Antenna Design for 6G

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***Abstract*—The primary objectives of next-generation technology for communication and 6G Antennas functioning in the terahertz (THz) frequency technologies are to attain elevated data rates, minimize energy consumption, and facilitate extended connectivity. These goals are driven by the substantial proliferation of devices belonging to the Internet of Things and 6G antenna technology. These electronic devices are expected to be used for a variety of services including cellular communication, environmental monitoring, telemedicine, biological applications, and intelligent traffic management, among others. Hence, the present communication devices have difficulties in accommodating a large variety of services. This article provides a concise overview of the underlying factors driving the development of the 6G communication system, as well as an examination of its inherent capabilities and distinguishing characteristics. Subsequently, a concise overview is provided regarding the present cutting-edge 5G antenna technology, including the utilization of prevailing 6G Antennas functioning in the terahertz (THz) frequency ranges. The research also delineated the efficacious methodologies and strategies used in current antenna design endeavors, which have the potential to alleviate the obstacles and apprehensions associated with the nascent 5G & 6G applications. The research article concludes by presenting the main characteristics and prerequisites of 6G Antennas that operate in the terahertz frequency range, catering to the demands of future-generation technology.**

Keywords—antenna design, 6G characteristics, CST

I. Introduction

Worldwide mobile data traffic has experienced a significant surge over the last few years due to the growing need for secure, high-speed, and efficient transmission of large volumes of data. In this regard, the existing 3G/4G/WiFi wireless communication networks are under significant demand to enhance their capacity and performance. Every successive iteration of mobile and wireless communication systems has been developed to fulfill these requirements. However, the proliferation of data-intensive devices used in the applications above has significantly grown, necessitating substantial data transmission speeds [1,2].

Among the potential approaches for improving capacity and data rates in both present and next mobile as well as wireless generations is by expanding the available bandwidth [3,4]. The relationship between data rates and bandwidth is one of direct proportionality. According to sources [5,6], increased bandwidth results in greater data rates.

The existing frequency bands, including the 1.7 GHz GSM band, 1.8 GHz 4G/LTE band, 2.0 GHz 4G/LTE band, 2.1 LTE band, and 2.6 GHz band, provide a restricted amount of bandwidth. Lately, there has been a growing interest in using high-frequency ranges for 5G usage.

In millimeter-wave communication, it has been shown that the route loss is considerably elevated. Therefore, it is essential that the selected antenna has radiation patterns with high directional gain in the direction of wave propagation to effectively reduce path loss. A significant obstacle encountered in several applications, such as mobile communication in microwave and mm-wave bands, is the lack of continuous communication direction [7].

The precise geographical position and alignment of the mobile phone in relation to the base station remain undetermined. Therefore, there is a need for innovative and unparalleled methods that may provide comprehensive antenna beam coverage, consistent radiation patterns, and increased directional gain. Furthermore, throughout the migration towards millimeter-wave (mm-wave) 5G communication, it is important to note that existing technologies such as 3G, 4G, WiFi, and sub-6 GHz 5G will continue to coexist. Therefore, the use of shared-aperture antenna architectures is essential for the development of fully integrated antenna modules.

In addition, the extent of coverage is a significant factor to consider in the context of both present and future communication systems. The current 5G systems, which are mostly terrestrial, have limitations in achieving comprehensive coverage and delivering consistent data rates for outdoor communications in various settings, such as aerial, maritime, rural, and isolated places.

Therefore, it is anticipated that space communication systems, which serve as a supplement to terrestrial communication systems, will merge with 5G systems to establish a comprehensive and integrated 6G communication system [8]. Fig. 1, presents a schematic representation of the envisioned integrated 6G communication infrastructure.

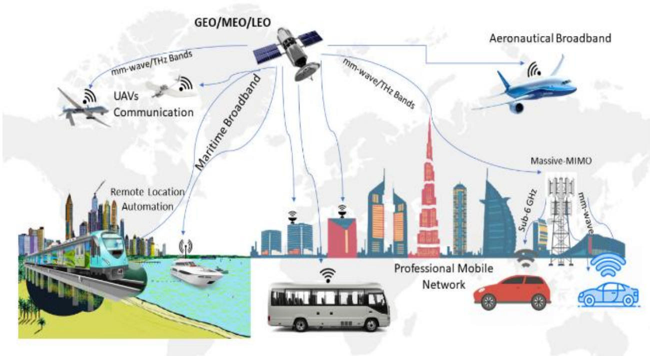

Fig. 1. A schematic representation of the envisioned integrated 6G-communication infrastructure.

Based on historical patterns of mobile technology evolution, characterized by generational shifts occurring about every decade (e.g., 1G in the 1980s, 2G in the early 1990s, 3G in the latter part of the century, 4G in the 2010s, and 5G in the 2020s), it is anticipated that the deployment of 6G will likely occur by 2030 or maybe earlier, driven by advancements in transition technologies. The following section provides an overview of the components and specifications of an interconnected 6G communication system [9].

According to [10], the rationale for using bandwidth in excess of 100 GHz is their capacity to deliver a broad bandwidth, making them very suitable for the goal of short-range communications. The first development of the antenna used a transmitter frequency of 300 GHz, and its efficiency was assessed by comparing three different patch substances: copper, graphene, and gold. The analysis of the antenna properties was thereafter conducted. The results suggest that the graphene patch has a coefficient of return of -27.70 dB, a peak bandwidth of 10.4 GHz, and a maximum radiation efficiency of 98.38%. The study is on the assessment of the budget allocated to the mobile network Unity, with a specific emphasis on achieving a data rate objective of 100 GB/s. This evaluation pertains to the operation of the connection within a bandwidth of 30 GHz and across a distance of 10 meters. The validation of link budget estimations is achieved by considering many criteria, including coding rate, target signal-to-noise ratio (SNR), path loss, and the required number of antenna components. The proposed connection budget is eventually verified for several modulation techniques using the MATLAB software. Consequently, it has the capacity to facilitate the development of efficient and extensively interconnected wireless communication networks, with data speeds that approach 100 Gb/s. This article provides a comprehensive examination of hardware integration in the context of a thorough analysis of the current research. It discusses the many obstacles and potential solutions pertaining to the implementation of real 6G wireless systems in the D-band [11].

In [12], the visualization of the anticipated output or result via simulation of the proposed patch antenna is of utmost importance in the design of antennas, as it plays a critical role in attaining the desired outcomes for future research endeavors. The simulation enables us to assess many characteristics, such as bandwidth and antenna isolation, in order to determine the higher performance criteria of the built device. The Duroid 5880 substrate is often used in designs because of its low-loss and cost-effective properties. In the context of 6G frequencies, it is essential to have a bandwidth above 20 GHz, since this characteristic has significant value for both research and practical applications.

According to [13], the antenna under consideration was simulated in order to evaluate the power transfer at the antenna terminal through the transmission line. This evaluation was conducted to determine the impedance bandwidth ($S11 < -10$ dB) at frequencies of 326.67 GHz, which corresponds to a power level of −50.524 dB. It is worth noting that this frequency range has been designated by the Federal Communications Commission for the allocation of 6G applications.

II. Towards The Growth Of 6G Communication Systems

The design development and formation of 6G communication is now underway [14]. The increasing need for high data rates has led to the adoption and enhancement of existing 5G technology into 6G communication systems, prioritizing attributes such as ultra-low latency, exceptional capacity, heightened security, and expanded coverage for both broadcast and mobile applications in academic and industrial domains.

The scope of this technology encompasses a wide range of communication situations. The scope of coverage encompasses expansive geographical regions, including urban, rural, distant, oceanic, and aerial domains. These categories, together with their corresponding scenarios for implementation, are shown in Fig. 2.

A. The key characteristics of 6G communication

Each generation of wireless communication technology has brought revolutionary capabilities. As we move beyond 5G, expectations for 6G are growing [15,16]. The 6G communication method is intended to revolutionize wireless networks. This latest generation is expected to have several characteristics that surpass 5G. From ultra-high data speeds and ultra-low latency to artificial intelligence and worldwide connectivity, 6G promises to change how people connect, communicate, and engage with the digital world.

1) Connectivity

Connectivity stands out as a prominent attribute in the shift from the 5G to the 6G of wireless communication technology. It is anticipated that a substantial quantity of IoT devices will be interconnected in various circumstances, including both line-of-sight and non-line-of-sight connections. The attainment of uninterrupted connection may be realized via the use of reconfigurable meta-surfaces that are helped by artificial intelligence. The attainment of connectivity across expansive regions is anticipated via the use of combined satellite and 5G networks.

2) Mobility

The anticipated advancements in intelligent transport systems are predicted to result in increased mobility characterized by much higher speeds. The use of ultra-low latency in data transmission has the potential to enhance the efficiency and effectiveness of the transportation system. The maximum velocity taken into account for airplane communication situations in 6G is 1000 Km/h, a much greater value compared to 5G.

Fig. 2. The essential characteristics of the 6G-communication technology.

3) Security

The preservation of data privacy and security has significant importance within communication systems, particularly within areas such as the military and finance. The use of deep learning and artificial intelligence methodologies inside the physical and network layers of 6G networks has the potential to enhance security measures for devices, infrastructures, and assets.

4) Broadcasting

The next 6G technology promises novel multimedia applications and facilities that prioritize ultra-high video streaming, live broadcasting, and pleasure. The attainment of a high standard of service is expected to be accomplished by the integration of satellite communication, television, and cell phone technologies.

5) Ubiquity

The anticipated coverage area of ubiquity is projected to surpass that of 5G technologies. The next 6G systems are anticipated to include space and marine communication in addition to ground-based communication in order to attain extensive coverage and enhanced data speeds. The availability of the service will be facilitated via the use of a hybrid network consisting of both GEO/LEO satellite and terrestrial components. This aspect has significant importance, particularly in the context of communication inside aircraft, maritime vessels, and individuals living or operating in isolated regions.

6) Data Rates

According to Shannon's equation, the enhancement of bandwidth and the increase in the number of antennas have a direct proportional relationship with the improvement of data rates. The millimeter-wave/terahertz (mm-wave/THz) frequency bands provide a substantial increase in bandwidth ranging from 1 to 10 GHz. Therefore, the use of a large number of antennas and the utilization of the Mm-wave/THz band are two direct approaches to meet the increasing need for faster data speeds.

The anticipated performance target is to attain a data transmission rate of 1 Tbps, surpassing the capabilities of 5G technology in both the uplink and downlink directions. The increased data rates have considerable importance across several industries, including activities such as ultra-high-definition video streaming and the handling of enormous data files in office environments.

B. The Frequency Spectrums of 6G

During the process of transitioning to the 5G communication network, it is important to note that the 3G, 4G, and WiFi systems of communication continue to coexist. Hence, the use of sub-6 GHz communication continues and will be integrated within the framework of 6G communication. The implementation of 5G communication, particularly in the realm of mobile communication, has commenced and is now functioning within the sub-6 GHz frequency range. The allocation of sub-6 GHz bands for 5G networks varies across various nations. In the United States, these bands are designated as 3100–3550 MHz and 3700–4200 MHz. In Europe, the allocated range is 3400–3800 MHz. China has designated the bands as 3300–3600 MHz and 4800–5000 MHz, while South Korea has allocated the 3500 MHz band [17]. The chart is further illustrated in Fig. 3, illustrating the anticipated frequency spectrums for 6G communication together with their corresponding bandwidth.

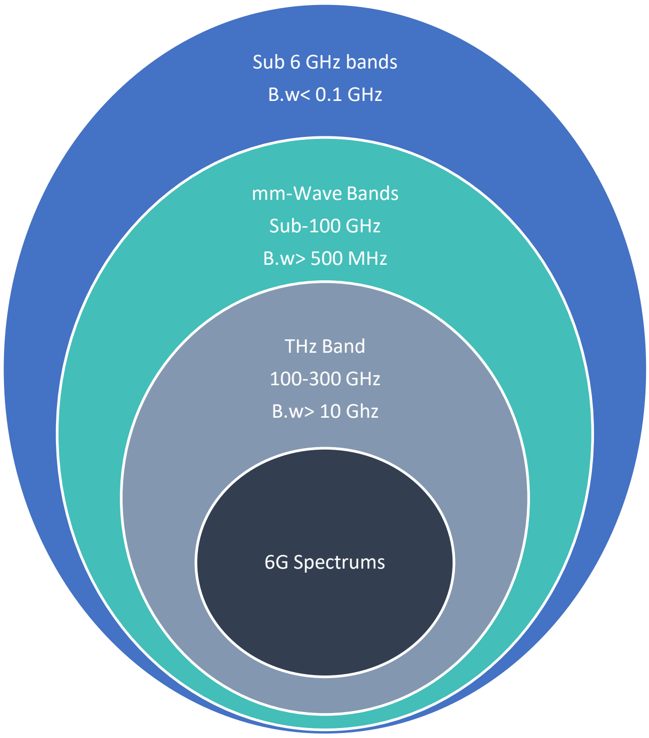

Fig. 3. The frequency spectrum used in 6G transmission.

III. 6G Antennas Operating Within the Terahertz (THz) Frequency Bands

As previously mentioned, the frequency bands ranging from 100 to 300 GHz in the terahertz (THz) range are being explored for use in 6G communication systems. The complexity of antenna design escalates with higher frequencies, leading to increased difficulties in material selection, design procedures, manufacturing methods, and experimental verifications. Therefore, this section provides a comprehensive summary of newly published designs for 6G antennas [18]. Several kinds of antennas have been examined in recent literature for their suitability in the 6G terahertz (THz) frequency bands. The paper [19] introduces a conical horn antenna operating inside the 300 GHz frequency range. The horn antenna exhibits highly directed radiation patterns with significant gain at a frequency of 300 GHz. Additionally, it has a wide bandwidth ranging from 270 to 330 GHz, making it a suitable choice for applications in this frequency range. The performance shown is exceptional and meets the criteria set out by the 6G specifications.

An additional antenna design is introduced in reference to operation inside the 60 GHz frequency range. The development of an antenna in a package was facilitated via the use of printed circuit board technology [20]. The use of an antenna in a package technology is both cost-effective and highly advantageous for applications operating at high frequencies. Fig. 4 illustrates the comprehensive design of the antenna, together with the several stages of its evolutionary development. It is important to mention that, the antenna has a frequency range of 292 to 297 GHz, resulting in a bandwidth of 5 GHz. The procedure of fabricating the antenna is achieved by the use of laser technology. In contrast, a dielectric waveguide is used in several methodologies to get antennas with high gain, directional properties, and compact dimensions.

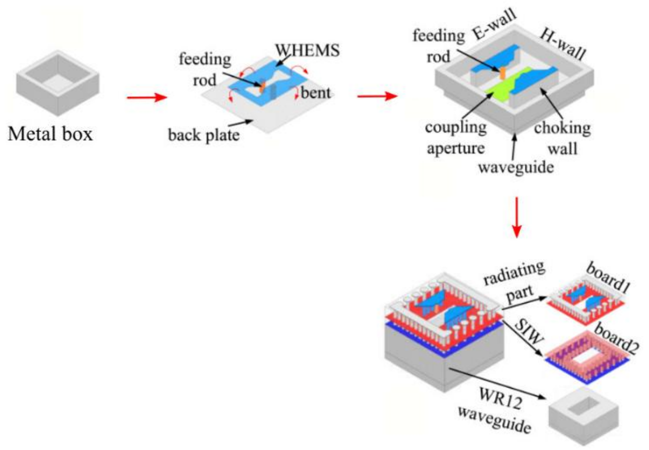

Fig. 4. The progressive development of a packaged antenna operating at a frequency of 60 GHz.

IV. CONCLUSION

This article provides a summary of the prospective 6G communication technology and its essential characteristics. The next iterations of communication systems and 6G antennas operating within the terahertz (THz) frequency band technologies, often referred to as 5G, B5G, and 6G, have been proposed with the objective of attaining many key advancements. These advancements include fast data rates, enhanced security measures, reduced energy consumption, ubiquitous access to broadband internet, and the ability to support a vast number of Internet of Things (IoT) connections. Due to the inclusion of many services operating across various frequency spectrums (Sub-6 GHz, mm-wave, and THz), the task of integrating a larger quantity of antennas into a single device poses a significant challenge. Therefore, this paper provides a comprehensive overview of the latest advancements in 5G antennas and arrays, highlighting their potential for future communication systems. The essay concludes by presenting the essential characteristics and prerequisites of 6G antennas that operate in the terahertz (THz) frequency range, catering to the demands of future technology. In future works, the gain, bandwidth and efficiency performances of the antenna can be improved by conducting multi-objective optimization studies for the design parameters.

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