Dual Band Reconfigurable Antenna For Sub 6GHz and Millimeter Wave Bands For 5G Mobile Applications

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Abstract. The reconfigurable dual-band antenna under consideration is structured in the form of a round necktie patch and is capable of interchanging and/or switching between millimeter wave and sub-6 GHz bands. Positioned at the front apex is a meandered radiating patch element featuring an H slot shape, while the reverse/back side contains a shortened or truncated ground plane, purposely to improve and/or enhance the total or overall operation and efficiency of this designed antenna. A dual-band antenna has been developed on a Rogers 3003 substrate measuring 27.80 mm x 14.0 mm with a thickness of 1.520 mm utilizing CST Microwave Studio. The substrate is characterized by a dielectric constant of 2.20 and a loss tangent of 0.00090. The SMP1321-079LF PIN diode is positioned at the middle and/or between the two components to adjust the antenna for resonance at both 3.50 GHz and 28.0 GHz through modification of its switching or toggling state. Activation of the PIN diode enables the antenna to function at both 3.50 GHz and 28.0 GHz, whereas deactivation confines the antenna's operation to the 28.0 GHz mm-wave band, effectively excluding the 3.50 GHz band. The antenna that is being suggested has an extremely 19.650 GHz larger bandwidth, covering and/or spanning almost the entire range of millimeter wave bands, such as 23.0 GHz, 28.0 GHz, and 38.0 GHz (ranging from 22.650 GHz to 42.300 GHz). In addition, the sub-6 GHz band presents a bandwidth of 0.970 GHz (970.0 MHz), spanning from 3.020 GHz to 3.990 GHz. The antenna exhibits a return loss of -31.330 dB at 3.50 GHz and -49.720 dB at 28.0 GHz. Despite these challenges, the antenna maintains a compact form factor and demonstrates the ability to function across two separate frequency bands, with a notable frequency 8:1 ratio in between the millimeter wave band and the sub-6 GHz band.

Keywords: Milli Meter Wave, Larger Bandwidth, Dual Band Antenna.

1 Introduction

Reconfigurable antennas have garnered significant consideration and/or attention in recent years due to their ability to exhibit variability in radiation pattern, polarization, frequency, and directivity, as documented in the references [1-8]. It is noteworthy that, these antennas may incorporate two or three diversities within the same structure. The reconfigurable designs of

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antennas with Microstrip technology have many desirable features and/or characteristics that make them a good choice for attaining reconfigurable properties, including their small size, lightweight, and conformability. Because of this, adopting its reconfigurable properties is a highly recommended strategy. Rapid data and information development necessitates a higher data rate with minimal latency in today's wireless networks. It is expected that 5G cellular and LAN networks will be an effective or efficient way to surmount the shortcomings of the existing methods of communication [1]. The Federal Communications Commission has strongly advised the adoption of the millimeter-wave (mm-wave) spectrum for 5G communication, citing its potential to significantly enhance data transfer speeds and network capacity. This spectrum comprises the frequencies 24, 28, 37-39, and 60 GHz. However, there are propagation issues with the proposed spectrum that may hinder network rollout. The bands used for short-range indoor connections in the millimeter-wave range are currently being developed, so the ITU WRC-15 has designated and put into operation the primary 5G sub 6GHz mid-band (3.40-3.60 GHz) for broadband and wider cellular network communication. However, this frequency range can offer wider and expanded coverage with reduced signal loss. The emergence of millimeter-wave bands (such as 28.0 GHz) makes this primary 5G frequency particularly feasible for dense, compact, and packed 5G fewer-cell arrangements of networks in urban environments, addressing the critical need for additional capacity. Macro-cells, which encompass larger areas, can also utilize these frequencies. To deliver the most high-speed 5G services, it is necessary to allocate approximately or nearly 100.00 MHz of bandwidth in sub 6GHz 5G mid-band (3.50 GHz) and 1.00 GHz of bandwidth in the mm-wave spectrum. This allocation effectively manages substantial volumes of traffic at elevated data speeds (28.0 GHz).

Multiband antennas with a high-frequency ratio will be crucial for 5G deployments in the future, as they will provide coverage of both the sub-6 GHz and mm-wave bands [7]. The majority of the investigations that have been reported used dedicated antennas for each frequency band. However, accommodating many antennas with one (single) band in the constrained area of handheld devices is a formidable challenge. Researchers are interested in this field because of the potential for breakthroughs in the reconfiguration and integration or combinationation of the sub-6 GHz and mm-wave bands. Small, frequency-configurable antennas are needed for future 5G technology so that all available wireless bands can be used. Band notching is a benefit of reconfigurable antennas over wideband and multiband antennas for reducing interference [7].

The author in reference [20] designed a set of dipole antennas with the capability to switch between functioning at frequencies ranging from 3.30 to 3.60 GHz and 4.80 to 5.00 GHz, intended for potential use in 5G systems. These antennas were designed to be supported by an artificial magnetic conductor surface. The proposed structure, however, was too massive to reach the 5G mm-wave bands (72 mm x 72 mm x 3.5 mm). Literature-presented reconfigurable antennas are single-antenna elements with related constraints; they cannot operate in the sub-6 GHz and mmm-wave frequencies. In various countries, such as the South Korea and US (United States), the primary and/or main 5G mid-band (3.5 GHz) and mm-wave band (28 GHz) have already been designated for upcoming 5G communication.

This study presents a small, dual-band, frequency-configurable antenna for use in upcoming 5G mobile devices. The antenna proposed utilizes *SMP1321-079LF (*RF PIN diode) switch or toggle between two operating modes, providing a maximum frequency range of 3.390-3.660 GHz in the ON condition or level whilst 27.400-28.600 GHz in the OFF condition or level, making it suitable for potential 5G network development. By combining a meandering radiating patch with a truncated and/or shortened ground structure, a size reduction and bandwidth improvement were accomplished. The design of the intended antenna from a single element, dualization of the bands as well as the reconfiguration from one band to another with a higher ratio of frequency is presented below.

2 Design of the Dual-Band Reconfigurable Antenna

2.1 Dual Band Antenna Covering Sub 6 GHz and Milli Meter wave Bands

To design an antenna that can operate or resonate at more than one frequency, either dual or multi-functional operating frequency antenna, there is a need to first design the antenna to resonate or trigger at a single frequency before introducing any available technique to make it dual or multi-functional frequency of operation antenna. This proposed antenna is not in any way against this procedure. This intended antenna is first designed and optimized using a parametric study on different dimensions to trigger at 28.0 GHz with unreasonable impedance bandwidth before the introduction of two slits attached to the circular patch to increase a reasonable value of bandwidth. However, in following the initial procedure of making this antenna a dual antenna, a rectangular patch is then linked at the uppermost top to this bottom round neck-shaped antenna. An H cut or slot is then introduced to the center of the rectangular patch to make the antenna resonate on two optimized frequencies (3.50 GHz as well as 28.0 GHz). A defected Ground cut (partial ground) is then introduced at the back and/or ground side of the merged antenna to increase or enhance the bandwidth and gain of the dual-band antenna and to reduce the mutual coupling of the intended antenna. The physical attributes of a dual-band antenna operating at 3.50 GHz and 28.0 GHz, corresponding to millimeter wave and sub-6 GHz bands, are illustrated in Figure 1. Rogers 03003, with its 2.20-parameter dielectric constant, 0.00090-parameter loss tangent, and 1.520-millimeter thickness, is used as the antenna's substrate.

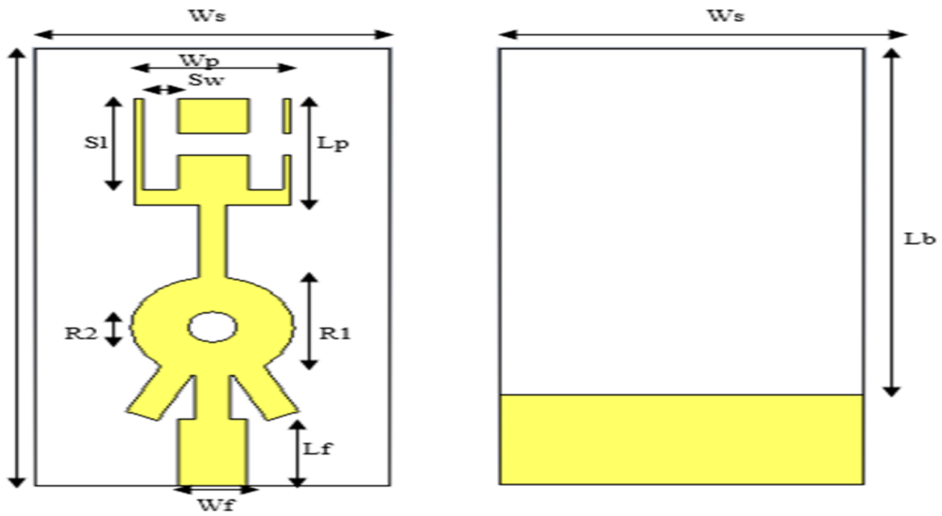


Fig. 1. Geometry (Front and Back) of the Dual Band Antenna

Table 1. Antenna Dimensions of the Dual Band Structure

Parameters	Dimensions (mm)
Substrate Width Ws	14

Substrate Length Ls	27.8
Radius R1/R2 (inner and outer)	0.967/3.2
Width (Wp) of the Patch	6.1
Length (Lp) of the patch	6.78
Feeding Width Wf	2.71
Feeding Length Lf	4.28
Width of the Cut/Slot Sw	2.79
Length of the Cut/slot Sl	5.76
Length of the Shortened/truncated Lb	22.09

After being planned to resonate at 28.0 GHz in a round neck-tide configuration, the antenna's bandwidth was increased by the addition of two diagonal rectangular patches to its periphery. The first frequency, under sub-6 GHz range consideration (3.50 GHz), is being generated by connecting a neck-tide round form microstrip patch antenna that resonates in the millimeter wave band (28.0 GHz) to a meandering radiating patch with an H-shaped slot and/or cut at the uppermost part of the antenna. The research results indicate that the millimeter wave band has an 8:1 frequency ratio with the sub-6 GHz band. Table 1 depicts the intended antenna dimensions and/or sizes.

2.2 Reconfigurable Dual Band Antenna Between Sub 6 GHz and Millimeter Wave Bands

For a dual-band antenna to operate in a reconfigurable mode, a switch must be introduced to trigger the operational frequency on different modes (ON and OFF modes). The radiator of the given antenna, illustrated in Figure 2, consists of a patch in a rectangular shape and a meandering radiating structure, and a switch (PIN diode) is connected between them to provide a dual-band antenna that can be switched between the sub-6 GHz and Millimeter wave bands. The suggested one-band antenna (single) component is just 27.80 mm by 14.0 mm by 1.520 mm, making it extremely portable. As can be seen in Figure 2, miniaturization and broad bandwidth are accomplished by employing a truncated ground structure and two rectangular slots attached to the circular form of the neck tide-shaped patch. A 2.710 mm wide, 50 ohms matched microstrip feeding line supplies power to the antenna. To function at frequencies below 6 GHz, a microstrip antenna and a meandering section are coupled using the structure's reconfigurability (3.50 GHz). Positioned between the two parts, the PIN diode modifies the switching state to cause the antenna to resonate at 3.50 and 28.0 GHz frequencies, respectively. Nevertheless, this intended antenna operates at both 3.50 GHz as well as 28.0 GHz when the PIN diode is turned ON, but only at 28 GHz when it is turned OFF, making it a mm-wave antenna. Due to its minimum insertion inefficiency or loss and rapid or fast switching or triggering time, Infineon's silicon PIN diode (SMP 1321-079LF) is employed in the suggested design. Figure 3 depicts the ON and OFF circuit configurations, as well as the PIN diode's connection to the antenna. It can be seen from the circuit configuration of the PIN diode (SMP 1321-079LF) that, the antenna output indicated as pin 2 and 2^1 is directly connected to the two pins of the switch indicated as output pin 2 and input pin 1 respectively. This switch configuration enhances the performance of reconfiguration at the fastest time between the bands of operation.

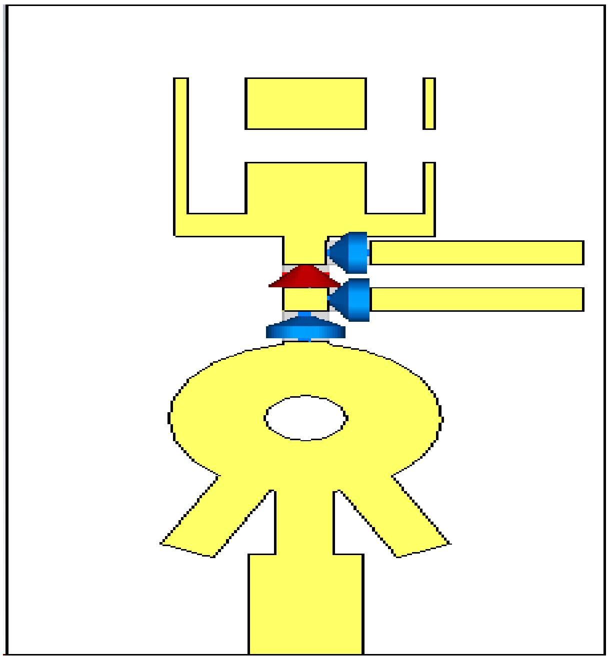


Fig2. Proposed Reconfigurable Dual Band Antenna

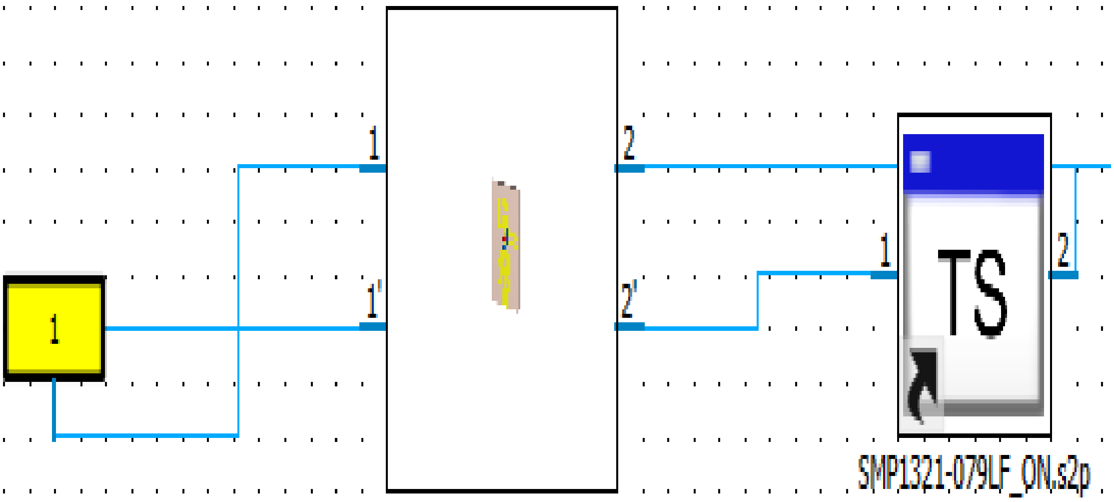


Fig 3. PIN Diode connected to the Proposed Reconfigurable Antenna

3 Results and Discussion

Simulations of the proposed antenna were run in CST MWS studio. Figures 4a and b display the dual-band antenna's gain and reflection coefficient (S11) before reconfiguration respectively. The S11 measurement indicates a value of -31.330dB while demonstrating 0.970 GHz (970 MHz) spanning from 3.020 GHz to 3.990 GHz of impedance bandwidth, specifically at the 3.50 GHz frequency. However, at 28.0 GHz, the reflection coefficient or return loss (S11) shows or indicates a value of -49.720dB having an ultra-wideband of nearly 19.650 GHz, spanning from 23.0 GHz to 43.0 GHz which includes; 23.0 GHz, 28.0 GHz, and 38.0 GHz bands. Figure 5 displays the pattern of the 3D of the given or recommended antenna, illustrating a 2.670 dBi gain for the sub 6 GHz band (3.50 GHz) whereas 5.170 dBi at the millimeter wave band (28.0 GHz). Despite its size, this antenna covers two distinct frequency ranges, with 8:1 as a ratio of frequency between the millimeter wave and sub-6 GHz bands.

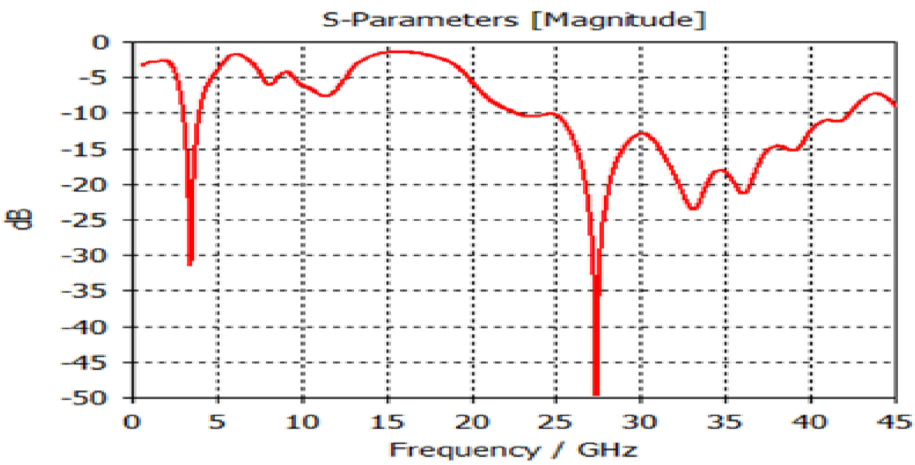


Fig. 4 (a). S11 of the Proposed Dual Band Antenna

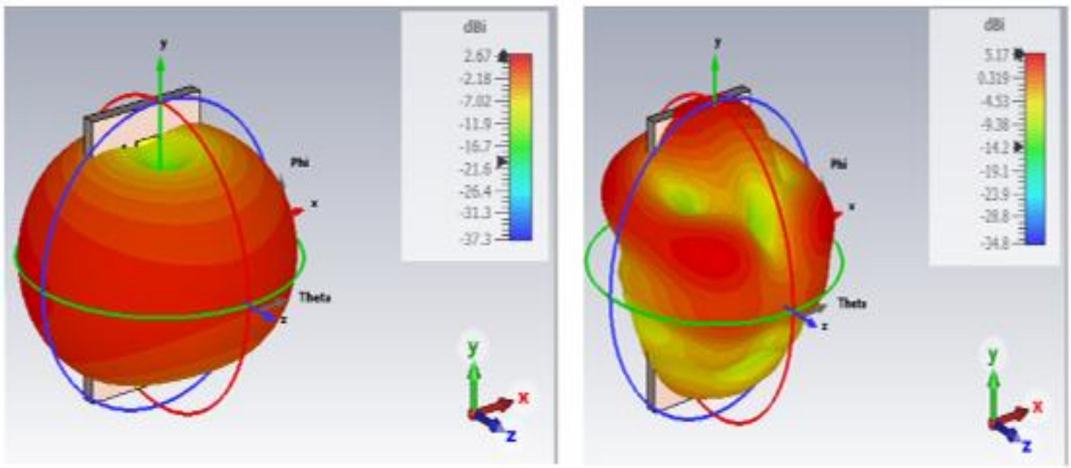
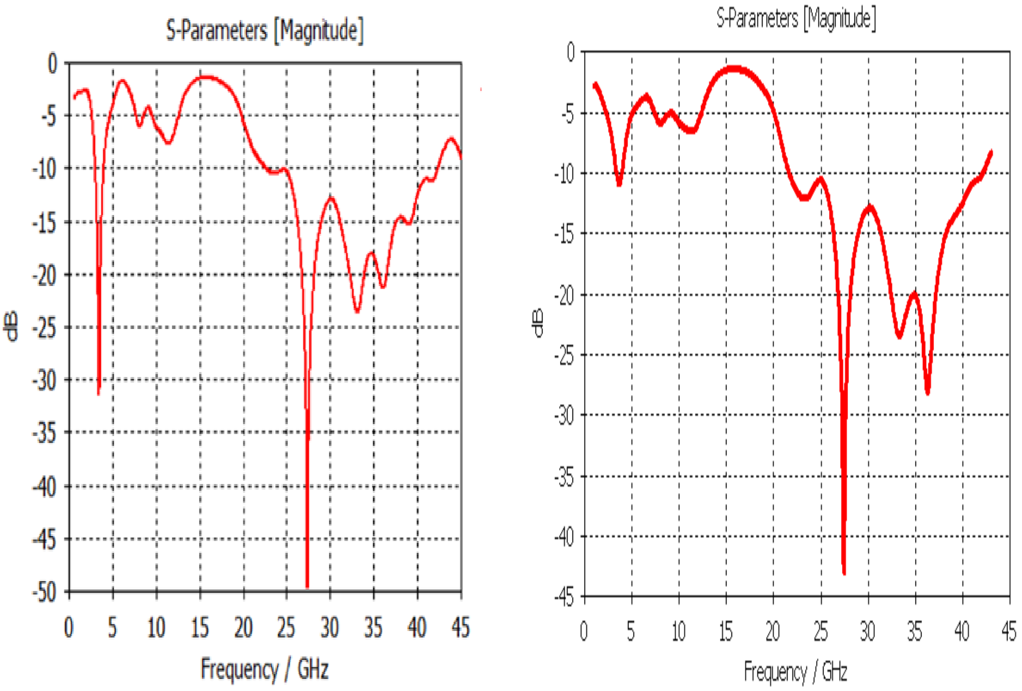


Fig.4 (b). Gain of the Proposed Dual Band

As illustrated in Figure 3, this suggested antenna is then reconfigured using a PIN diode (SMP 1321-079LF) for transition between operating frequency bands. While the PIN diode is switched to ON condition or state, the antenna functions at frequencies of 3.50 GHz and 28.0 GHz. However, during the OFF or zero state of reconfiguration or switch, the PIN diode removes the frequency band below 6 GHz and operates specifically in the 28 GHz millimeter-wave band. However, if the PIN diode is triggered or switched in its ON condition or state, both frequencies are displayed, but in its OFF state, the 3.50 GHz frequency is eliminated (as seen in Figure a and b of the reflection coefficient results).



(a) **(b)**

Fig 5 (a) and (b). S11 Results Before and After Reconfiguration (Swiching ON and OFF)

Based on prior research citing in [7], it is clearly obvious that at 3.50 GHz, the peak attainable was found to be 270MHz, while at 28.0 GHz, it was determined to be 1200MHz respectively, with a reflection coefficient of -26.0 dB and -22.0 dB. At 3.50 GHz, the antenna gained 2.30 dBi, while at 28.0 GHz, it gained 7.70 dBi. Operational frequency, return loss, gain, and bandwidth are just a few of the performance measures summarized in Table 2. By comparing the previous works with the proposed work, it can be observed that this intended antenna will be a better match for future 5G reconfigurable antenna, as the intended antenna covers many bands of millimeter wave as well as a larger bandwidth at sub 6 GHz. This antenna is unique in terms of several techniques applied to accomplish the design which include slot introduction, partial ground plane and size reduction.

Table 2. Comparison of Antenna in [7] with Proposed Antenna

Antenna Features	Suggested Work	[7]
Operational Frequency	3.50 GHz 28.0 GHz	3.50 GHz 28.0 GHz
Ranges of Frequencies (Bandwidth)	3.020 – 3.990 (0.970 GHz) 22.650 – 42.300 (19.650 GHz)	3.390 – 3.660 (0.270 GHz) 27.40 – 28.60 (1.20 GHz)
S11 (dB)	-49.720 -31.340	-26.0 -22.0
Gain (dBi)	2.670 5.170	2.30 7.70
Frequency Reconfigurability	Yes	Yes

4 Conclusion

It is difficult to design a dual-band antenna that can be switched between multiple configurations. However, this study provides a workable alternative by first proposing the design of a 28 GHz circular neck-tie-shaped antenna that can be coupled to a 3.5 GHz meandering patch via an H-shaped cut and/or slot at the patch's uppermost center. The suggested and/or proposed antenna's configuration is then changed with the use of a PIN diode (SMP 1321-079LF) to allow for frequency hopping and switching between the sub-6 GHz (3.50 GHz) and millimeter wave (28.0 GHz) bands. This antenna is designed to operate within the sub-6 GHz range and also covers the millimeter wave bands, offering comprehensive coverage of the millimeter wave spectrum of nearly 40.0 GHz. The recommended antenna features an exceptionally wider bandwidth of 19.650 GHz, encompassing the 23.0 GHz, 28.0 GHz, and 38.0 GHz (22.650 to 42.300 GHz) frequency bands, as well as a bandwidth of 0.970 GHz (3.020 to 3.990 GHz) within the sub-6 GHz frequency range. Additionally, the antenna demonstrates return loss values of -31.330 dB as well as -49.720 dB in the 3.50 GHz and 28.0 GHz ranges, respectively. However, this latest performance results provide solid confirmation that the recommended antenna is an ideal fit for 5G mobile communication systems.

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