Conference Paper

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Dual-Band Microstrip Patch Antenna for Millimeter Wave and Sub-6 GHz Bands with High Frequency Ratio for 5G Application

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***Abstract*—Considering the ever-increasing and high demands in wireless communication applications for 4G, LTE, and 5G, a proposed antenna design has been put forth that incorporates dual-band millimeter wave technology with the sub-6 GHz band. This design has been expertly created to cater to the growing needs of the telecommunications industry and aims to effectively meet the requirements of modern-day 5G applications. The integration of dual-band millimeter wave technology with the sub-6 GHz band offers a seamless user experience and improved network reliability. The round-shaped antenna boasts four inverted-cone slots located at the center of the circle and is connected to a radiating patch element at the top front. This element features a square slot shape and is complemented by a partial ground plane to optimize its functionality and performance. The antenna is designed on a Rogers 3003 substrate, 2.2 dielectric constant with dimensions of 35 mm x 25 mm x 1.52 mm, and a loss tangent of 0.0009 using a CST microwave Studio. This antenna boasts an impressively wider bandwidth of 8.293 GHz, spanning from 27.009 to 35.302 GHz. Additionally, a bandwidth of 1.54 MHz (between 2.23 GHz and 3.77 GHz) was observed at the sub-6GHz band. Notably, the antenna also exhibits impressive return loss values of -36.46 dB and -30.44 dB at the sub 6GHz band (3.5 GHz) and millimeter wave band (28 GHz), respectively. This antenna, despite its small and compact size, can combine two discrete frequency bands, namely the millimeter wave band and the sub-6 GHz band. Notably, the frequency ratio between the two aforementioned bands stands at 8, which is a remarkably large ratio.**

Keywords — 5G, LTE, Inverted-Cone, Dual Band, Square-Slot, Power Gain, mmWave.

I. INTRODUCTION

With the exponential growth of data and information, wireless networks must be capable of supporting high-speed data rates and low latency. As a result, the wireless communication sector is continually evolving, and Long-Term Evolution (LTE), commonly known as the 4th generation (4G) of communication, is at the forefront by bringing and/or providing exceptional data rates and throughput [1].

Current wireless communication technologies, like 4G and Wi-Fi, struggle with bandwidth limitations and congestion problems, resulting in only modest data rates [2]. To enable technological progress, 5G technology demands a revamped spectrum allocation mechanism that can accommodate broader bandwidth [3]. This development would unlock the potential for more efficient and impactful communication networks. The mm-wave band, as proposed by the International Telecommunication Union and Federal Communication Commission (FCC), is under investigation for its potential to provide enhanced bandwidth and data rates in comparison to sub-6 GHz bands. According to sources, a bandwidth of 500 MHz is the minimum requirement for 5G applications [4], [5], [6].

It is important to note that using mm-wave signals can pose certain challenges, such as multipath fading and atmospheric absorption losses [7]. While the proposed spectrum holds promise, propagation challenges and limitations may hinder network deployment. To address this, the ITU WRC-15 has identified the 5G mid-band (3.4-3.6 GHz) as the optimal choice for broadband cellular communication systems. This band offers broader area coverage with fewer propagation losses compared to mm-wave bands, which are currently in the developmental phase for indoor links of shorter ranges [6].

The 28 GHz millimeter-wave frequency band is a desirable option for deploying high-density 5G small-cell networks in densely populated urban environments. Conversely, macro-cells are used to provide wider coverage in less populated areas. To facilitate high-speed data transfer for the most advanced 5G services, a bandwidth of approximately 100 MHz in the 5G mid-band (3.5 GHz) and 1 GHz in the mm-wave band (28 GHz) are required. Antennas that possess the ability to cover both the sub-6-GHz and mm-wave bands are highly coveted in the realm of 5G applications.

These antennas must possess multiband capability and a significant frequency ratio. Considerable research has been devoted to developing antennas for sub-6GHz 5G communication, while several compact-sized mm-wave antennas have also been put forth as potential solutions [8]. Typically, distinct antennas were utilized for different frequency bands, posing a challenge for mobile phones with limited space for multiple single-band antennas. However, researchers are now exploring the integration and/or combination of sub-6-GHz and mm-wave bands as a potential solution to this issue. As the demands of 5G technology continue to increase, compact antennas that can be frequency-reconfigured to cover and resonate allocated wireless frequency bands, including sub-6-GHz and/or mm-wave bands, are necessary. The exponential growth of 5G communication calls for a high-throughput system with efficient spectrum use, as highlighted in recent studies.

The task at hand entails designing an antenna system that can accommodate multiple wireless standards, offer fast data rates, and make optimal use of spectrum. What would be the recommended approach to achieve this objective? This is a complex task due to the constant addition of new services and standards for wireless devices. Lately, numerous proposals for frequency-reconfigurable antennas have been tailored to meet the demands of 5G applications [9] – [14].

In this article, an innovative dual-band microstrip patch antenna is introduced, capable of covering both the 28GHz and 3.5GHz bands. The antenna's design features a distinctive neck-tie round-shaped patch that is connected to a meandered radiating patch, an "H" slot shape, and a fractional/truncated ground plane. The technology employs Roger's substrate, which exhibits a dielectric constant of 2.2, and a loss tangent of 0.0009. This dual-band antenna addresses the challenge of limited single-antenna elements in dual-band antennas, by accommodating both sub-6-GHz and mm-wave bands.

A novel dual-function antenna has been developed to enable seamless integration of sub-6-GHz and millimeter-wave bands for 5G wireless communications. Thanks to its frequency reconfigurability, it operates at both 3.5 GHz and 28 GHz with remarkable efficiency. The antenna design features a microstrip patch and meandered radiating structure with a truncated ground plane, resulting in a significant reduction in size without sacrificing performance. Furthermore, a MIMO system with 8x8 antenna placement configurations was demonstrated, showcasing exceptional characteristics without the need for external decoupling structure [7] This research study introduces a cutting-edge model that is uniquely designed to accommodate sub-6 GHz and 5G mm-wave frequencies. The model is equipped with a 2x2 dual-band PIFA MIMO and incorporates a total of eight components, thus offering exceptional performance for sub-6 GHz frequencies, 5G signals at 3.8 GHz, and LTE band-46 at 5.4 GHz. The study documents the model's impressive capabilities and outlines its potential for advancing the field of wireless communication, as described in [10].

The antenna design under consideration showcases a circular form supplemented by four inverted cone slots placed at the center. These slots are linked to a radiating patch element located at the top front. The patch element boasts a square slot shape, while the back is equipped with a fractional and/or truncated ground plane to enhance the antenna's efficiency and efficacy.

This cutting-edge design utilizes dual-band millimeter wave and sub-6 GHz frequencies, achieving a remarkable bandwidth of 8.3 GHz that spans from 27.009 GHz to 35.302 GHz. The antenna, crafted with precision using CST Microwave Studio, is made with a Rogers 3003 substrate that measures 35mm by 25mm and has a thickness of 1.52mm, with a dielectric constant of 2.2. Moreover, the sub-6 GHz band provides an additional bandwidth of 1.54 GHz, ranging from 2.23 GHz to 3.77 GHz. The antenna boasts impressive -36.46 dB and -30.44 dB return loss at the sub-6GHz band (3.5 GHz) and millimeter wave band (28 GHz) respectively.

II. ANTENNA DESIGN AND CONSIDERATION

In Figure 1, the diagram illustrates a dual band microstrip patch antenna designed for 5G applications. The aforementioned antenna is designed to resonate and/or operate at two distinct frequencies namely 3.5 GHz and 28 GHz with a high-frequency ratio. The antenna's substrate material is made from Rogers 03003, which is a high-performance substrate used in high-frequency applications. The material that serves as the substrate manifests a thickness of precisely 1.52 millimeters, a dielectric constant of 2.2, and a loss tangent of 0.0009. These properties of the substrate material make it an excellent choice for constructing high-frequency antennas. The round-shaped antenna contains four inverted-cone slots placed in the center of the circle. The microstrip antenna resonates at approximately 28 GHz and is connected to a meandered radiating patch with a square slot shape. The antenna's functionality and performance are optimized by a partial and/or truncated ground plane at the backside, which provides another frequency (second) at the sub-6 GHz band (3.5 GHz. Antenna dimensions in Table 1 have an 8:1 frequency ratio between millimeter wave and sub-6 GHz bands.

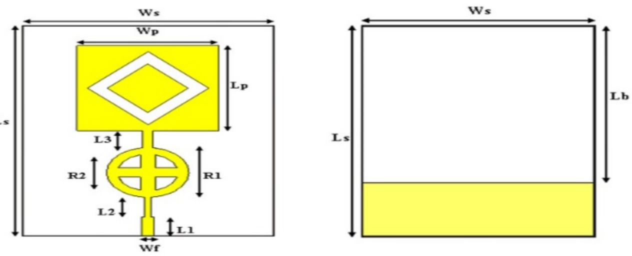

Figure 1: Geometry of the Dual Band Antenna (Front and Back)

TABLE 1 PARAMETERS OF THE ANTENNA

Parameters	Dimensions (mm)
Substrate Width Ws	25

Substrate Length Ls	35
Outer and Inner Radius R1/R2	4.098/3.0
Width of the Linked Patch, Wp	14
Length of the Linked Patch, Lp	14
Feeding Width, Wf	1.24
Feeding Length, Lf = L1+L2	6.51
Cone Slot length Lc	3
Back Truncated length Lb	25.89
Square Slot Length Lss	6
Linked Length L3	3.33

III. RESULTS AND DISCUSSION

This single-antenna component is impressively compact, measuring just 35mm x 25mm x 1.52mm. Its smaller size is made possible by utilizing a truncated and/or partial ground structure, as depicted in Fig. 1. In addition to achieving miniaturization, this design also delivers remarkably wider bandwidth. Antenna powered by 50-matched 1.24 mm microstrip feed line. Suitable for wireless, satellite, and radar systems.

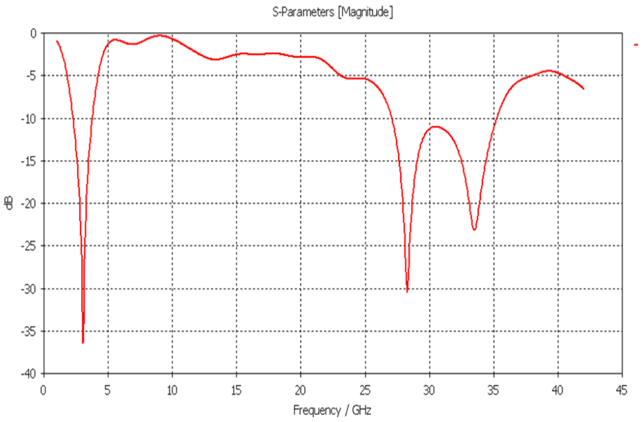

Figure 2. S_{11} of the Suggested Antenna.

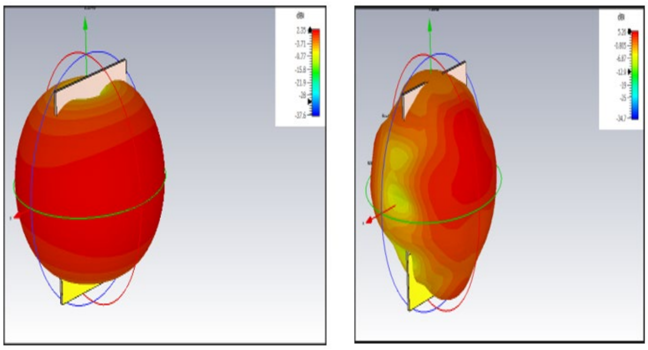

Figure 3. Antenna Gain at 3.5 (left) and 28 GHz (right).

TABLE 2 ANTENNA COMPARISM WITH [3,7]

Ref.	Frequency (GHz)	S11	Gain	Bandwidth
3	3.5	-49.72	2.67	970 MHz
	28	-31.34	5.17	19.65 GHz
7	3.5	-26	2.3	270 MHz
	28	-22	7.7	1.2 GHz
This Work	3.5	-36.46	2.35	1.54 GHz
	28	-30.44	5.26	8.29 GHz

The antenna comprises two distinct elements - a rectangular patch and a meandered radiating structure - that are interconnected, as illustrated in Figure 1. A CST MWS studio software was employed to conduct simulations of the suggested antenna. The simulation outcomes for the reflection coefficient (S11) of the proposed antenna are demonstrated in Figure 2. For the sub 6GHz band, 3.5 GHz, S11 is -36.46 dB with an impedance bandwidth of 1.54 GHz (2.23 – 3.77 GHz), while at 28 GHz, S11 is -30.44 dB with a wideband of 8.29 GHz covering 27.009 – 35.302 GHz. Figure 3 presents the simulated 3D pattern of the proposed antenna, which demonstrates a gain of 2.35 dBi at 3.5 GHz and an impressive 5.26 dBi at 28 GHz. Despite its compact size, the antenna effectively combines two different frequency bands, resulting in a significant frequency ratio of 8 between the millimeter wave band and the sub-6 GHz band.

Previous research [3, 7] has demonstrated the antenna results in terms of performance and efficiency. Table 2 provides a concise, summary and brief of antenna performance metrics, that include S11 (return loss), central frequency, bandwidth, and gain.

IV. CONCLUSION

Developing a single antenna that can effectively operate in two distinct frequency bands with a significant frequency ratio poses a formidable challenge. However, a newly devised solution has emerged to tackle this challenge. This particular antenna boasts a circular design, with four inverted cone slots at its center. These slots are linked to a radiating patch element situated atop the front section. The patch element features a square slot shape, while the back is outfitted with a partial and/or truncated ground plane, thereby boosting the antenna's efficiency and effectiveness. This inventive design enables the antenna to function in both sub-6 GHz band and millimeter wave bands, resulting in a wideband on both bands. This exceptional antenna boasts an impressive ultra-wide bandwidth of 8.293 GHz, spanning from 27.009 GHz to 35.302 GHz. Additionally, it delivers a bandwidth of 1.54 GHz (ranging from 2.23 GHz to 3.77 GHz) in the sub-6 GHz band. With a return loss of -36.46 dB and -30.44 dB at 3.5 GHz and 28 GHz, respectively, this antenna is an ideal option. We are intended to extend this work based on applying the reconfigurability between the two frequency bands of sub 6GHz and millimeter wave, but better results are yet to be attained.

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