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Wideband, Sand-Timer-Shaped Antenna for 5G mmWave and 28 GHz Applications

Devendra Soni[1], Dinesh Yadav[2], Manish Tiwari[3]

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Abstract: This research paper introduces a novel, compact, and high-gain antenna design. The antenna, which has a shape resembling that of a sand timer, is specifically developed on a substrate made of Rogers/RT5880 material with a thickness of 0.8 mm. The proposed design exhibits a unidirectional radiation pattern, resulting in a wide impedance bandwidth of 9.18 GHz (ranging from 20.78 GHz to 29.96 GHz) and a gain of 5 dBi. The proposed design undergoes a transformation process and is afterwards evaluated through prototyping. A strong correspondence is observed between the measured and simulated data during the process of conducting measurements. The design exhibits a broader fractional bandwidth of 36.18% and a high-gain characteristic, rendering it well-suited for contemporary 5G millimeter-wave applications.

Keywords: *Sand-Timer-shaped antenna, wideband, mm-Wave Application.*

1. Introduction:

Millimetre waves, also referred to as mm-waves or mmW, encompass a segment of the electromagnetic spectrum characterised by wavelengths spanning from one millimetre (mm) to 10 millimetres. Millimetre waves, commonly referred to as mm waves, are an abbreviated term used in the field of telecommunications and electromagnetic radiation. These waves are constituents of the electromagnetic spectrum, which includes radio and microwave frequencies as well. The theory about millimetre waves encompasses a broad spectrum of subjects, encompassing its inherent properties, mechanisms of generation and propagation, as well as their diverse applications.

The production of millimetre waves can be accomplished through the use of a wide variety of techniques, including the application of electrical components such as frequency multipliers and Gunn diodes. These devices take advantage of the properties of semiconductors to generate coherent millimeter-wave signals that are then capable of being modified. In comparison to millimetre waves, shorter wavelengths such as microwaves and infrared waves are found further out on the electromagnetic spectrum. These entities' frequency ranges encompass a spectrum that extends from 30 gigahertz (GHz) up to 300 GHz. Frequency Spectrum Band for 4G, 5G and 6G are shown in Figure 1.

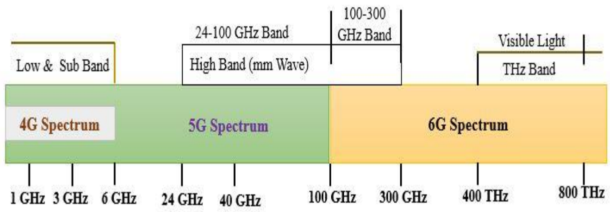


Figure 1 Frequency Spectrum Band for 4G, 5G and 6G

Millimetre waves have their distinct properties when it comes to how they propagate. Because of their relatively short wavelengths, they are susceptible to severe free-space path loss. This implies that they are unable to travel over long distances or penetrate obstructions as effectively as lower-frequency waves. Rainfall and the atmospheric absorption of radiation are two more factors that can influence their spread.

Millimetre waves are commonly employed in high-frequency wireless communication systems, such as 5G networks, due to their ability to transfer substantial volumes of data. The provision of additional bandwidth leads to an increased rate of data transfer. The utilisation of millimeter-wave radar is observed across various applications, including weather radar, airport security scanners, and vehicle radar systems designed for accident prevention. Millimetre wave applications are shown in Figure 2.

Department of ECE, Manipal University Jaipur, Jaipur, India[1, 2, 3]
sonierdevendra6486@gmail.com[1],
dinesh.yadav@jaipur.manipal.edu[2],
manish.tiwari@jaipur.manipal.edu[3]

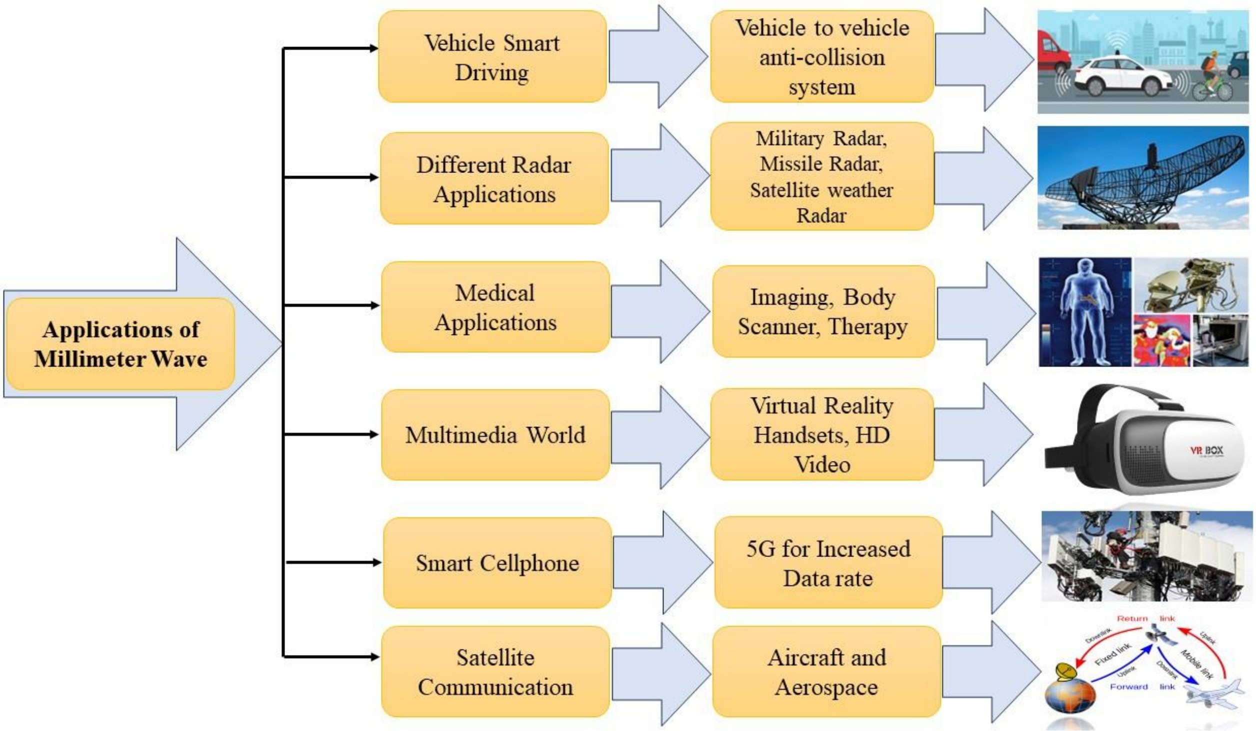


Fig 2 Applications of Millimetre Wave

The growing data traffic and changes in user requirements paved the door for researchers to investigate the millimetre range of frequencies. These frequency bands are most suited for communication, particularly for 5G applications [1]. Applications for millimetre waves are found in satellites, 5G connectivity, the military and medical imaging. Broadband and high-gain antenna technologies have advanced quickly, particularly in the high-frequency band of 5G mobile communication, in response to the ever-growing demand for high-speed and wide channel capacity in today's mobile communication systems [2-4].

For 5G mobile communications, the ITU has approved several frequency bands, including 24.25-27.5 GHz (EU), 26.5-29.5 GHz (Korea), 27.5-28.35 GHz (USA), 27.5-28.28 GHz (Japan), 25.3-27.5 GHz (China), and 26.5-27.5 GHz (Sweden) [5-9].

To support 5G communications, a compact antipodal Vivaldi antenna (AVA) featuring a high gain has been developed [10].

A new mobile network standard that goes by the name '5G' has been developed as a direct result of the increased demand for wireless wideband services. Utilising the millimetre wave band (24-300 GHz) is something that the industry should do for 5G to achieve the basic requirements for bandwidth. In addition, future gadgets with limited amounts of available space will require miniaturised antennas that can work across many frequency bands [11-14].

The objective is to investigate the performance of a rectangular Dielectric Resonator Antenna (DRA) throughout a broad frequency spectrum. The utilisation of Printed Electromagnetic Band Gap (EBG) technology has been employed to provide power to the antenna and mitigate the presence of any undesired radiation originating from the feed line [15-19].

This paper presents a novel high-gain antenna design in the shape of a wideband Sand-timer, intended for operation within the mmWave frequency range. The material utilised as the substrate for the antenna is Rogers/RT-Duroid 5880. The antenna exhibits a frequency range spanning from 20.78 GHz to 29.96 GHz, with a pass-band gain of 5 dBi. The measured and simulated results were found to be consistent and in agreement. The proposed design is utilised for applications in the high-gain, broad frequency bands of 26/28 GHz in the mmWave range.

2. Design, Analysis, and Results:

Figure 3 demonstrates that the antenna is supported by a substrate that is 0.8 millimetres thick and is fed by a microstrip wire with a resistance of 50 ohms. The Rogers substrate possesses both a consistent frequency response and a high level of stability. Iterative simulation with software that is available for purchase, CST-MWS, is used to optimise the design for the frequency range of 20 GHz to 30 GHz so that it functions optimally. An impedance bandwidth of 9.09 GHz appears to be offered by the antenna. This spans the frequency range of 20.78 GHz to 29.87 GHz. Additionally, in our earlier work [6], we designed a Sand Timer Shaped Microstrip Patch Antenna with a Metasurface for Gain Enhancement.

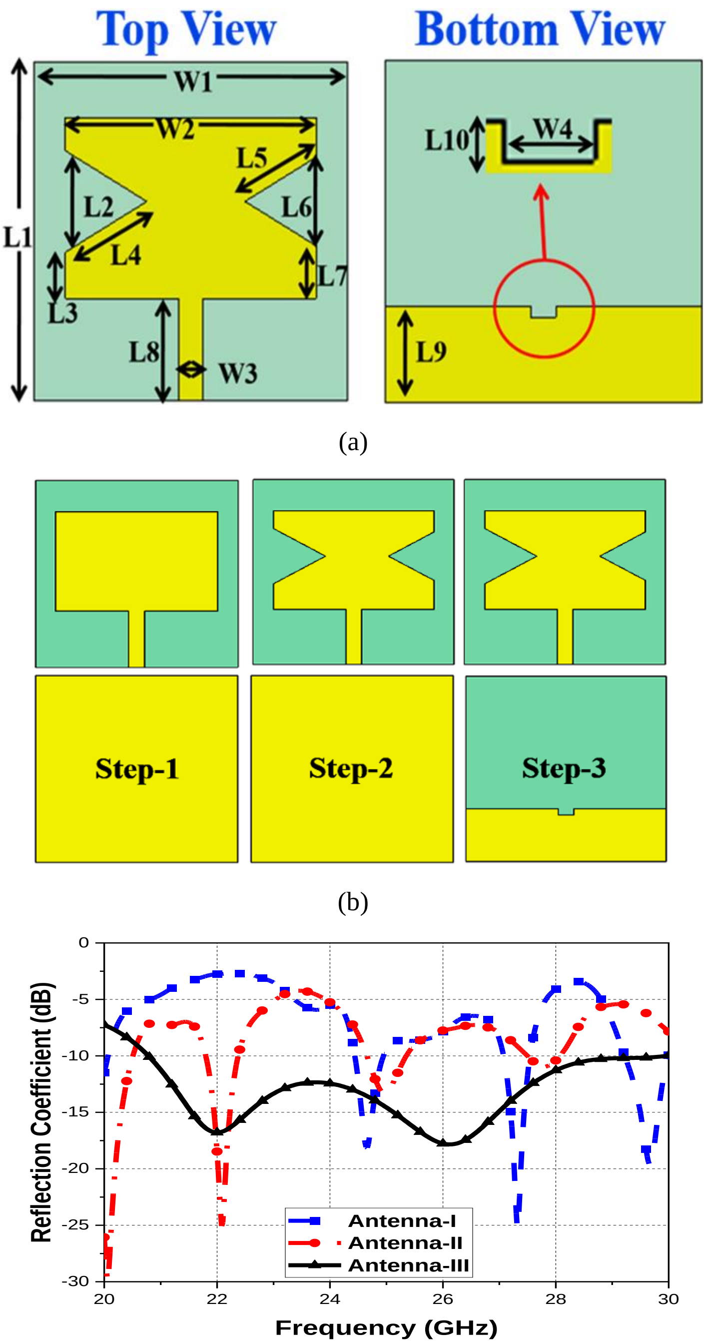


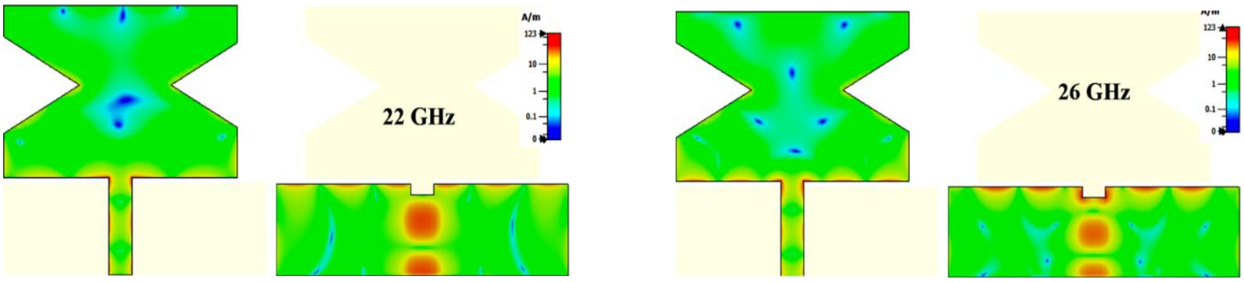
Fig 3. (a) Proposed Sand Timer-Shaped Antenna (where *L1*= 30, *L2*=9, *L3*=4.1, *L4*=9, *L5*=7.85, *L6*=7.85, *L7*=4.67, *L8*=9. *L9*=8.5, *L10*=1, *W1*=30, *W2*=24, *W3*=2.37, *W4*=2.37 (all are in mm)), (b) Evolution of the proposed antenna, and (c) reflection coefficient versus frequency plots of evolution stages.

2.1 Design Evolution:

The first step of the evolution of the proposed antenna is a microstrip line-fed rectangular patch antenna given the name Antenna-I. The evolution of the proposed antenna is finished in three phases, as shown in Figure 3(b). According to the findings, the Antenna-I has three distinct narrow operational bands with the centre of each band located at either 24.6 GHz, 27.3 GHz, or 29.6 GHz. To get the necessary response, the modifications to the design are working towards the goal of combining various frequency bands into a single, broader band. Antenna-II is the name given to the revised design, which is now a patch in the shape of a sand timer. It has been found that the variations in the geometry cause these bands to shift towards the side of the spectrum that has lower frequencies. The following phase involves introducing the faults in the ground plane, which are given the name Antenna-III. These several narrow bands are combined into a single wideband as a result of the faults in the ground plane. The impedance bandwidth that was achieved is 9.07 GHz (beginning at 20.78 GHz and ending at 29.96 GHz). To get the correct frequency response, the design is subjected to extensive simulations, which are then optimised. Figure 3(c) depicts a comparison analysis of the different outcomes of the design evolution process.

Surface Current Distribution:

To gain a deeper understanding of the antenna design from a purely physical perspective, the surface current distribution at various frequencies was analysed and is depicted in Figure 4. The two resonant frequencies of the design, which are 22 GHz and 26 GHz, were used to determine the frequencies that were selected. The distribution of the current is not constant across all frequencies; rather, it varies depending on the frequency that is selected. It can be seen that the current flows evenly across the ground plane, feed line, and patch areas.

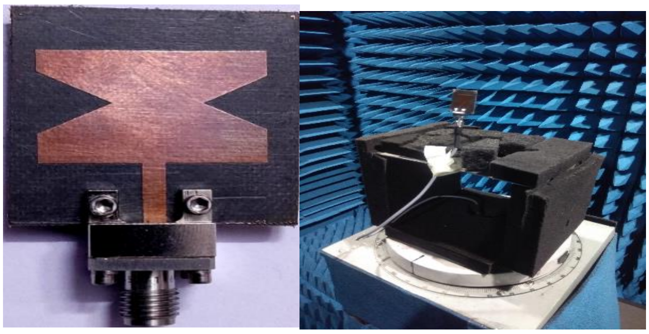


(a) (b)

Fig 4. Surface current distribution at the chosen frequencies of 22 GHz and 26 GHz.

3. Measured Result and Discussion:

Fabrication of the suggested antenna, which features design dimensions that have been optimised, is followed by measurement of the findings with a Vector Network Analyzer (PNA-L, 10MHz - 43.5 GHz) in an anechoic chamber. Figure 5 displays some images that were taken of the prototype that was manufactured as well as the measurement setup.



(a) (b)

Fig 5. (a) Photographs of the fabricated prototype and (b) Antenna placement in an anechoic chamber.

Figure 6(a) illustrates the comparison between the measured and simulated reflection coefficient. The measured results exhibit a high level of concordance with the simulated results. The observed lower and upper cutoff frequencies, 20.9 GHz and 28.8 GHz respectively, exhibit small deviations from the simulated cutoff frequencies of 20.78 GHz and 29.96 GHz. The observed discrepancies in the cutoff frequencies can potentially be attributed to factors such as manufacture tolerance, losses in connectors, and errors incurred during prototype measurement. The figure displays the simulated and observed realised gain, as seen in Figure 6(b). The design's gain remains rather consistent throughout the working band and has been confirmed through measurement validation. Figure 6(c)-6(d) displays the radiation patterns of the proposed antenna design at the robust resonances of the operational bands, both in simulated and measured forms. At the transmitter end, a conventional pyramidal Horn antenna was employed, whereas at the receiving end, the proposed antenna was utilised. The observed patterns exhibit a nearly omnidirectional nature and display similarities at both of the selected frequencies. The generated patterns and the measured patterns exhibit a high degree of agreement.

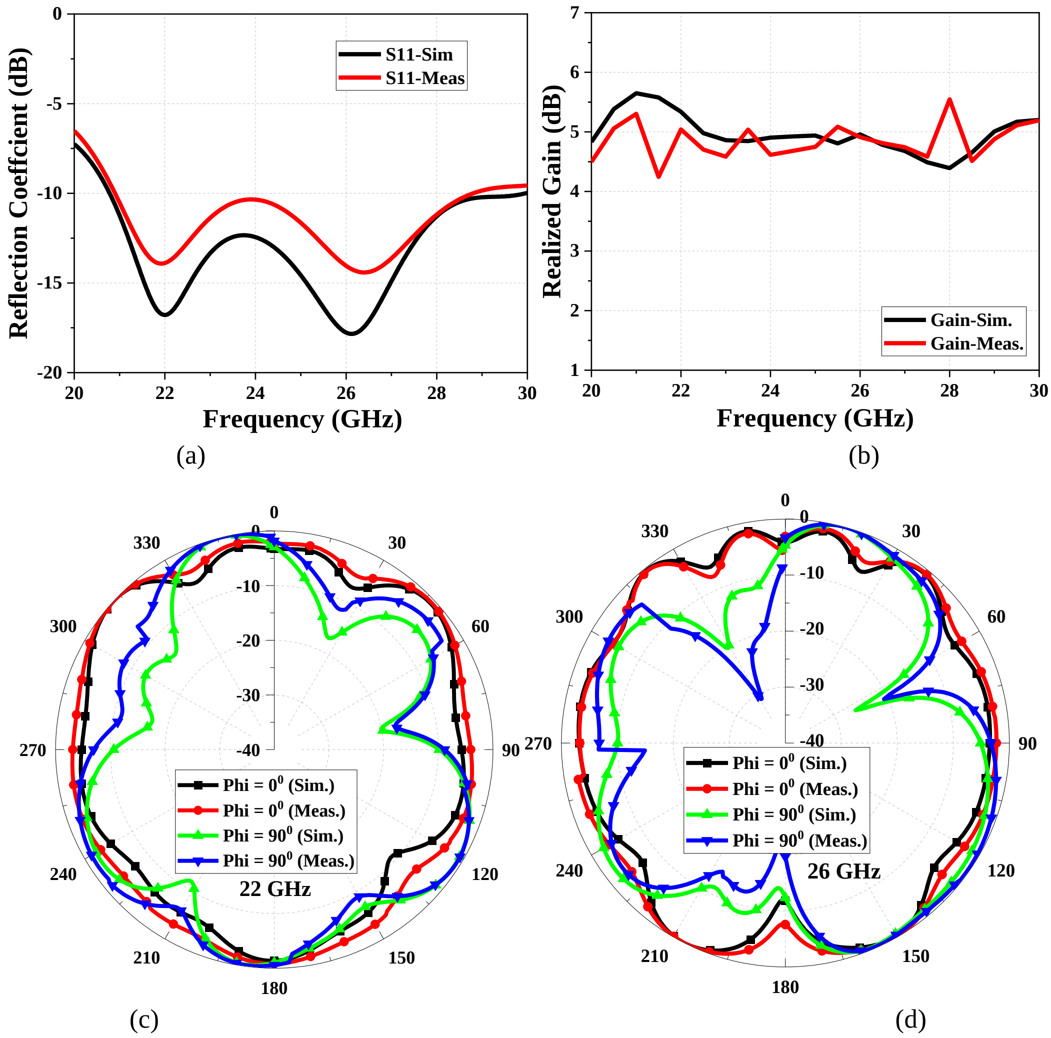


Fig 6. Simulated and measured: (a) Reflection coefficients vs frequency, (b) gain vs frequency, (c) radiation patterns at 22 GHz, and (d) at 26 GHz.

The proposed antenna is compared to similar antennas outlined in Table I of the relevant literature. The comparison is predicated upon the parameters of operating band, bandwidth, fractional bandwidth, and gain. The proposed design demonstrates superior performance in comparison to alternative designs.

Table I: The suggested antenna is compared to existing research.

Ref.	Operating band (GHz)	Bandwidth (GHz)	Fractional Bandwidth (%)	Gain (dBi)
[10]	24.25-29.5	5.25	19.53	10.13
[11]	25.99-27.72	1.73	6.44	5.36
[12]	24.71-29.93	5.22	19.10	5
[14]	27.50-28.84	1.34	4.75	7.2
Here	20.78-29.96	9.18	36.18	5

4. Conclusion

In this study, we suggest the use of a microstrip line-fed antenna with a Sand-timer-shaped geometry for mmWave application. The design that has been presented offers a broad bandwidth of 9.18 GHz, encompassing a frequency range that spans from 20.78 GHz to 29.96 GHz. The antenna is designed to operate within the frequency ranges of 26 GHz and 28 GHz, specifically known as the n258, n257, n260, and n261 5G frequency bands. The design that has been proposed exhibits a nearly consistent gain of 5 dBi across the whole operating spectrum. The design undergoes experimental manufacture and testing. The findings of the simulation and measurement exhibit a high level of concordance. The proposed antenna demonstrates compatibility with ultra-high-speed mobile broadband services intended for 5G communication.

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