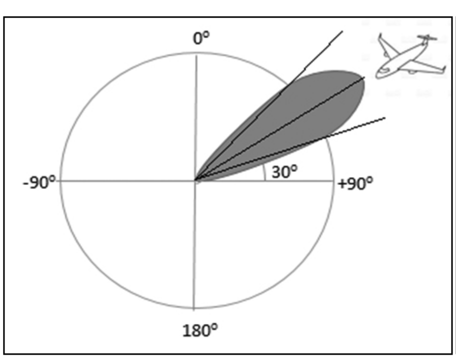
Keywords: Beam reconfigurable antenna, Embedded biasing network, Beam scanning; Non-stationary target, p-i-n diode

I. INTRODUCTION

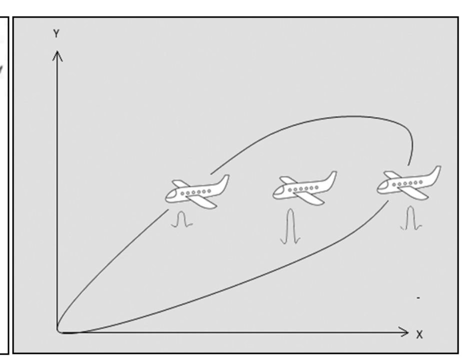
CURRENTLY, reconfigurable micro-strip antennas (RMA) are in great demand [1]. Four types of RMAs, namely Frequency reconfigurable antenna, Pattern reconfigurable antenna, Polarization reconfigurable antenna, and the combination of these three are used [2]. Many techniques are adopted to scan non-stationary target. Patch antenna array with multi-feeding techniques face difficulties in mounting [3]. A travelling wave antenna was proposed [4] with rectangular waveguide for frequency beam-scanning array antenna operating in 220-325 GHz. Beam steering is achieved by changing RF signal relative phase and switching antenna elements [5]. All mutually synchronized patches of equal sizes are used for beam-scanning. Directivity of antenna decides the direction of target [6]. Sensors may be attached with reconfigurable antenna to make it as a smart sensing antenna [7].

To provide safety of the driver, UBW automotive radar sensor has been proposed with grid antenna of 33 radiating elements [8]. Direct sequence ultra wideband system could be used for measurement of short range radar system [9]. Strohmet *al.* [10] considered two nested C slots on the patches and CPW transmission line with two distinct characteristics for Wi-MAX and WLAN (3.4/3.5) [10]. Considerable research was done on microcontroller based electronic beam steering system for stationary and non-stationary system targets. This study suggests design and develop rotating antenna based on six micro-strip patches, six *p-i-n* diodes and microcontroller based driver circuit. ATMEGA 2560 microcontroller and six *p-i-n* diodes were used for it. Frequency reconfigurable behavior is achieved by varactor diode [11]. A microcontroller-based embedded biasing network (EBN) is employed for switching positions of these diodes. No biasing for passive elements are required in microcontroller-based EBN.

Here, a beam-steering radiation beam is achieved via six *p-i-n* diodes. Switching positions of these diodes is controlled by a microcontroller-based EBN. It allows EBN to be integrated with Microstrip antenna on a single PCB, obviating need for passive elements for biasing [12]. 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* [13]. With knowledge of amplitude and time



(a)



(b)

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

interval between two consecutive echoes, speed and distance of the target is calculated.

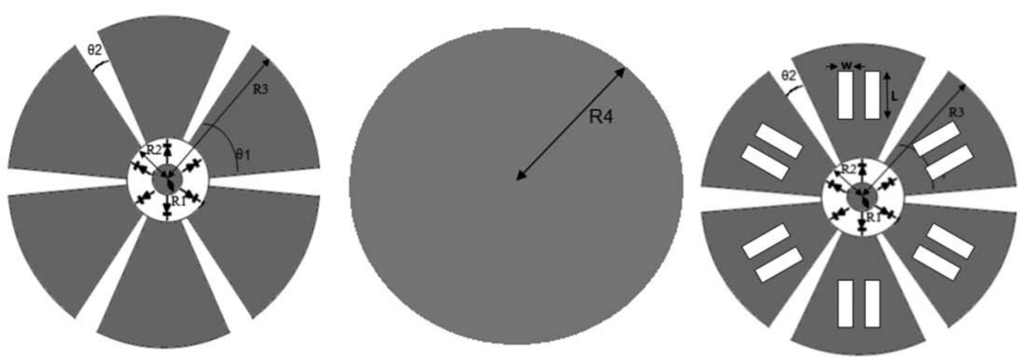
II. ANTENNA DESIGN CONSIDERATION

First we discuss design of antenna. Next, methodology of achieving reconfigurable behavior in the radiation pattern is explained. Resonant frequency remains same for every radiating patch, and only radiation direction changes. To achieve this, an angular patch is designed. Sectoral micro-strip patch antenna design formulae for calculating the radius R_3 of the patch are used [14]. R_3 is optimized 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 (Fig. 2*a*). R_1, the feed circle radius is optimized and is found to be 4.2 mm. Feed circle is excited by a 50-Ω coaxial probe. Six *p-i-n* diodes are used for connecting six patches with feed circle (Fig. 2*a*). When an individual patch is excited, the corresponding p-i-n diode is turned on and other five are OFF. ON-OFF controlling of is done by a microcontroller via a program that provides a 100-ms delay between switching of two consecutive *p-i-n* diodes. Since switching time is negligible, each patch will radiate for 100 ms. Two designs of the patch are highlighted, one without a rectangular slot and other with a rectangular slot.

Figures 2*a*, 2*b* and 2*c* show design of a simple patch, ground plane, and slotted patch respectively. Table 1 lists the dimensions. The designed antenna is fabricated and tested. Figure 3 shows the fabricated antenna. Notice that two small rectangular slots are fabricated on every patch to achieve antenna radiation in the desired direction (Fig. 2*c*). Additionally, it results in a new resonant frequency. To ensure that radiation remains between the *x*- and *y*-axis, length and width of the slot are optimized. Radiation is obtained orthogonal to each other at both received resonant frequencies.

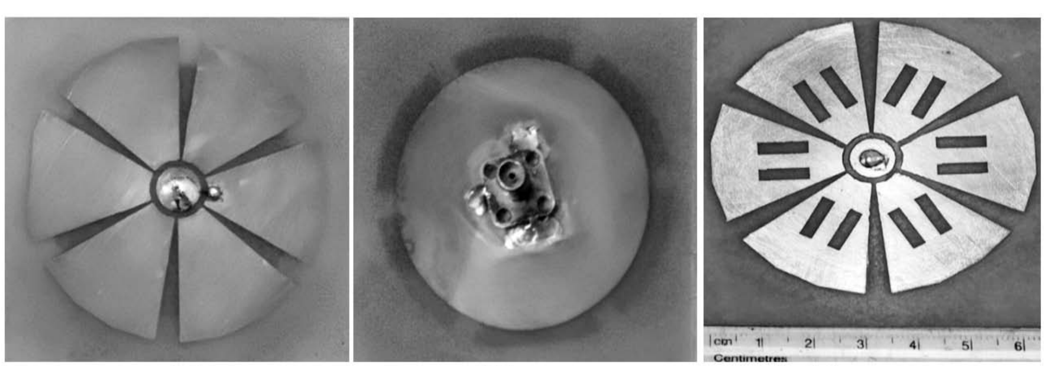
TABLE 1 -- DIMENSIONS OF THE PROPOSED ANTENNA

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



(*a*) (*b*) (*c*)

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



(*a*) (*b*) (*c*)

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

Dual frequency band operation is achieved to suit requirements of modern communication. Rectangular slot performs as a series resonant circuit altering total impedance of the patch [15]. Due to impedance change, another current flows on the patch and antenna resonates at a different frequency.

III. EMBEDDED BIASING NETWORK

The microcontroller-based EBN is used as a driving circuit that works on DC supply. But, it may get damaged on receipt of an AC signal at its terminals. Separation is necessary between AC signals from antenna and DC signal from EBN. This is achieved by a circuit made up of capacitors and inductors (Fig. 4). Two capacitors C_{b1} and C_{b2} of 0.1μF block the DC signal from EBN to protect the AC source and antenna. Likewise, two 6.8 nH R.F. coils block the AC signal from source or antenna and protect the EBN.

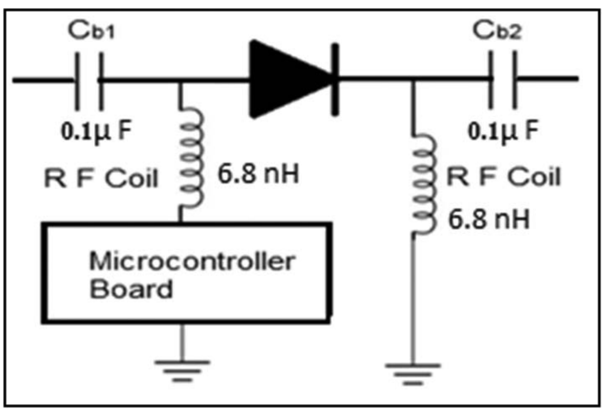


Figure 4. DC biasing circuit of a p-i-n diode using embedded biasing network.

The circuit in Fig.5 consists of ATMEGA 2560 microcontroller, Signal conditioning circuit, and AC-DC separator circuit. Microcontroller sends the DC signal in a required fashion to turn *p-i-n* diodes ON and OFF, whose logic configuration is given in Table 2.

IV. RESULTS AND DISCUSSION

HFSS is used for designing and simulation. 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.

Resonant frequency depends on radius of the patch (Fig. 7). Table 4 lists radius of the excited patch and the corresponding resonant frequency. On varying patch radius from 28 to 33 mm, resonant frequency changes from 4.82 to 4.52 GHz. Return loss is found better than -23 dB at resonant frequency.

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

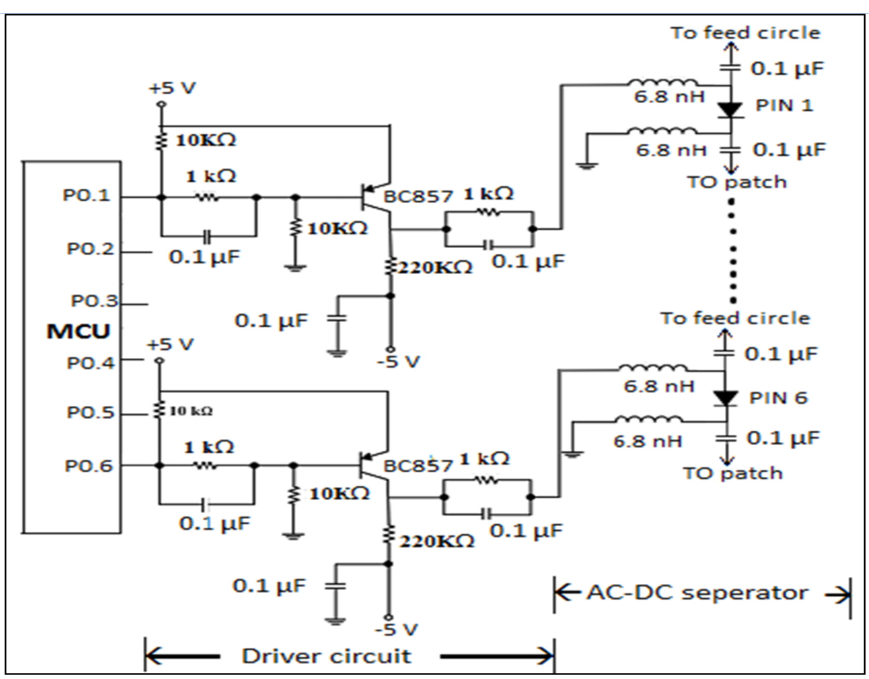
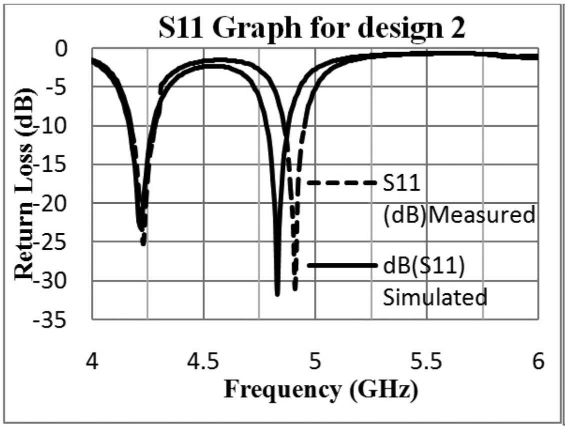
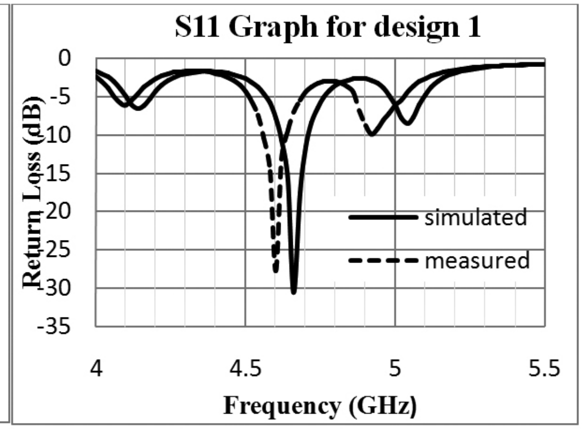


Figure 5. Embedded biasing network using ATMEGA 2560 microcontroller.





(*a*) (*b*)

Figure 6. The simulated and measured return losses of the antenna with 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

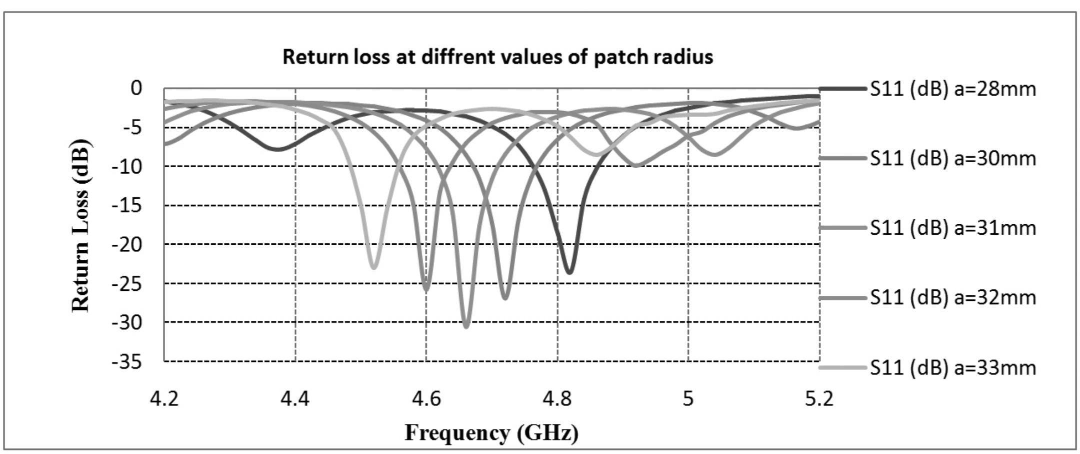


Figure 7. Return loss at different values of patch radius.

TABLE 4. RESONANT FREQUENCY AND RETURN LOSS ON DIFFERENT RADII OF 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 at 4.66 GHz. As we provide the input to the single antenna element without slots, the antenna will radiate in the direction 70^o to 90^o 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, direction of propagation is changed. Dimensions and position of slot were chosen so that its radiation is around 40°-70° from the ground. In case, all six elements are fed at the same time, then it will radiate in broadside direction covering 70°-90° from the horizontal (ground).

3D radiation patterns for design 2 when *p-i-n* diodes are turned ON successively are depicted in Figure 8. First, *p-i-n*1 turns ON, Patch 1 (φ= 90°) radiates in the direction of φ=0° (Fig. 8*a*). On turning ON *p-i-n* 2, Patch 2 (φ=150°) radiates in the direction of φ= 60° (Fig. 8*b*). Direction of the exciting patch and the direction of maximum radiation is shown in Table 5. It is noticed that radiation pattern gets rotated by 60° for change in the excitation of the consecutive patch.

Two-dimensional radiation pattern of design1 in the X-Y plane gets rotated by 60° for change in the excitation of the consecutive patch (Table 5). Figure 10 shows two-dimensional radiation patterns (simulated and measured) for the slotted patch at both frequencies. Notice from Figs. 10*a* to 10*f* that radiation of both frequencies is perpendicular to each other. When *p-i-n* 1 turns ON, patch (φ= 90°) radiates in the direction of φ= 0° at 4.82 GHz and in the direction of φ= 90° at 4.21 GHz.

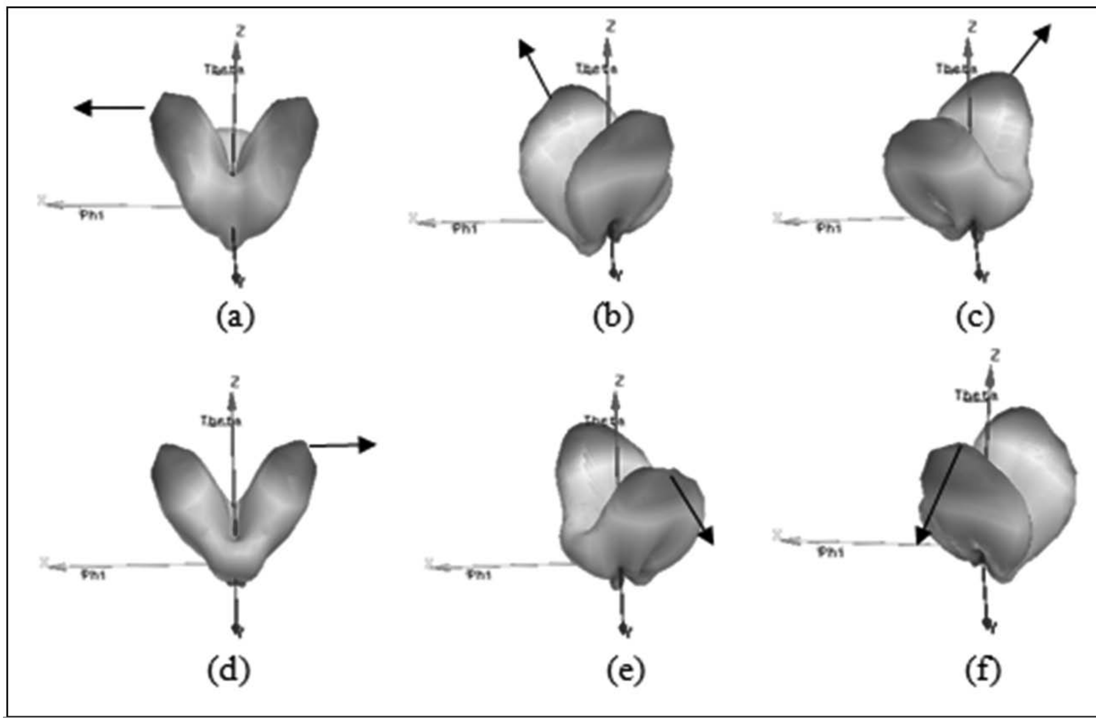


Figure 8. 3D Radiation patterns for design 2 (slotted patch) of proposed antenna when (*a*) *p-i-n* 1 on (*b*) *p-i-n* 2 on (*c*) *p-i-n* 3 on (*d*) *p-i-n* 4 on (*e*) *p-i-n* 5 on and (*f*) *p-i-n* 6 on.

TABLE 5. DIRECTION OF THE EXCITING PATCH AND ITS MAXIMUM RADIATION

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

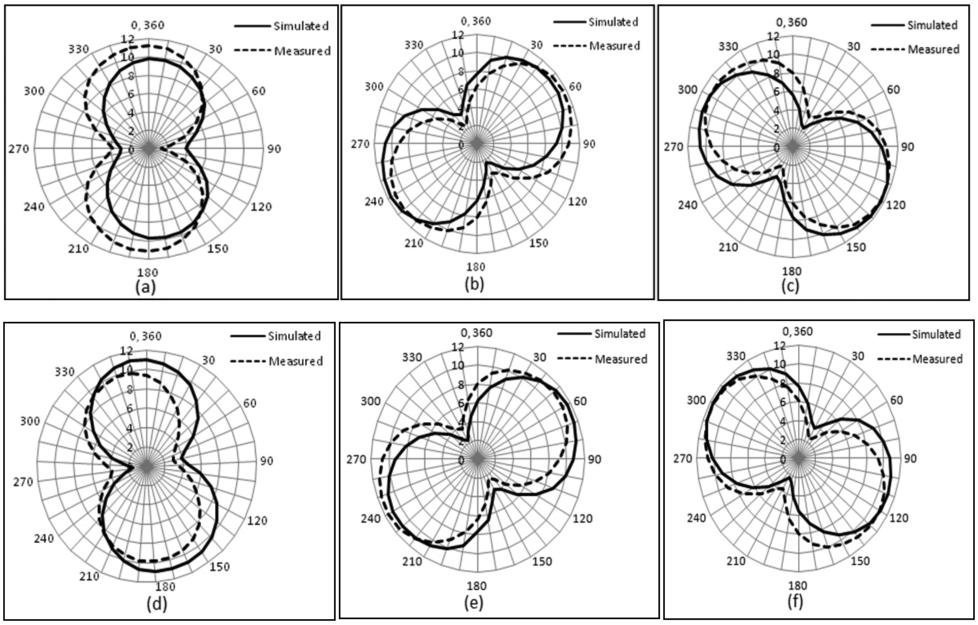


Figure 9. 2D radiation patterns (simulated and measured) of the antenna (patch without slot) when (*a*) *p-i-n* 1 on (*b*) *p-i-n* 2 on (*c*) *p-i-n* 3 on (*d*) *p-i-n* 4 on (*e*) *p-i-n* 5 on and (*f*) *p-i-n* 6 on.

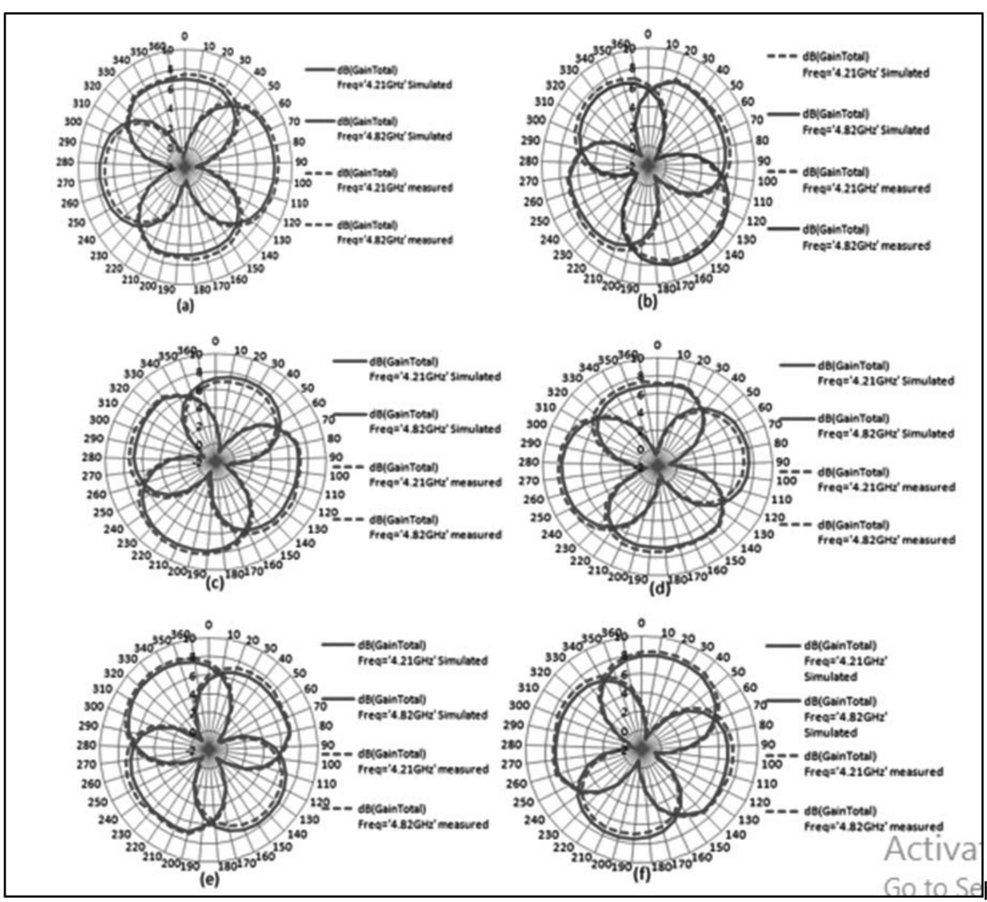


Figure 10. 2D radiation patterns (simulated and measured) of the slotted patch antenna when *(a) p-i-n* 1 *on (b) p-i-n* 2 *on (c) p-i-n* 3 *on (d) p-i-n* 4 *on (e) p-i-n* 5 *on and (f) p-i-n* 6 *on.*

It is observed that radiation beam of design 2 moves at 60^o with the excitation of the next patch which is similar to design 1. Table 5 depicts direction of the exciting patch and their radiations in terms of angle φ corresponding to *p-i-n* diode configuration. By rotating radiating patch by 60^o clockwise, Radiation pattern also rotates by 60^o clockwise.When electronic switching is used for rotating beams, direction of the radiated beam is adjusted by cutting two parallel slots in the radiating patch. Both these methods give novelty to the poposed work.

V. CONCLUSION

A rotating radiation beam slotted antenna with two orthogonal frequencies is designed, simulated and tested. The simulated and measured results are in good agreement. This antenna radiates in C-band (4-8 GHz) at two frequencies 4.21 and 4.82 GHz with radiation pattern 90^o away from each other. The proposed antenna can be used for short-range radar ground surveillance, missile control, and mobile battlefield surveillance for military. It is suitable for 5G applications.

As beam is controlled electronically, no mechanical movements are required unlike conventional radar systems. Here, a single patch provides two radiation beams 180^o apart simultaneously doubling rate of scanning rate to the switching rate.

REFERENCES

[1] P.K. Li, Z.H. Shao, Q. Wang and Y.J. Cheng, "Frequency and pattern reconfigurable antenna for multi-standard wireless applications", *IEEE Antennas and Wireless Propagation Letters*,vol.14, pp.333-336, 2014.

[2] H. L. J. Xiong, Y. Yu and S.A. He, "Simple compact reconfigurable slot antenna with a very wide tuning range", *IEEE Trans. Antennas and Propagation*, vol.58, no.11, pp.3725-3728.

[3] C.A.Yu, E.S. Li, H. Jin, Y. Cao, G.R. Su, W. Che and K.S. Chin, "24-GHz horizontally-polarized automotive antenna arrays with wide fan beam and high gain", *Ibid.* vol. 67, no.2, pp. 892-904, 2019.

[4] K. Sarabandi, A.J.M. Vahidpour and J. East, "A novel frequency beam-steering antenna array for submillimeter-wave applications", *IEEE Trans. Terahertz Science and Technology*, vol.8, no.6, pp.654-665, 2018.

[5] X. Cai, A. Wang, M.A. Ning and W. Leng, "Novel radiation pattern reconfigurable antenna with six beam choices", *J. China Universities of Posts and Telecommunications*, vol.19, no.2, pp.123-128, 2012.

[6] L. Du, Q. Sun, C.Cai,Y. Zhang and H. Hu, "Antenna beam-widths of above-the-road radar for traffic speed enforcement in China", Hindawi Publishing Corporation, *International Journal of Antennas and Propagation*, 2012.

[7] F. Yang, J.Virtanen, A.Z. Elsherbeni and L. Ukkonen, "Reconfigurable sensing antenna: a slotted patch design with temperature sensation", *IEEE Antennas and Wireless propagation letters*, vol.11, pp.632-635, 2012.

[8] J. Wenger, "Short-range radar being on the market", *Proc. European Radar Conference* (EuRAD), pp.255-258, 2007.

[9] M.G.N. Alsath, L. Lawrance and M. Kanagasabai, "Bandwidth-enhanced grid array antenna for UWB automotive radar sensors", *IEEE Trans. Antennas Propagation*, vol. 63, no.11, pp.5215-5219, 2015.

[10] K.M. Strohm, H.L.Bloecher, R. Schneider and J. Wenger, "Development of future short range radar technology", *Proc. European Radar Conference* (EuRAD), pp.165-168, 2005.

[11] H.G. Schantzand G.P. Wolenec, "Ultra-wideband antenna having frequency selectivity", U.S. Patent 6774859B2, 2004.

[12] Q.X. Chu and Y.Y. Yang,"A compact ultra-wideband antenna with 3.4/5.5GHz dual band-notched characteristics", *IEEE Trans. Antennas Propagation*, vol.56, no.12, pp.3637-3744, 2008.

[13] A. Romputtal and C. Phoncharoenpanich, "Frequency reconfigurable multiband antenna with the embedded biasing network, *IET Microwave. Antennas Propagation*, vol.11, no.10,pp.1369-1378, 2017.

[14] A.A. Deshmukh, S.B. Nagarbowdi, N.V. Phatak, A.A. Desai, S.A. Shaikh, K.A. Lele, and S. Agrawal, "Broadband gap-couple shorted 60° sectoral microstrip antenna", *International J. Computer Applications*, vol.5, pp.1-5, 2015.

[15] Aneesh Mohammad, A. A. Jamshed, Ashish Singh, Kamakshi and Saiyed S. Sayeed,"Analysis of Microstrip Line Feed Slot Loaded Patch Antenna Using Artificial Neural Network", *Progress in Electromagnetic Research*, vol.58, pp. 35 - 46, 2014.

Dr. Manoj Garg is working as a Professor and Head, Department of Electronics and Communication Engineering. Possesses 15 years of academic and three years of corporate experience.

Obtained Bachelor's degree in Electronics and Communication Engineering from Uttar Pradesh Technical University, M. Tech in Digital Communication from Rajasthan Technical University; and Ph.D in Microwave Engineering from Jaypee University Noida. Published research papers in national and international journals. Participated and presented research papers in conferences, seminars at national and international level.