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ORIGINAL ARTICLE

Radiation Pattern Reconfigurable Antenna for 5G Applications

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ABSTRACT

This paper proposes a novel radiation pattern reconfigurable antenna for 5G (Fifth Generation) applications. A rectangular patch is enclosed by a hollow rectangular radiating structure. The patch is connected to the rectangular structure by two switches SW1 and SW2, which will in turn provide three different radiation patterns, Modes, depending on the ON and OFF states of the switches. When SW1 is OFF and SW2 is ON, Mode 1, pattern radiates in a direction with an angle of 38o. While SW1 is ON and SW2 is OFF, Mode 2, the pattern radiates in the radiating plane, exactly opposite to Mode 1, with an angle of -38o. In Mode 3, the pattern is directed simultaneously towards the angles of ±41o; for this case both switches, SW1 and SW2, are turned OFF. The proposed design resonates in the constant 38GHz frequency range which is useful for 5G broadband cellular communication networks. And this design can also be used for 60 GHz resonant frequency with certain adjustments. Additionally, the return loss is -31.5 to -42.5, while directivity is from 5.69-6.76dB, and gain lies in the range of 5.4- to 6.4dBi. Moreover, Voltage Standing Wave Ratio, VSWR, varies from 1.01 to 1.05. Size of the antenna is 3.34x6.73mm2 which is mounted on a 0.381 mm thick, Roger RT5880 having a relative permittivity of 2.2. *Central Standard Time, (CST)* microwave studio software is used for simulating the design. The miniscule size, a smaller value of the return loss, an ideal value of VSWR with a reasonable value of directivity and gain make the proposed design best for future 5G mobile communications.

Keywords: Re-Configurability, Cellular Communication, CST.

Author`s Contribution
[1,2] Manuscript writing, Data Collection Data analysis, interpretation, Conception, synthesis, planning of research, and discussion

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INTRODUCTION

Contemporary requirements like higher capacity and data rate, lower latency, Massive input and output systems, reduced cost and miniscule design in the telecommunication systems are call of the hour. To cope with these a consistent struggle started from first generation and now the 5G is a new dream. The realization of 5G can become true by adopting higher frequencies, from 3-300GHz, also called mm Wave range [1-6]. The use of low frequency bands is simpler and cost effective, but the major demand of higher data rates is not achievable in this case. This problem can be solved by using higher frequencies which have a huge data rates and smaller antennas. This will enable the IoT (Internet of Things) [7], an emerging technology. Frequencies higher than 6 GHz are considered mm Wave range [8]. And the frequencies from 24-86 GHz are identified for 5G studies [9]. Specifically the spectrums of interest are 28, 38, 60 and 73 GHz [4, 6]. Different research shows that 38 GHz spectrum is far better in terms of average user throughput, consistent coverage, efficiency and fairness index [5, 6]. Moreover, this pattern has more potential for cellular mobile, peer to peer wireless communication systems by using the technique of beam forming and directional transmission [10- 13]. The rapid growth in telecommunication desires mechanism for the effective and efficient control of different parameters, which will be capable to maximize the performance in a changing scenario to fulfill the changing operating requirements. 5G antennas can be smart and reconfigurable [14]. In reconfigurable antennas switching is due to change in shape of the radiating element while in smart antennas the reconfiguration is achieved by connecting smart systems rather than the antennas. This setup is capable to provide enhanced directivity in a particular direction and a better SNR (Signal to Noise Ratio) [15]. Amid the prevailing shortage of global bandwidth, the carriers are motivated to explore the new methods. Hence, the re-configuration best suits the demands because smart antennas are costly and expensive due to the external circuit's elements [16]. Besides, Reconfigurable antennas are best suited to cope with these conditions [17, 18] and hence a degree of freedom in elements pattern and frequencies is available for new levels of performance.

Radiation pattern reconfigurable antennas have attained attention. The diversity in pattern can be achieved by adopting electrical, physical, and optical ways or through material changes [18], especially at a constant frequency via employing electrical or mechanical switching [19]. Commonly used are switches like varactors, RF-MEMS (Radio Frequency Micro electromechanical Systems), PIN diodes, FETs (Field-Effect Transistor), photoconduction, structural iteration or by using ferrites and crystal liquids [20-23]. Various configurable parameters of an antenna are radiation pattern, frequency, polarization or a hybrid of these [24-29]. The property of re configurability can be achieved by varying physical parameters of an antenna or by designing arrays [30]. This process will ultimately decrease the number of antennas into a single versatile antenna, removing the bulk of switches to improve the system performance [31]. A comparison among these techniques for the purpose of reconfiguration, the CMOS (Complementary Metal Oxide Semiconductor) switches are best suited due to easy integration and lower cost [32, 33].

Previously, research shows the reconfigurable antennas for 4G. In [34], a pattern reconfigurable antenna is proposed for 7.5GHz. Directivity is from 9.67-9.8 dB while return loss is from -20 dB to -33. In [24], a radiation pattern antenna is designed for 3.7 GHz with VSWR up to 1.8 and gain of 5.6 dBi while directivity is 4 dB. In [35], a radiation pattern reconfigurable annular is designed for 1.05 GHz. Maximum gain is 3.81 dBi while return loss is -10.2 dB. In [36], a reconfigurable pattern antenna is designed for 2.4GHz. Maximum gain is 2.46, while the value of return loss is -11 dB. Table I shows the performance parameters of the discussed 4G antennas. Besides, 5G reconfigurable antennas are also getting attention in [15], a design is proposed for 28/38 GHz dual band non configurable antenna. The dimensions in this case are also large while providing a gain of 7.47 dBi at 28GHz and 12.1 dBi at 38GHz. Similarly, in [37], design is proposed for 28/38GHz dual band. In this case the gain for 28GHz is 4.2dBi while for 38GHz is 6.9 dBi. Likewise, in [38], a dual band 28/38 GHz antenna is proposed with a value of return loss in the range from -51 to -54 dB, while the value of gain is from 6.38-8.3 dBi. Directivity in this case is from 6.4-8.3 dB and value of VSWR is in the range of 1-2. Moreover, in [39], a configurable antenna is designed for 20/29 GHz. For various 5G antennas, Table II is provided for ready reference. The issues in non-configurable antennas are the lacking of properties like directing beams towards direction of interest which leads to unwanted signals, jamming, compromised security and lower gain as well as dissipation of energy. Ultimately, a degree of freedom in elements pattern and frequencies is not available for new levels of performance.

Table I: Comparison With 4G Pattern Reconfigurable Antennas

References	Size (mm)	Return Loss (dB)	Frequency (GHz)	Gain (dBi)
Huff et. al. [24]	6x16	-14.2	3.7	3.2
Aris et. al. [34]	15x15	-30	7.5	4.4
Aziz et. al. [35]	120x120	-10	1.05	3.81
Kang et. al.[36]	54x34	-11	2.4	2.46

Micro strip patch antennas are widely used for the purpose of re configuration due to its superior properties [40]. Planar pattern reconfigurable antennas are best suited for mobile station due to easy integration, providing optimum results, having low profile, ease of integration and light weight [41, 42]. Due to the significance of pattern reconfigurable antennas, the related research is analyzed and as a result at a constant desired frequency, a radiation pattern reconfigurable antenna is implemented.

In this paper, we present the design having high gain, directivity, an ideal VSWR and lower reflection coefficient with pattern re configuration at a constant frequency of 38GHz which will best suit for 5G mobile communication. The novelty of the proposed design is that it will resonate at a constant 38GHz frequency range with diversity in radiation pattern and easy fabrication. Additionally, depending on the ON and OFF states of the switches, three Modes provide a diverse radiation pattern. When SW1 is OFF and SW2 is ON, Mode 1, pattern radiates in a direction with an angle of 38o. While SW1 is ON and SW2 is OFF, Mode 2, the pattern radiates in the radiating plane, exactly opposite to Mode 1, with an angle of -38o. In Mode 3, the pattern is directed simultaneously towards the angles of ±41o, for this case both switches, SW1 and SW2, are turned OFF. The electronic switching of the radiation pattern in E-plane has a maximum gain of 6.4dBi and is controlled by circuit architecture with simple two switches combination for all the three different modes. Parasitic structure enclosing the patch is used for the purpose of reconfiguring radiation pattern. Moreover, the spacing is used for lowering the side lobes level and enhancing the major lobe. CST microwave studio software is used for the purpose of simulating the design.

Table II: Comparison with 5G Pattern/Frequency Reconfigurable Antennas

References	Size (mm)	Type	Frequency (GHz)	Return Loss (dB)	Gain (dBi)
Venkat Babu and Srinivasan [15]	20x20	Non-Configurable	28/38	-34.5	12.1
Haraz et. al. [37]	7.5x8	Non-Configurable	28/38	-35	6.9
Hakim et. al. [38]	8.2x9.6	Non-Configurable	28/38	-54	8.3
Rodrigues et. al. [39]	21.9x9.8	Re-Configurable	20/29	-21.3	7.12

PROPOSED DESIGN

2.1 Antenna Structure

Fig. 1 shows the structure of the proposed planar antenna design. A rectangular patch of 2.4x2.5mm2 is surrounded by another hollow rectangular patch of 3x4.75mm2 dimensions [43, 44], which is printed on 0.381 mm thick, Roger RT5880 with dielectric constant 2.2 and loss tangent of 0.0009. The feeding technique is coaxial probe which has a connecting diameter of 0.14 mm. The patch is connected by two switches with the outer hollow patch, which will in turn reconfigure the pattern based upon the ON and OFF state of switches. Dimensions of the design and the separation between radiating structures are given in the Table III which are optimized for operation in the resonance frequency of 38GHz covering a band of about 1.8 GHz, and also providing a return loss less than -10 dB.

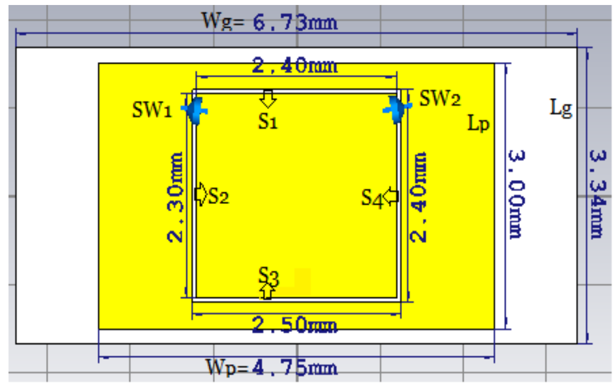

Fig 1. The proposed structure

Table III: Dimensions of The Proposed Design In MM

L_g\ (Length of Ground)	W_g (Width of Ground)	L_p (Length of Patch)	W_p (Width of Patch)	S_1 (Spacing 1) /S_3(Spacing 3)	S_2 (Spacing 2) /S4 (Spacing 4)
3.34	6.73	3	4.75	0.05	0.05

2.2 Switches Structure and Various Pattern Reconfigurable Modes

The ground plane dimensions are 3.34x6.73mm2, and substrate dimensions are same to the ground plane. A conventional patch antenna is modified and the spacing around the patch is carefully optimized for achieving a constant resonant frequency and a minimum level of side lobes. The electrical connection is achieved through two switches for the purpose of diversity in radiation pattern at 38 GHz, constant frequency. The equivalent model of the switches used is given in Fig. 2. Care full studies revealed that the values of the resistance and capacitance for ON state are 10.2 ohm and 47.1 pF, whereas, the OFF state values are 13.3 M ohm and 39 pF. The basis of radiation pattern reconfiguration is achieved by proper design of the spacing between the patch, hollow conductor and the switches state. Width of the antenna is a key factor for the variation of the resonant frequency according to the choice of the designer and for the adjustments of return loss accordingly [45]. States of the switches and pattern diversity is shown in Table IV for convenience.

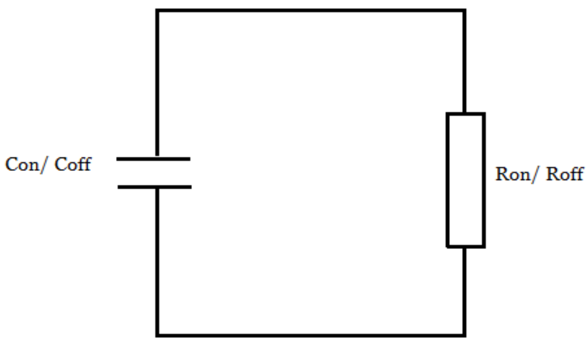

Fig 2. Simplified model for the switch used

Table IV: Pattern re configuration for different modes			
Mode	Switch-1	Switch-2	Pattern (Degrees)
1	OFF	ON	38
2	ON	OFF	-38
3	OFF	OFF	±41

RESULTS AND DISCUSSION

The proposed design is a planar patch antenna, which is used widely due to enormous properties. The diversity in pattern and concurrently resonating at a single frequency is an arduous task, which is achieved by altering the design. In fact, the switches used for reconfiguration are available as lumped elements in CST MW studio with R, L and C elements. All the performance parameters depend upon each other. Obtaining a higher directivity will provide a large value of return loss which is not desirable by a designer and vice versa. Same is the case for Gain, Efficiency and VSWR. This section includes the performance of the antenna and different parameters like return loss, directivity, gain and the diversity in radiation pattern, a prime purpose of this research study.

3.1 Return Loss and Impedance Bandwidth

Due to reflection, a part of the input power is wasted resulting in standing waves in the system, calculated in dBs, is called return loss. The simulated return loss of the antenna is shown in Fig. 3 for the three modes depending on the condition of the switches as depicted in Table IV, when the antenna resonates at a constant 38GHz frequency. It is clear that return loss is in the range from -31.5 to -42.5. The impedance bandwidth is 4.6% for Mode-1 and Mode-3 and 4.9% for Mode-2, at S_{11} less than -10 dB. It is also obvious that the resonant frequency is constant, and the design has a diverse radiation pattern. Thus the proposed design is well suited for 5G operation and especially for wireless communication. Additionally, as obvious from the plots of return loss, the same design can be implied for the radiation pattern re configurability at 60 GHz resonant frequency by certain adjustments.

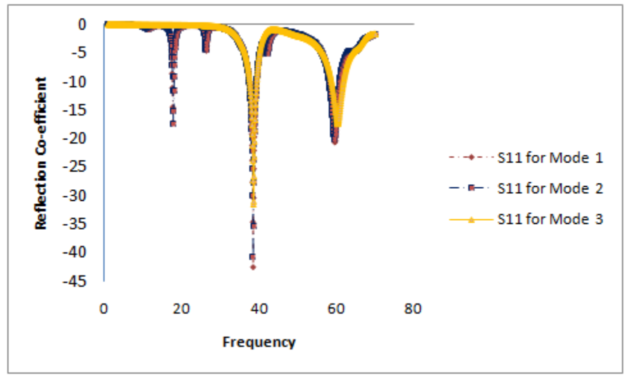

FIG. 3. Simulated Return Loss For Mode-1,2 and 3

3.2 Radiation Pattern and Directivity in dB

Directivity is the measure of the density of power, which is radiated by a design in its direction of maximum strength, to the radiated power with reference to an ideal isotropic radiator. The directivity, an important parameter for the three states shows a value up to 6.77 dB at constant 38 GHz frequency with diversity in radiation pattern. Fig. 4 shows the directivity and diversity in radiation pattern for the Mode-1, i.e. when switch SW1 is OFF and SW2 is ON. In this state the directivity is 6.76 dB while the pattern is directed in the radiating plane towards 38°. The directivity for Mode-2, i.e. when switch SW1 is ON and SW2 remains OFF, is 6.77 dB while the pattern is directed in the radiating plane towards -38°. In Mode-3, both switches SW1 and SW2 remain OFF, the directivity in this case is 5.69 dB while the pattern is directed simultaneously towards the angles of ±41°.

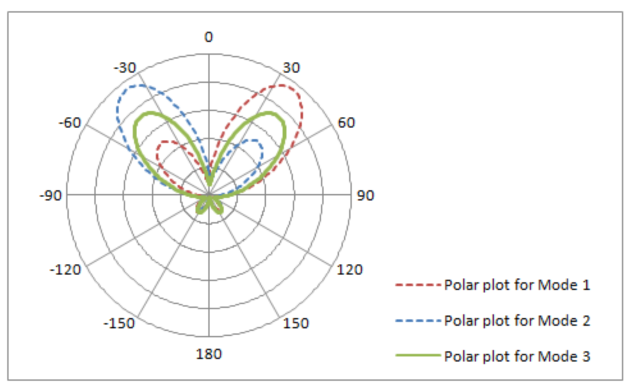

FIG. 4. SIMULATED POLAR PLOT FOR MODE 1,2 and 3

3.3 Gain in dBi

In 3D (Three Dimensional) Spherical Coordinates any of the Field Patterns can be represented. Gain is the property of an antenna that how efficiently an antenna is converting input power to radio waves in space as shown in Fig. 5, for the given three modes. The proposed design has a good gain, at constant 38 GHz frequency, which is up to 6.4 dBi. Gain for the first state, i.e., Mode-1, when a single switch, SW1, is OFF while SW2 remains ON, is 6.4 dBi. Gain for the second state is also 6.4 dBi, i.e., Mode-2, when SW1 is ON SW2 is OFF. The third state, Mode-3, is when both of the switches remain OFF, Gain in this case is 5.4 dBi. The given figure is also showing diversity in radiation pattern in plane with 38°for Mode 1,-38° for Mode 2 and simultaneously towards the angles of ±41˚ for Mode 3.

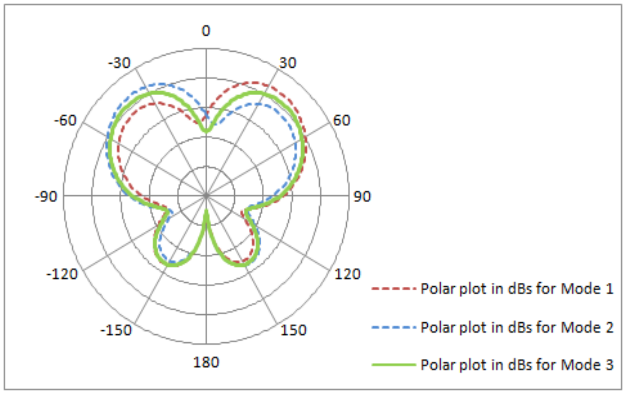

FIG. 5. POLAR PLOT IN DB FOR MODE 1,2 AND 3

3.4 Voltage Standing Wave Ratio

Due to mismatch between the input impedance and the transmission line a part of the signal is reflected back. This ratio is called VSWR. Its range is from 1-2, real and a positive number, and its ideal value is 1. The minimum limit is the indication of the impedance match and denoting a maximum delivery of power to the antenna. Fig. 6 shows the VSWR graphs for the three modes. The value of VSWR is from 1.01 for Mode-1 and Mode-2 while 1.05 for Mode-3, at constant 38 GHz frequency, using for 5G wireless applications, which is almost equal to 1.

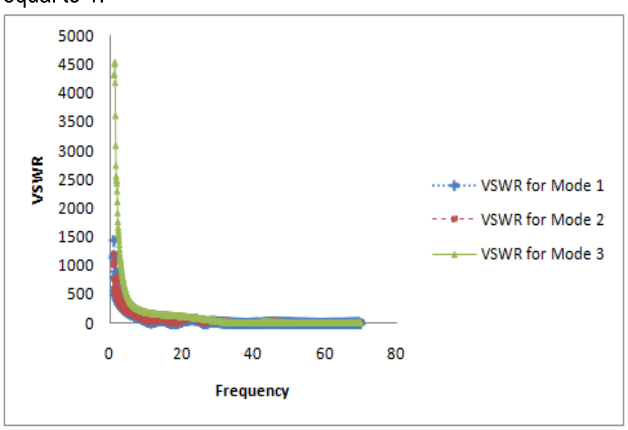

FIG. 6. VSWR Plot For Mode 1,2 and 3

3.5 3D Pattern Re-Configurability

The position of the switches can easily divert the pattern in desired direction. Three diverse dimensional patterns can be shown in Figs. 4-5. The pattern is tilted towards 38º for Mode-1, when switch, SW1, is OFF and the second switch, SW2, remains ON. In Mode-2, the beam is tilted towards -38º, when switch SW1 is ON while SW2 is OFF. A shift of 76º can be achieved by simply switching between Mode-1 and Mode-2. In Mode-3, when both SW1 and SW2 are OFF, the lobes are directed simultaneously and the pattern is broken in two different directions, i.e. towards the angle of ±41º because of the perfect symmetry and feed location. In Mode-1 and Model-2 the switches function is to control the split beam direction as per choice of the designer and to enhance a lobe and minimize the second lobe in the desired direction as shown in Figs. 3-5. This unique property at constant resonance, 38GHz, frequency makes it a better choice for employing in 5G wireless communication. Table V shows the summary of the proposed antenna performance parameters.

Table V: Performance Parameters Of The Proposed Antenna

Mode	Return Loss (dB)	Directivity (dB)	Gain (dBi)	VSWR
1	-40.8	6.76	6.4	1.01
2	-42.5	6.77	6.4	1.01
3	-31.5	5.69	5.4	1.05

CONCLUSION

In this research a 5G pattern reconfigurable antenna is designed. The diversity in pattern can be achieved by a patch antenna enclosed by a hollow rectangular conductor. The spacing's in the between the two conductors are used for enhancing the main beam and minimizing the level of side lobes. Depending on the ON and OFF states of the switches, three Modes provide a diverse radiation pattern. When SW1 is OFF and SW2 is ON, Mode 1, pattern radiates in a direction with an angle of 38º. While SW1 is ON and SW2 is OFF, Mode 2, the pattern radiates in the radiating plane, exactly opposite to Mode 1, with an angle of -38º. In Mode 3, the pattern is directed simultaneously towards the angles of ±41º, for this case both switches, SW1 and SW2, are turned OFF. Additionally, the novelty of this design lies in the pattern diversity at a constant, of 38 GHz, resonant frequency. Directivity varies from 5.69 to 6.77 dB while gain fluctuates in the range 5.4 to 6.4 dBi, whereas, the value for VSWR is from 1.01 to 1.05. The compact size of 3.34x6.73mm² will make it a first choice for integration with future 5G cellular communication systems.

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