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Metamaterial Inspired Azimuth Pattern-Reconfigurable Antenna for 5G Applications

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Abstract: A Radiation reconfigurable antenna is presented for n78 band 5G applications. A planar monopole is combined by a tuning fork and a U shaped strip to form radiating element. A partial ground is maintained at back side. Four metamaterial unit cells are used in this design, two at each side of the radiator to achieve the radiation re-configurability. Comb shaped metamaterial unit cells are placed in a clock wise direction around the antenna and connected to radiator via BAR-64-02V PIN diodes. The proposed reconfigurable antenna operates at 3500MHz for almost all switching conditions. On the basis of the condition of switching diode the antenna radiation pattern is mainly reconfigured into 45o and 135o directions. The antenna's overall dimensions in X×Y×Z directions are 30mm×26mm×1.57mm. The designed antenna achieved different pattern combinations when diode switching conditions are applied, making it suitable for n78 band 5G applications.

Keywords: Monopole antenna, Radiation re-configurable, n78 band, 5G, PIN diode.

I. INTRODUCTION

These days several wireless communication systems are in need of antennas that can reconfigure their radiation energy when required. The ability to alter the coverage in desired area proved significantly helpful in maintaining stronger signal strength in several applications. The reconfigurable antennas can reconfigure their frequency of operations, radiation coverage or their polarization based on the design and implementation. Antenna development for radiation pattern re-configurability mainly depends on maintaining the same frequency of operation while reconfiguring the coverage. Different kinds of antennas by utilizing various techniques have been developed over the years by researchers. Feeding structures, slots or additional structures with PIN diodes combination can achieve the radiation re-configurability.

Metamaterial inspired structures are being used in recent times due to their advantage in manipulating the incident radiation energy. Different types of metamaterial unit cells like, split ring resonator structures, frequency selective surfaces, parasitic elements, and electromagnetic band gap structures are being used to achieve the radiation pattern reconfiguration.

L shaped feeding probe along with PIN diodes combination is used to achieve circular polarization reconfigurable antenna in [1]. A slotted ground plane with feeding at centre is used to develop pattern reconfigurable antenna in [2]. In [3], two slots with inverted U shape are used symmetrically along with two separate coaxial cable feed points to achieve wideband radiation reconfigurable antenna. Tunable resistors based on graphene are incorporated into Vivaldi antenna to achieve the pattern re-configurability for mm-wave applications in [4]. Dielectric or metal liquid models are being used to develop the radiation reconfigurable antennas [5-6]. Metal walls connected via PIN diodes for an aperture fed antenna is developed with radiation reconfigurable capabilities with multi directional beams in [7]. In [8], four arc dipoles are used with PIN diode switching conditions to achieve pattern reconfigurable antenna. Metamaterial inspired structures garnered much attention in developing radiation reconfigurable antennas. Radiation re-configurability is mainly seen in azimuth plane for several antennas, antenna with pattern re-configurability in azimuth plane is developed to have enhanced gain with the help of artificial metamaterial unit cells in [9]. In [10], four complimentary split ring resonators are placed on bottom side of the antenna on ground part to achieve the multidirectional pattern. Pattern reconfigurable antenna is developed by utilizing metasurface unit cells with PIN diodes to achieve the polarization and pattern diversities [11]. Eight metasurface unit cells are placed around the antenna with eight PIN diodes combination to achieve the pattern re-configurability in all 360 degrees in [12]. In order to create pattern re-configurability, [13] combines a metamaterial-inspired dipole antenna with two resonator parasitic elements on either side. By positioning the metamaterial unit cells on the antenna's rear side, one PIN diode combination is used to create a wearable reconfigurable antenna

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in [14]. In [15], parasitic strips are placed around the monopole antenna to implement pattern reconfigurable antenna.

Now a day's reconfigurable antenna found more applications in IoT and 5G. The reconfigurable antennas have their advantages just like in wireless sensor networks in IoT [16-19]. The reconfigurable antenna in 5G are implemented to serve in GHz and mm-Wave frequencies. 3D parasitic enclosure along with PIN diodes are utilized to develop 5G reconfigurable antenna operating in 4.8-5.2GHz band in [20]. Phased array model with hybrid switching conditions is used to develop pattern reconfigurable antenna for 5G mobile terminals in [21]. In [22] describes the development of a radiation and frequency reconfigurable antenna for 5G and sub-6GHz applications.

In this paper, a planar monopole model is used as antenna and four comb shaped metamaterial unit cells are placed around the radiator. Between the antenna and the metamaterial unit cells are four PIN diodes. In order to achieve the variation in pattern the position of metamaterial unit cells is changed. Each of this unit cells are placed in a way that they project clock wise direction with each other perpendicular. The proposed antenna operates at 3.5GHz n78 band for 5G applications. The antenna radiation pattern variation in azimuth plane when switching conditions are varied is presented with comparison in bellows section.

II. PATTERN RE-CONFIGUABLE ANTENNA DESIGN CONFIGURATION

A. Antenna Design

Figure 1 depicts the pattern reconfigurable antenna architecture, while Table 1 lists the geometrical dimensions. The model consists of a planar monopole antenna made by, connecting a tuning fork shaped model with a U shaped Strip. Antenna is fed by coaxial feed method. Four metamaterial inspired unit cells are positions at both sides of the radiator. Comb shape model with equal strip width and gap between the strips is utilized and each unit cell is placed in perpendicular with each other in a clock wise manner. Four BAR-64-02V PIN diodes were used to connect the radiator with the metamaterial unit cells. Direction of these PIN diodes biasing is mentioned in the Figure 1 and the forward and reverse biasing equivalent circuit is illustrated in Figure 2. Rogers 5880 substrate (relative permittivity of 2.2) of size 30×26×1.57mm3 is used as substrate.

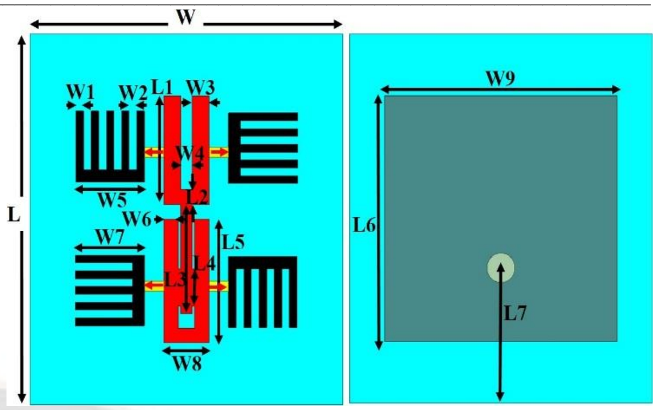

Figure 1. Pattern reconfigurable antenna model: (a) Top view; (b) Back view.

Table 1. The dimensions of the proposed re-configurable antenna.

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
L	30	*L5*	10	*W2*	0.633	*W7*	5.75
L1	8.8	*L6*	20	*W3*	1.4	*W8*	3.8
L2	1.2	*L7*	11	*W4*	1	*W9*	20
L3	8.8	*W*	26	*W5*	5.7		
L4	3	*W1*	0.64	*W6*	1.2		

Initially the diodes are placed in reverse bias condition to tune the antenna to operate at 5G n78 band (3500MHz). To reach the required operating frequency with good impedance matching, the antenna's geometrical dimensions and that of the metamaterial unit cells are changed. Here the dimensions of the metamaterial unit cells can vary the operating frequency drastically, which is explain via parametric study in the below section.

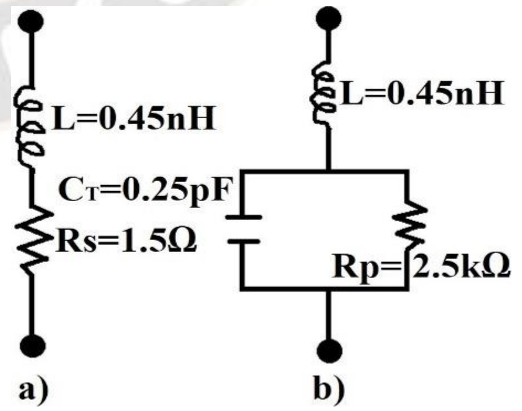

Figure: 2 Forward and reverse Bias Conditions for BAR-64-02V

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B. Parameter Study

The geometrical dimensions of the suggested pattern reconfigurable model are modified, and their effects on antenna reflection coefficient are examined in order to determine the dimensions that provide better impedance matching and the necessary operational band. The dimensions which give better response are considered for further analysis. The parametric study on each of these dimensions is carried out and the optimal values are listed in above Table 1. The following Figure 3 compares the reflection coefficients for different metamaterial unit cell sizes.

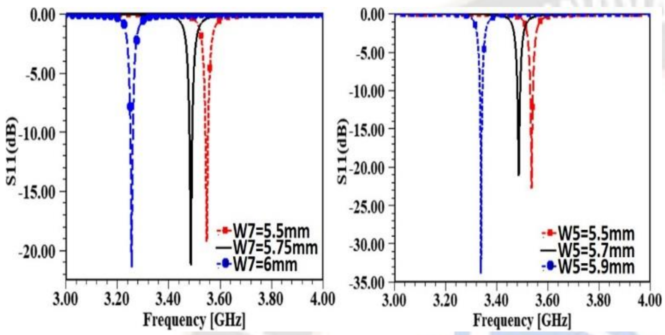

Figure: 3 Reflection coefficient comparison a) Parametric study for W7 & b) Parametric study for W5

The size of the metamaterial unit cells can change the antenna operating frequency to a lower or higher resonance, as seen in Figures 3a) and b). The operating frequency of the antenna shifts towards lower resonance as the size of the metamaterial unit cell increases. The proposed antenna maintained narrow band with good impedance matching in all variations.

C. Simulated Performance Discussion

The simulated analysis is presented utilizing the reflection coefficient and radiation patterns in the azimuth plane for the potential switching conditions using the four PIN diodes. The proposed antenna simulated reflection coefficient, VSWR, 3D gain and the current distribution curves are presented in the following Figure 4.

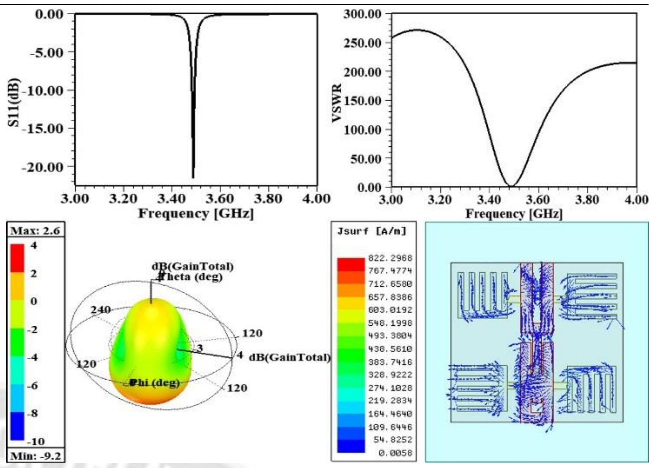

Figure: 4 Antenna simulated performance when all diodes are off a) Reflection coefficientb) VSWRc) 3D radiation plot & d) Current field distribution

1. Reflection coefficient when diodes switching conditions changed.

For a pattern reconfigurable antenna, the operational band maintenance at all switching conditions is important. The analysis will help in understanding under which switching conditions the antenna is operating at same n78 band while reconfiguring its radiation pattern. Except when D1 is alone in ON condition for all other switching conditions the proposed antenna maintained the operational band at 3500MHz.

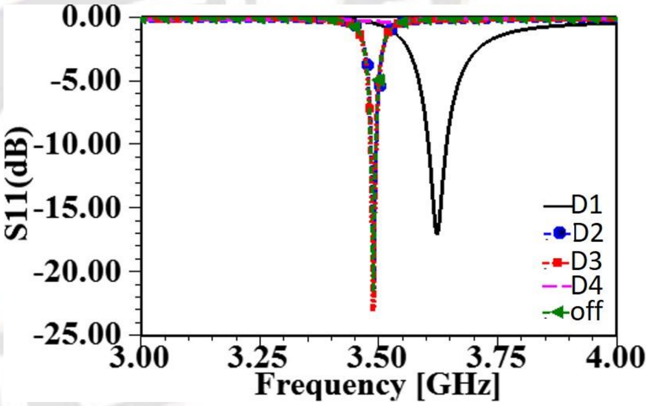

Figure: 5Reflection coefficient comparison when each of the diodes is on with all diodes off condition

2. Azimuth patterns for different switching conditions

The azimuth patterns are compared while the diodes switching conditions are changed. Initially when all diodes are OFF condition is compared with while all diodes are ON in Figure 6. For single diode ON condition the comparison is given for D1 and D2 diodes in Figure 7. For any two diodes in ON condition the comparison is provide for D1&D2 on, D2&D3 and D4&D1 on conditions in following Figure 8. Similarly for any three diodes in ON condition, the comparison

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is provided for D1D2D3, D1D2D4 and D1D3D4 ON conditions in the Figure 9.

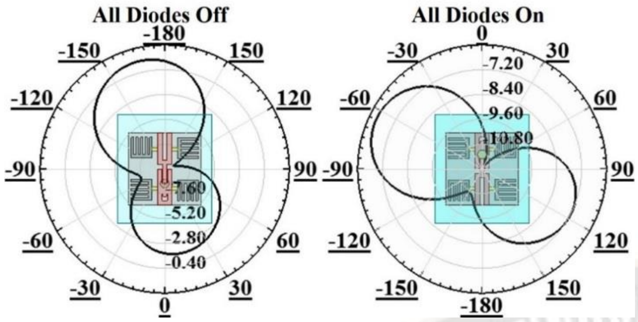

Figure: 6Radiation pattern comparison a) All diode OFF & b) All diodes ON

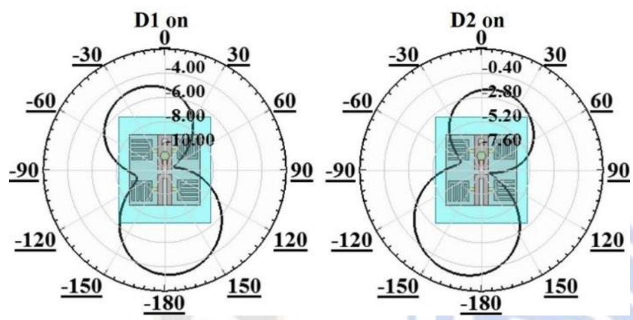

Figure: 7 Radiation pattern comparisons a) Only D1 ON& b) Only D2 ON

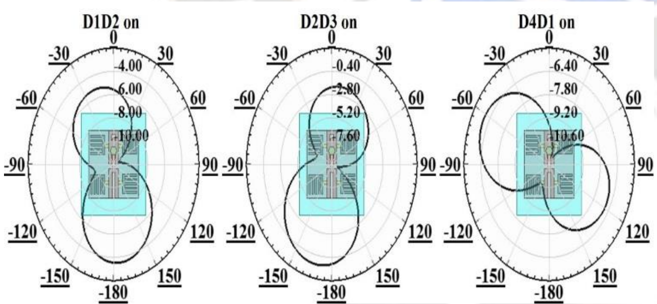

Figure: 8 Radiation pattern comparison a) D1&D2 ON & b) D2&D3 ON& c) D4&D1 ON

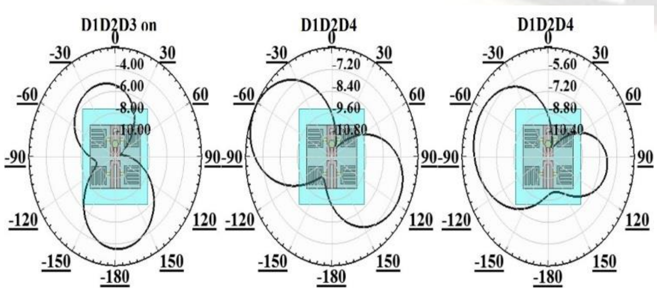

Figure: 9 Radiation pattern comparison a) D1D2D3 ON & b) D1D2D4 ON & c) D1D2D4 ON

Figures 6 to 9 show that the overall radiation pattern curve in the azimuth plane significantly changes for each of the switching conditions. The diode switching conditions can be utilized to change the direction of the pattern to desired area around 360˚. While the pattern is formed in the shape of 8, the pattern is vertical, horizontal or formed in 45˚ or 135˚ covering around the 360˚ in azimuth plane based on the switching conditions used. The designed antenna is suitable for sensors networks and Internet of Things (IoT) applications which work in 5G n78 band.

III. RESULTS AND DISCUSSION

The pattern-configurable antenna with dimensions stated in Table 1 is depicted in Figure 1 is created, and the prototype is displayed in Figure 10 below. Here, Figure 10 a) shows the antenna with diodes and the connection for providing biasing voltage for PIN diodes. Figure b) shows the fabricated antenna along with cable to measure the reflection coefficient. Similar to that, Figure 11 shows the measurement setup for determining the reflection coefficient and the radiation pattern in the E and H planes.

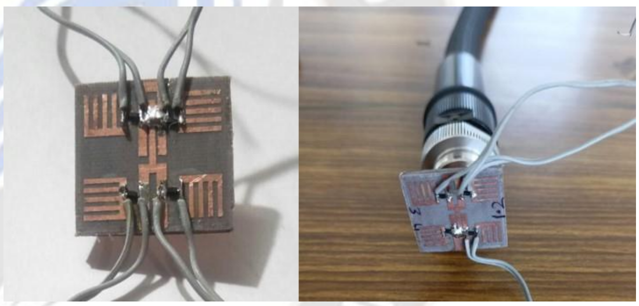

Figure: 10Pattern reconfigurable antenna for 5G n78 band: Fabricated prototype

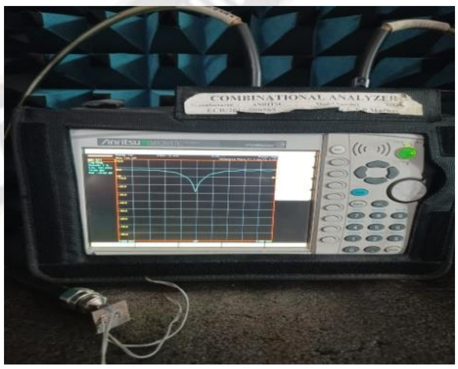

Figure: 11Measurement setup

The reflection coefficient measurements for the proposed antenna when all diodes are in OFF condition is compared with simulated data of the same in the below Figure 12. Where from the Figure 12, the antenna measured S11 is having same operational band as simulated with good band width and impedance matching, the coaxial cable connection and the presence of the other diode and biasing condition could cause some minimum change in measured analysis.

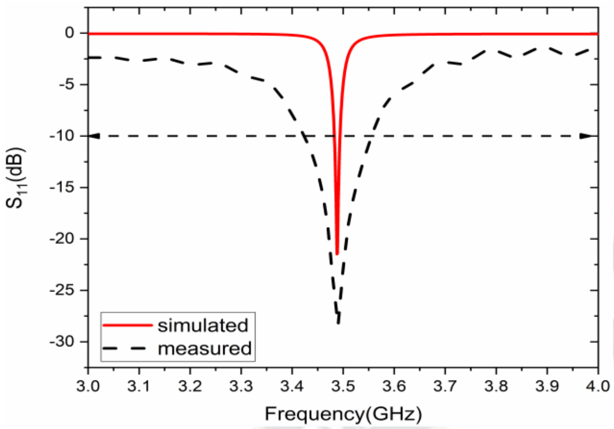

Figure 12. Reflection coefficient: Comparative study that is simulated and measured

In the accompanying Figure 13, the measured radiation pattern for each diode in OFF conditions is compared with a simulated analysis. The majority of the time, the simulated and measured patterns coincide accurately.

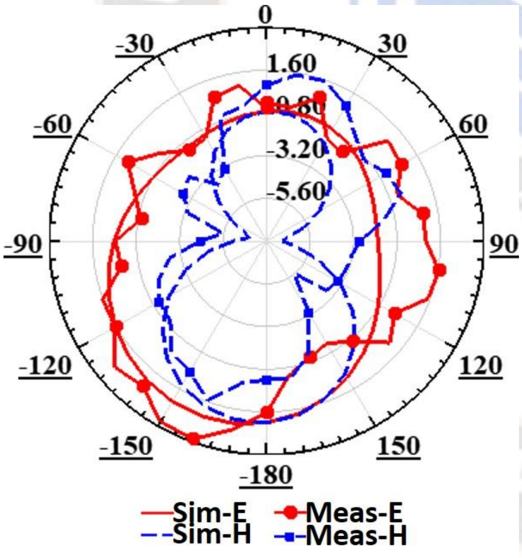

Figure 13. Comparison of E and H plane radiation patterns between simulations and measurements

Table 2 below compares the proposed antenna's pattern configurability to previously used models. Where the comparison is provide based on operating frequency, size, method used to achieve pattern re-configurability number of metamaterial unit cells or PIN diodes used to achieve how many number pattern reconfigurable combinations.

Table 2. Performance evaluation of the proposed antenna in comparison to state-of-the-art work.

Ref	Operating Frequency (GHz)	Dimensions (mm)	Method for using PIN diodes	No of unit cells	Reconfigure combinations
Proposed Work	3.5	30×26×1.57	Metamaterial	4	>8
[11]	5	39×39×1.75	Metasurface	9	2
[12]	2.45	90 (diameter circular)	Metasurface	8	>8
[13]	1.5	21.8×51.4×0.508	Parasitic elements	2	2
[14]	2.45	89×83×1.52	AMC	9	2

IV. CONCLUSION

An azimuth pattern reconfigurable antenna is developed for 3.5GHz 5G applications. The design is made of a planar monopole antenna with four metamaterial unit cells. The metamaterial cells are positioned in a clock wise direction on both sides of the monopole to achieve different patterns when respective switching conditions are applied. More than eight pattern combinations are achieved around 360o for the designed model. The narrow band antenna frequency of operation is maintained mostly for all switching conditions except for only D1 is ON condition. The measured S11 data showed it covers the intended n78 band with good bandwidth and the measured patterns have good coverage similar to simulated data. The developed antenna is good candidate for pattern reconfigurable 5G communications systems.

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