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Inverted Matchstick Slotted Rectangular Patch (IMSRP) Antenna for Dual-Band (28/38GHZ) 5G - MM Wave Applications

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The fifth generation (5G) of telecommunication is a promising technology that is yet to become globalized for the effective and fastest mode of communication. This wireless communications system has an extended entail for different Multiple Input Multiple Output (MIMO) antenna systems, focusing on low and high, and less gain, also at millimeter frequency. The frequency ranges have more capability varying from 28 GHz to 150 GHz with the easiest generation of 5G for higher data rates. A mono-element antenna working over the two different 5G mm-Wave frequency bands [n257 (28 GHz) and n260 (38 GHz) bands] is proposed to obtain. The prototype is built upon Duroid-5880 substrate having a permittivity of 2.3 and Loss tangent value of 0.00092. The prototype resonates at 28 GHz and 38GHz of the spectrum to yield better return loss than conventional. The proposed antenna- Inverted Matchstick Slotted Rectangular Patch (IMSRP) is implemented to be 9.84 dBi at 28 GHz band and 1.1195 dBi at 38 GHz by dual band for 5G. The overall designed parameters of the antenna are 16.5 × 20 × 0.508 mm, also does not have any defective in the ground portion made to resonate for dual bands of millimeter wave frequency band of 5G communication.

Keywords: Mono-Element; Millimeter-wave frequency band, Dual bands, 5G Communication.

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1. INTRODUCTION TO 5G

The initiative for 5G or the fifth generation of telecommunication was kick-started in the year of 2019 and focuses mainly on flawless and high-speed mobile communication purposes. As soon as the word arises the frequency allocation to 5G is also made as a continuation with 4G frequency bands. The frequency spectrum of 5G is classified into many divisions of low, mid, and High band micrometer frequencies. The Low band functions similarly to 4G, and the frequency band covers from 1.7 GHz to 4.7 GHz. But the maximum operations happen at High band Micrometer frequencies starting from 24 GHz and extending up to 54 GHz as a Licensed spectrum and 60 GHz as an Unlicensed spectrums. Within that 24-54 GHz licensed spectrum the grown countries already started implementations for the 5G in their own spectrum allocation within their country regions. USA, South Korea, and Japan are already deploying n257 and frequencies for their 5G communications. EU is planned to work over the n260 band frequency. Hence it is the right time for designing and manufacturing Microstrip antennas that resonate for multiple frequencies.

2. LITERATURE REVIEW

The exponential growth of mobile users makes an enormous usage of the existing bandwidth of 4G frequency spectrum. The enormous number of users in a particular region like a metropolitan area directly has an impact on the installation of a large number of antennas making the situation even worse and high exposure to radiation. So, the need for higher frequency bands, which are able to deliver a wide range of bandwidth covering a large number of people with higher data transmission, rates [1]. The wireless mobile technology growth always aims in achieving this strategy, even after four generations of evolution the data speed is not sufficient for the users, and demand increases for much larger in modern day-to-day life [2]. Having a discussion over the pros and cons of achieving a larger frequency band are to be discussed hereafter. The main reason for choosing this millimeter range of frequency is to attain higher bandwidth for the satisfaction of many users' fastest applications by attaining extraordinary data rates on the scales of Gigabit-per-second (Gbps) [3].

Another main reason for searching for new bands of frequencies is that the former existing frequencies were already deployed for various other wireless purposes like Wireless Fidelity, Worldwide Interoperability for Microwave Access, Bluetooth, and so on, but the large frequency spectrum remains untouched [4] so can be used for the fifth generation. Discussing the disadvantages of large frequencies, free space propagation, and lower coverage are the main drawbacks of implementation. Free Space propagation means the ability of signals to penetrate through other solid surfaces lying on the path of transmission. As the frequency increases the distance of coverage usually reduces, this can be overcome by the introduction and initialization of smaller base stations on the vicinity

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regions of the heavy signal drop [5]. The waves that are electromagnetic in nature experience heavy losses in signal quality and strength due to atmospheric attenuations, which can be nullified by means of designing antennas which are highly directive and have high gain [6]. The literature [7] discusses quad-antenna structures covering the frequency range of 26.5-29 GHz with a peak gain of 8.2 dB for 5G applications. In [8] SIW method is fed with the slot to cover frequencies of 27.5-28.35 GHz and 24.25- 27.5 GHz, where gain alters from 8.2 to 9.6 dB. In [9], a Monopolar patch antenna with a Y-shape structure is used to resonate for 3.3-4.2 GHz frequency introducing a 120-degree phased directional difference to attain high gain. In [10], dual antenna Pairs were used with orthogonal mode for the purpose of metal-rimmed smartphone applications.

In [11], an elliptical slotted circular microstrip patch antenna operating at 28 and 40 GHz is proposed, while in [2], two electromagnetically connected patches creating resonance at 38 and 60 GHz are considered. A parasitic patch-loaded radiator resonates between 24 and 40 GHz [12], a four-element tree-shaped MIMO antenna resonates between 23 and 40 GHz [13], a transparent rectangular patch with some branches made of AgHT-8 material produces a wideband response from 23.9 to 23.8 GHz [14], and incorporating slots at the right locations [15-16] results in a dual-band resonance at 28 and 38 GHz. Parasitically coupled antenna with slot in it [17] produces dual-band resonance at 28 and 38 GHz.

Section 2 discusses the design parameters for the proposed design and section 3 describes the design evolution of the proposed design, followed by section 4 discussion over reports analysis of the simulated antenna, moved on to section 5 deals with the comparison of features of reference antennas and the designed antenna, at last, the section 6 sums up the conclusion points of the proposed design.

3. ANTENNA DESIGN

The antenna proposed here is made on Rogers RT Duroid-5880 substrate having a loss tangent value of 0.0009 and relative permittivity of 2.2. The height of the substrate is made as 0.508 and parametric calculations were made to resonate for the fixed frequency. The geometrical layout of the designed antenna is shown below in Fig. 1, having substrate dimensions as 20 mm × 16.5 mm × 0.508 mm. Other parameters of the antenna design are provided in Table 1. To yield higher gain with lower radiation of the ground plane, the scheme single antenna elements are backed by the substrate. The overall simulation and analysis are made using HFSS Ansoft 15.0 software.

4. DEVELOPMENTS IN ANTENNA DESIGN

Initially based upon the parametric calculations a Simple fully grounded rectangular patch antenna as per Fig. 2a was designed and the resonance frequency is measured to be 27, 34, and 39 GHz. Then the method of

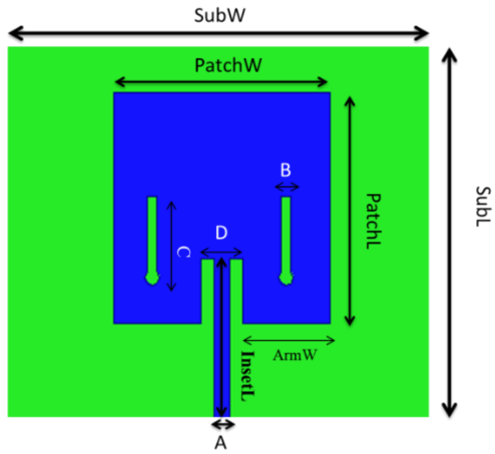


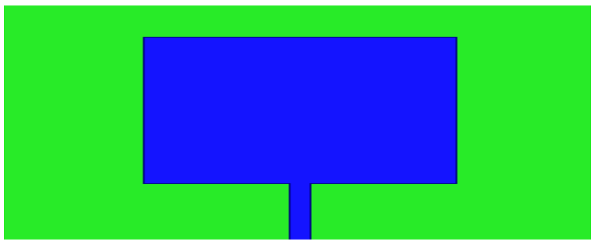
Fig. 1 – 2D view of designed single element antenna

Table 1 – Parameters of designed single element antenna

Antenna Parameters	Values (in mm)	Antenna Parameters	Values (in mm)
SubL	16.5	A	0.7
SubW	20	B	0.4
PatchL	10	C	3.256
PatchW	9.9	D	1.9
InsetL	7	ArmW	4

Inset feed is used to improve the resonance frequency for a particular operation and using that technique it was found that the resonance happens at 35 GHz as Fig. 2b. Later on, the slots were introduced in the rectangular patch at particular regions as Fig. 2c so that it does not affect the gain of the antenna at the same time improvising the resonance for desired bands.

The detailed design modifications, as well as the changes that happened during these changes, were plotted and the comparison charts were displayed below in Fig. 3 and Fig. 4.



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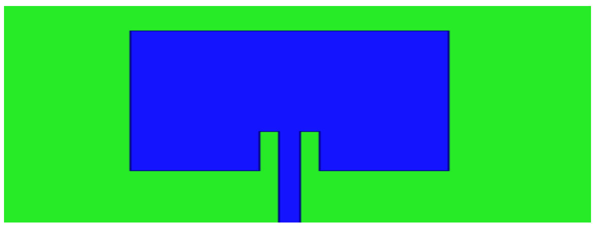

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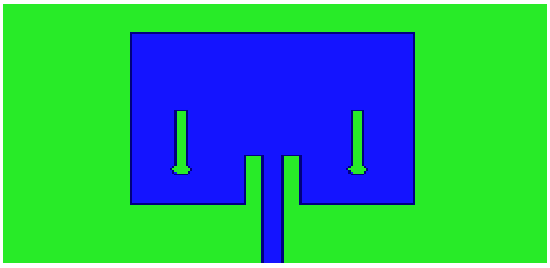

c

Fig. 2 – (a) Simple antenna; (b) antenna with Inset Feed technique, (c) Proposed antenna design with slots

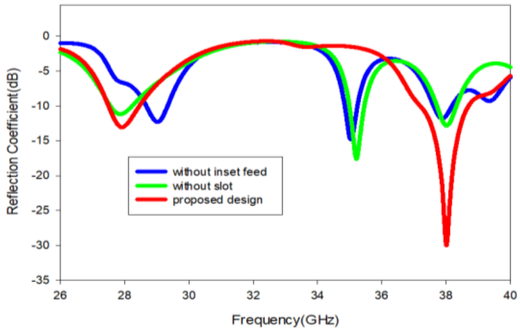

Fig. 3 – Comparison chart of Reflection coefficient variation

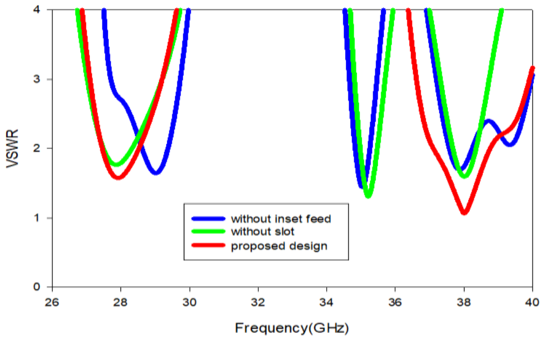

Fig. 4 – VSWR variation with respect to modifications

5. SIMULATED RESULTS ANALYSIS

The detailed analysis of the designed antenna is case studied in detail in this section. The RF Connector on the bottom middle is used to feed the element and simulations cum analyses were done using HFSS Ansoft Software v 15.0. While simulating the results the port is terminated in 50 Ω load to achieve impedance matching.

5.1 S-parameter

A good resonance was achieved by the antenna. It is measured as impedance bandwidth based on the – 10 dB criterion and the results were found to be resonate for two important bands of 5G millimeter frequency bands n257 (28 GHz) and n260 (38 GHz) and the bandwidth is observed as 947.7 MHz and 1.5254 GHz at 28 and 38 GHZ frequency bands as depicted by Fig. 5.

5.2 VSWR Plot

The Voltage Standing Wave Ratio Plot or simply the VSWR Plot plays a vital role in the stability of the

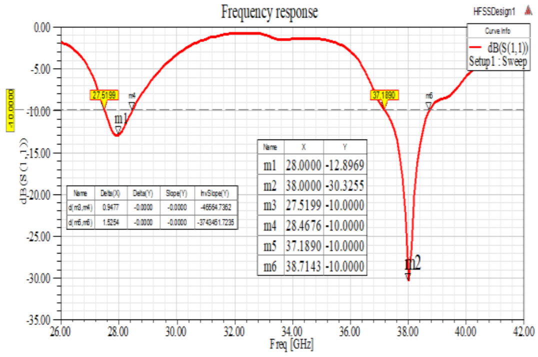

Fig. 5 – S-parameter plot showing resonance at 28 GHz and 38 GHz

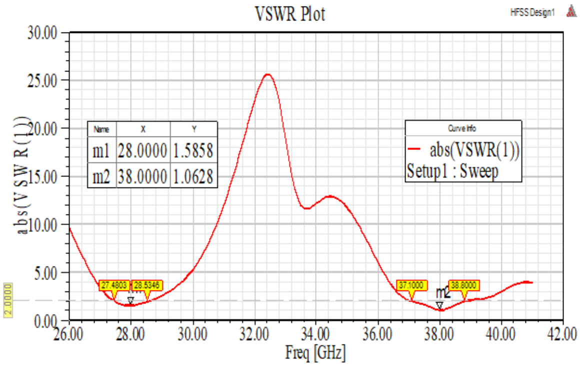

Fig. 6 – VSWR Plot

antenna. The VSWR range at the resonating frequencies needs to be lesser in order to get stabilized resonance. In our designed antenna, it is well known from the plot that the VSWR values at the resonating frequencies lie below 2, hence the stability of the antenna at the pre-mentioned ranges is heavily stable as shown above in Fig. 6.

5.3 Gain Plot

The Frequency vs. Gain plot helps in analyzing the Gain achieved by the antenna over a wide set of frequencies. An antenna of high gain helps in handling a lot more people and efficient usage of the allocated spectrum. From the Plot, we infer that the antenna reaches a maximal gain of 9.84 dBi at 28 GHz the band and 1.1195 dBi at 38 GHz the band inferred from Fig. 7.

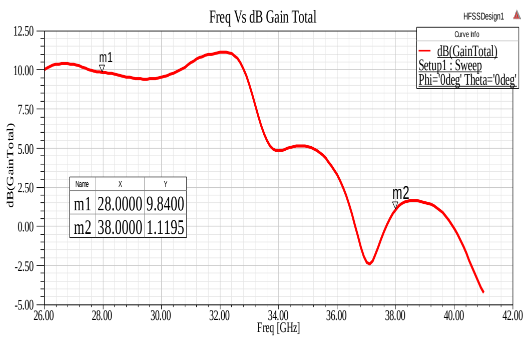

Fig. 7 – Frequency vs. Gain Plot

5.4 Radiation Pattern

The radiation Patterns are very helpful in referring to the antenna usage platform to be as a directive (Unidirectional or Multi-directional) or Non-Directive antenna. In results 8 (a), (b), (c) and (d) the planar polarization values are viewed.

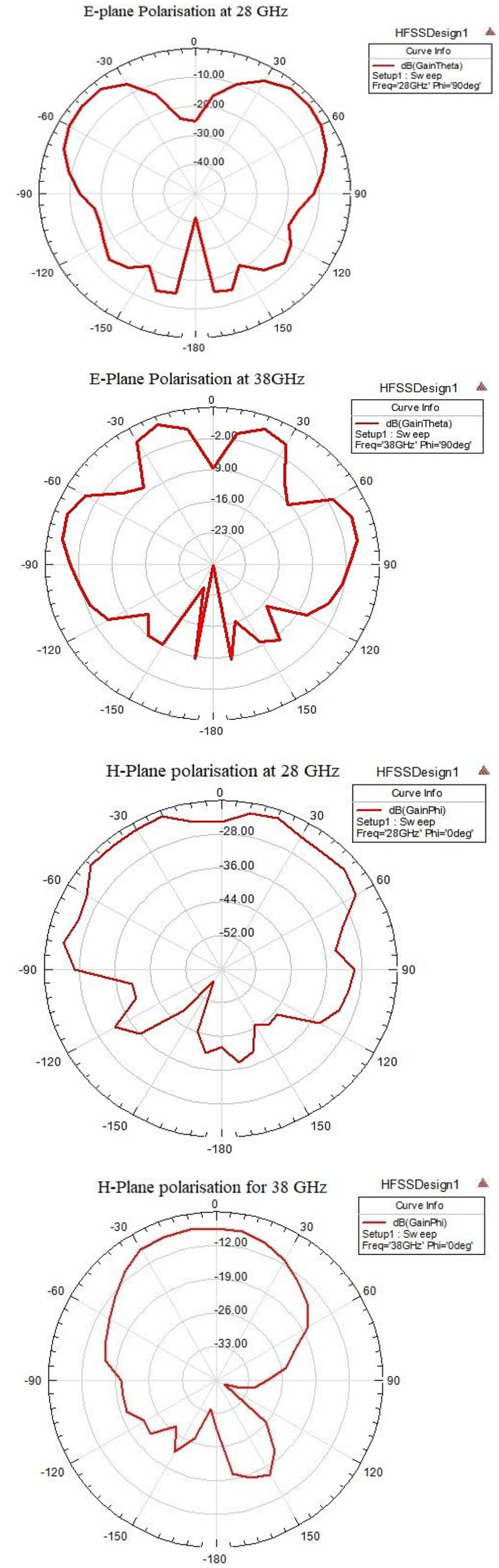

Fig. 8 – *E* and *H* plane polarizations at 28 and 38 GHz

5.5 3D Polarization Pattern

The above polarization charts are two-dimensional in view, however using HFSS Ansoft 15.0, we can visualize the three-dimensional gain plots and total directivity plots of the antenna through which we can able to determine the resonators of the antenna in all 360-degree directions and the suitable angle of antenna posture to achieve higher efficiency and gain in trans-reception purposes. Figure 9 represents the 3D Gain view of the proposed antenna.

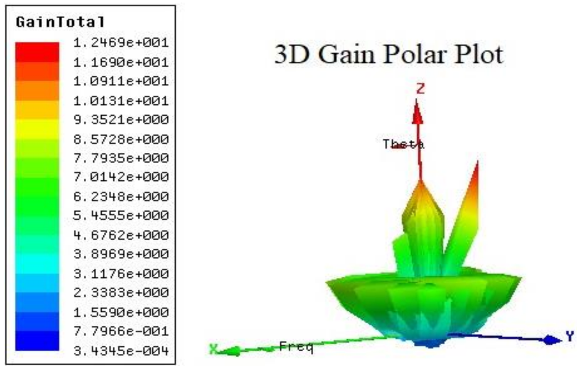

Fig. 9 – 3D Polar Gain Plot

5.6 Comparison with Reference Papers

This section deals with the features available in the proposed work to that of the features available in reference papers taken for the analysis. Nearly most of the common parameters as well as some special features in every reference are also going to get discussed in this section. All the points to be discussed are summarized in Table 2 below.

Table 2 – Comparison of discussed antenna parameters

Resonant frequency band	Peak Gain (dB)	Size (mm^3)	Ground State (Defective /Not)
23-40	8.3	80 × 80 × 1.57	Defective (1)
3.4-3.6	4.5	145 × 75 × 6	Defective (2)
3-9	11-12	90 × 90 × 1.6	Defective (3)
3.4-3.6	4.8-5.1	150 × 75 × 7	Defective (4)
2.6-13	0.76-6.02	66.8 × 40 × 0.8	Not Defective
24-28 7.4	–	30 × 30.5 × 0.508	Defective (5)
25.5-29.6	8.3	158 × 77.8 × 0.381	Defective (6)
27.5-28.35 24.25- 27.5	8.2 to 9.6	32.8 × 40 × 0.8	Defective (7)
3.3-4.2	–	30.5 × 40 × 0.508	Defective (8)
27.51-28.46 37.18-38.71	9.84	16.5 × 20 × 0.508	Not Defective

6. CONCLUSION

In this paper, the design of a single element operating over two various bands of 5G millimeter frequency bands [n257 (28 GHz) and n260 (38 GHz)] is demonstrated. The Resonance of the antenna at 28 GHz and 38 GHz is attained by the proper impedance matching by inset feedline at the source point of the antenna and by infusing slots in patch using HFSS software. The designed antenna is compact in size possessing a wideband and high gain with good standardized results. Non-Defective Ground is implemented so as to make the prototype applicative in effective in wireless communication. The gain of the antenna is observed to be 9.84 dBi at 28 GHz band and 1.1195 dBi at 38 GHz in a single antenna system. This high gain of antenna helps in improvising the signal strength and provides a more precise way of targeting signals, there by helps in improved communication systems.

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Прямокутна антена з прорізами (IMSRP) для дводіапазонних (28/38 ГГц) 5G MM Wave додатків

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П'яте покоління (5G) телекомунікацій — це перспективна технологія, яка ще має стати глобальною для ефективного та найшвидшого способу зв'язку. Така система бездротового зв'язку має розширені можливості для різних антенних систем із багатьма входами та багатьма виходами (MIMO), зосереджуючись на низьких і високих частотах та меншому підсиленні на міліметровій частоті. Діапазони частот мають більше можливостей від 28 до 150 ГГц із найпростішим поколінням 5G для вищих швидкостей передачі даних. Пропонується отримати одноелементну антену, яка працює в двох різних діапазонах частот мм-хвиль 5G [n257 (28 ГГц) і n260 (38 ГГц)]. Прототип побудований на підкладці Duroid-5880, що має діелектричну проникність 2,3 і значення тангенса втрат 0,00092. Прототип резонує на частотах 28 і 38 ГГц спектру, щоб отримати кращі зворотні втрати, ніж звичайні. Запропонована антена – IMSRP (Inverted Matchstick Slotted Rectangular Patch) становить 9,84 дБл на частоті 28 ГГц і 1,1195 дБл на 38 ГГц у двох діапазонах для 5G. Загальні проектні параметри антени становлять 16,5 × 20 × 0,508 мм. Відсутні дефекти у наземній частині, створеної для резонансу для подвійних діапазонів міліметрового діапазону частот зв'язку 5G.

Ключові слова: Моноелемент, Діапазон частот міліметрового діапазону, Два діапазони, Зв'язок 5G.