

# 6G THz-Band Facing Propagation and Atmospheric Absorption Losses

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**Abstract**— More enhancements for the 5G mobile system are still in progress. At the same time, 6G system research millstones have already been started by academics and industries. It is expected that 6G systems will be introduced in 2030. It is expected that smart services based on internet of everything (IoE) will be supported by an intelligent wireless system represented by an artificial intelligent (AI) based 6G mobile system. 6G system structure, will be a virtual reality (VR), augmented reality (AR), extended reality (XR), and holographic communication application based. The 6G mobile system will be integrate the terrestrial, space, and under-sea communications into a global network to provide services over isolated or uncovered area beside the actual terrestrial cellular network. 6G will work at the THz band, starting from 0.1THz to 10 THz, supporting Tbps-level data rate,  $\mu$ s-level latency, and connection density of  $10^7$  per  $km^2$ . Atmospheric absorption loss and free space path loss (FSPL) are two of the biggest challenges for the adoption of the terahertz band in the future. In this paper, the sub-terahertz band general characteristics was investigated. The FSPL, the atmospheric absorption loss, and rain attenuation are also evaluated.

**Index Terms**—5G, Millimeter-band, Terahertz-band, 6G, Artificial Intelligence (AI), Free space path-loss (FSPL), Atmospheric absorption loss.

## I. INTRODUCTION

Due to the exponential increase of the wireless system capacity, a millimeter-wave (mm-Wave) communications, with a frequency band starting from 30 GHz up to 300 GHz, has been adopted for the 5G Mobile system and will be millstone technologies for sub-Terahertz band of the 6G system with a potential available band width of 252 GHz [1], [2].

New applications such as Internet of every Things (IoE), autonomous driving, and virtual/augmented reality (VR/AR), supporting by the free space optical (FSO) backhaul instead of optical fiber, will need less latency and greater data rates than what 5G networks will offer [2]. Tbps-level data rates and  $\mu$ s-level latency, will be needed to fulfill such application and this is represented by the 6G mobile system [3]–[5]. Researchers have initiated their work on the next 6G network after the deployment of 5G systems. Keeping up with the ten-year cycle law in mobile industry as depicted in Fig.1, the 6G mobile system will be expected to be deployed in 2030.

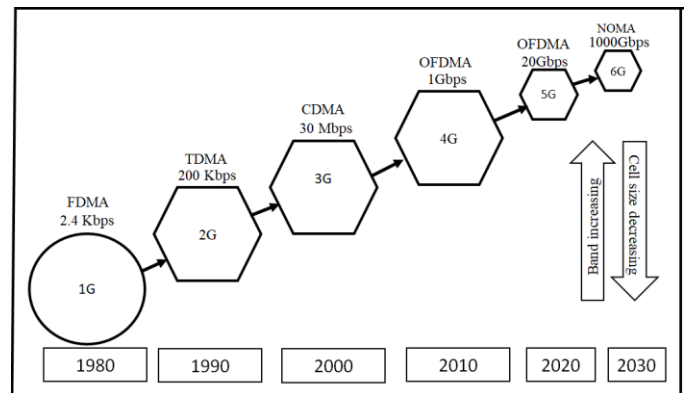


Fig.1: Evaluation of mobile system technologies

The Terahertz (THz) band (0.1-10 THz), will be used in the 6G to support subscribers with a huge data rates for many future applications [6]. The traffic volume per subscription in 2030 will become 257 GB per month, which represent 50 times of the traffic in 2020. The number of Machine-to-Machine (M2M) subscription will increase 422 times in 2030, as compared with 2020 [6], [7].

The four keywords together that constitute the 6G overall vision can be summarized by: "Deep Connectivity", "Intelligent Connectivity", "Ubiquitous Connectivity", and "Holographic Connectivity". [3], [4], [8]–[11]. Propagation path-loss represented by the free space path loss (FSPL) and the atmospheric absorption loss is one of the most challenges to enable the THz band in the future. Another main challenge is the required technologies domain, for the development of 6G platform, since around 10 years, is often needed, for a novel technology to reach the commercial state.

This paper is organized as follow: In section II a comparison between 6G and 5G was established. In section III Some of the most 6G mobile communication system applications are illustrated. In section IV the main features of the Terahertz-Band were discussed. In section V the health risks precautions related to radiation exposure concerning the Terahertz-Band was illustrated. Section VI was focused on the main Challenges that should be solved to make the 6G mobile system as a reality.

## II. 5G VERSUS 6G

6G wireless communication system is expected to be more than just faster than 5G system. For example, by employing the 6G

system, the cellular mobile system will be not just limited to terrestrial coverage, instead, it will integrate the terrestrial, space, and undersea services through a universal wireless network. 6G will use artificial intelligence (AI) as an integral part that has the capability to optimize a variety of wireless network problems, therefore, 6G system based on AI technology will be an "Intelligent connectivity system. Comparison between 5G and 6G for different main parameters is depicted in Table.1 below [3], [4], [10], [12]–[14].

TABLE I  
COMPARISON BETWEEN 5G AND 6G

Parameter	5G	6G
Peak data rate (Gbps)	20	1000
Latency (ms)	1	0.1
Maximum frequency (GHz)	90	10000
Spectral efficiency (bps/Hz)	30	100
Mobility (Km/h)	500	1000
Traffic capacity (Tbps/Km <sup>2</sup> )	10	100
Localization precision (cm)	10 on 2D	1 on 3D
Autonomous vehicle	Partial	Fully
Artificial intelligent (AI) integration	Partial	Fully
Satellite integration	Under development	Fully
Energy efficiency (Tb/J)	NA	1
Connection devices (device/Km <sup>2</sup> )	10 <sup>6</sup>	10 <sup>7</sup>
Channel bandwidth (GHz)	1	100
Core	Internet of things (IoT)	Internet of every things (IoE)
Real time Architecture	No	Yes
	Massive MIMO	Intelligent surface

### III. 6G WIRELESS COMMUNICATION POSSIBILITIES AND APPLICATIONS

In this section, some of the 6G wireless communication possibilities and applications will be illustrated.

#### A. Super intelligent society

The enhanced characteristics of 6G will expedite the development of smart societies, resulting in improved living quality, automation, and environmental monitoring via M2M communication and energy harvesting powered by AI [15]. Through the deployment of smart mobile devices, self-driving cars, and other applications, 6G wireless connectivity will transform our civilization into an ultra-intelligent one. Additionally, several cities worldwide will adopt flying taxis powered by 6G wireless technology. As soon as each piece of equipment can be operated remotely via smart device commands, the concept of "smart houses" will come to fruition.

#### B. Extended reality

The extended reality services, which include augmented reality (AR), mixed reality (MR), and virtual reality (VR), are critical components of 6G communication networks. 6G networks will give a genuinely immersive AR/MR/VR experience via collaborative design integration and high-quality 6G wireless communication [5]. VR is a 3D computer simulation of a real-world environment or a fictional cosmos. In VR, reality

headsets are utilized to deliver a realistic experience and to emulate a real-world setting or to create an imaginary world. Every sensation is stimulated in a VR experience. AR is a real-time representation of a physical reality supplemented with different computer-generated sensor inputs, including video, audio, graphics, and global positioning system (GPS) data. It uses existing world and augments it with some sort of device. MR combines the physical and virtual worlds to generate new atmospheres and visuals for real-time interaction. It is also sometimes referred to as "hybrid reality." One distinguishing feature of MR is the ability of artificial and real-world contents to interact in real time. Extended reality (XR) is a term that encompasses all integrated physical and virtual worlds, as well as human-machine interactions, that are enabled by computer technology and wearable devices. It encompasses all its descriptive forms, such as AR, VR, and MR. It is a word that encompasses VR, AR, and MR under one umbrella category. A true XR (i.e., AR, VR, and MR) experience necessitates the 6G system's high data rate, ultra-low latency, and extremely stable wireless connectivity.

#### C. Autonomous and connected robotics systems

Numerous automotive technology researchers are now conducting research into automated and connected automobiles. The implementation of connected robots and autonomous systems is facilitated by the power of 6G technologies. For instance, a drone-delivery facility is an illustration of this type of technology. The driverless car powered by a 6G wireless technology has the potential to fundamentally alter our daily lives. The 6G technology will accelerate the commercialization of self-driving automobiles. A self-driving automobile senses its environment with the use of many sensors, including light detection and ranging (LiDAR), odometry, GPS, sonar, radar, and inertial measurement units. Using the 6G system, vehicles will be able to connect to anyone and everything, as well as to servers, reliably. There are several uses for drones, including military, business, and research, as well as law enforcement and product delivery. They may also be used for surveillance and aerial photography. Furthermore, when the cellular base station (BS) is absent or malfunctioning, the drone will be broadcast wirelessly and send high-rate transmissions [16].

#### D. Brain-computer wireless interactions

The brain-computer interface (BCI) is a technique for controlling the appliances that are utilized on a daily basis in smart societies, most notably those in homes and medical systems [17], [18]. It establishes a direct connection between the brain and external equipment. BCI collects and analyzes brain signals transmitted to a computing device, converting them into further actions or commands. 6G technologies will enable the real deployment of BCI systems for leading a smarter life.

#### E. Smart healthcare

Extended reality and AI are just some of the developments that will help construct smart healthcare systems on the 6G wireless

networks [15]. In the healthcare sector, the 6G systems will offer a reliable remote monitoring solution. The use of 6G communication will even allow for remote surgery. Massive amounts of medical data can be sent quickly and reliably through a high-data-rate, low-latency, and ultra-reliable 6G network, which means that more people can get treatment and the quality of that care will be better.

#### F. Space-Air-Ground Integrated Network (SAGIN)

SAGIN is an acronym for space-air-ground integrated network. It is a network that combines satellite systems, aerial networks, and terrestrial cellular communications. By providing wide-area coverage and maintaining service availability, continuity, and scalability, SAGIN is able to meet requirements for everywhere and anytime connectivity. SAGIN is divided into three sections: space, air, and ground. The air network is an aerial mobile system that employs wireless communications aided by unmanned aerial vehicles (UAVs). UAVs may fly at low altitudes (> 100 m) and behave as relay nodes for the transmission and processing of terrestrial mobile communications. UAV-assisted communications are expected to be used in 6G-enabled IoT networks. To circumvent geographical and environmental constraints on wireless communications, UAVs can be used to install sensors in distant and isolated places, as well as in areas where terrestrial networks are not available. However, LoRaWAN and Narrowband IoT, which are the standard IoT communication technologies, cannot be used in these scenarios. The space network consists of a constellation of satellites at various altitudes, including Geostationary Earth Orbiting (GEO), Medium Earth Orbiting (MEO), and low Earth orbiting (LEO). For space-based platforms, altitude, beam footprint size, and orbit are the three most important features to consider [19]–[21].

## IV. TERAHERTZ BAND

Mobile communication network traffic is expected to increase by many folds in 6G cellular mobile system compared with that of 5G system, so a new bandwidth needs to be investigated according to the following items:

- A huge bandwidth has become necessary and this spectrum band can be easily covered by sub-THz and terahertz bands.
- The range of the terahertz band is between 0.1 and 10 THz, and whose wavelength is 30 to 3000 microns as depicted in Fig.2 [8], [22], [23].
- The terahertz band was strongly affected by free space path loss (FSPL) and atmospheric absorption loss due to the oxygen and water vapor, since the wave length of the terahertz waves are close to their size. The above terahertz band challenges limit the propagation distance to around 10m [24], [25].
- A high gain adaptive array antenna will be needed at the base station of the 6g mobile system to overcome the FSPL and the atmospheric absorption loss [24], [26]–[28].

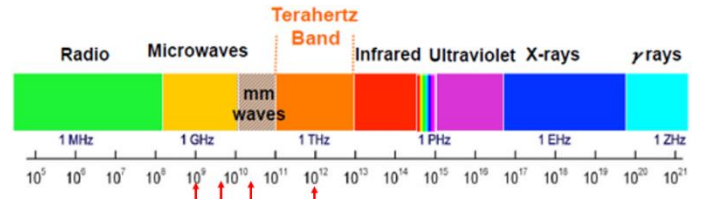


Fig.2 Electromagnetic spectrum [4]

Some of the main futures of the sub-terahertz band was illustrated below:

#### A. Potential Available THz-band

The Low-terahertz band (100 GHz-800 GHz) was evaluated depending on the related atmospheric absorption chart in Fig.7 and on Fig.3. It was found that this band had a potential available bandwidth of 454 GHz, which get great attention by researchers to initiate the 6G project [2], [26].

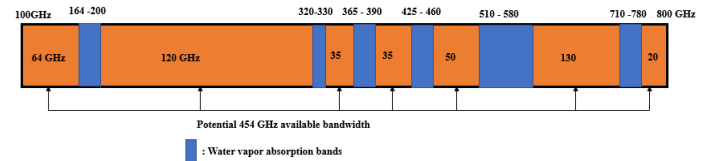


Fig.3 First portion of Terahertz band

#### B. Sub-Terahertz band frequency allocation

The Federal Communications Commission (FCC) voted in 2019 to open up a frequency band above 95 GHz, and provided 21.2 GHz of spectrum for unlicensed use and opened a licensing spectrum in the THz band up to 3 THz to push the develop of the required wireless technology for the 6G projects around the world. For global Wi-Fi purposes, the Institute of Electrical and Electronics Engineers (IEEE) in 2017 formed the IEEE 802.15.3d standard, initiating the first worldwide wireless communications standard in 252-325 GHz frequency band, with a nominal data rate of 100 Gbps. Table 2 illustrates a set of located frequencies in the sub-Terahertz band. Some of these frequencies are located either by the FCC, IEEE, while others are being investigated by researchers, as the most attractive frequencies, depending on the related atmospheric absorption chart [2], [29], [30].

TABLE II  
LOCATED AND INVESTIGATED FREQUENCIES IN THE SUB-TERAHERTZ BAND

Frequency (GHz)	Atmospheric attenuation state	Band type	Applications	Allocation reference
100, 140, 220, 410, 345, 460, 680, and 800	Acceptable	Licensed	6G Mobile cellular system	Research investigation
183, 325, 380, 450, 550, and 760	Sevier	Unlicensed	Short rang (indoor applications)	Research investigation
116 - 123, 1750 - 182, 185 - 190	Acceptable	Unlicensed	Industrial, scientific,	Federal Communication

244- 246			and medical (ISM) band	s Commission (FCC)
252 – 325	Acceptable	Unlicensed	IEEE 802.15.3d global Wi-Fi	Institute of Electrical and Electronics Engineers (IEEE)

V. ELECTROMAGNETIC WAVE RADIATION

All the radiation sources exist around us, whether coming from natural or manmade sources. There are two types of radiation as illustrated below and depicted in Fig.4.

- 1- Ionizing radiation
- 2- Non-ionizing radiation

There is a sufficient energy in the ionizing radiation that when interacted with an atom, it can remove electrons from the atom orbit, causing the atom to become charged or ionized which produces health risks by damaging tissue and DNA. The radiation source produced by the electromagnetic waves called non-ionizing radiation which has insufficient energy to cause ionization. Ionizing radiation like x-rays and gamma-rays, can cause a major health risk since it works in the upper portion of the ionization spectrum as depicted in Fig. 5. On other hand the photon energy produced by the millimeter waves (5G spectrum band) and Terahertz waves (6G spectrum band) are insufficient to release an electron from an atom, since it is too weak (0.1 to 12.4 meV), where typically 12 eV is required for ionization [2], [31]–[33].

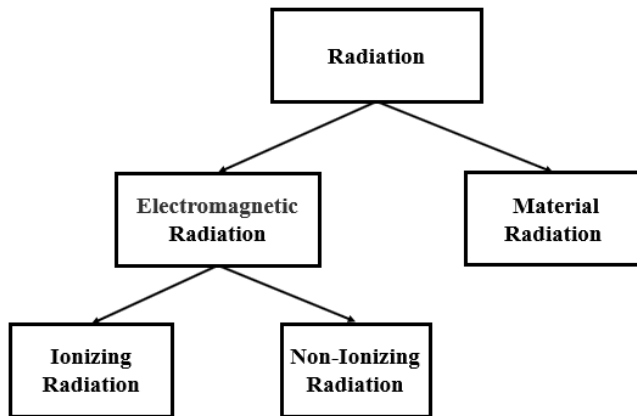


Fig.4 Radiation classification

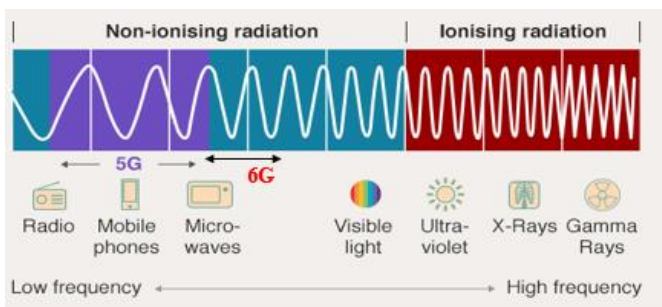


Fig. 5 Ionized and non-ionized bands

A radiation program has been established by the World Health Organization (WHO) to protect the public against radiation

exposure. The Non-Ionizing Radiation Protection (ICNIRP) and the Federal communication commission (FCC) have established a limit for safety to control the radiation exposure. Health effects related to RF energy emitting from wireless system are already studied by researchers in [2], [31]. As the terahertz band will be the basic spectrum portion for the future 6G technology, there should be essential efforts to be done to clarify the biological and molecular effect of the terahertz radiation on human health. As we have a plenty of time for the standardization of the terahertz technology, it is the time to perform more studies to achieve with high conviction that terahertz radiation has only the heating health concern.

VI. 6G MAIN CHALLENGES

Atmospheric absorption is one of the main challenging terms in the Terahertz band. The effects of the atmosphere absorption on high frequency based wireless communication system is well known [2], [34], [35]. At the terahertz band the atmospheric absorption, represented by Mie scattering, becomes more severe, since the wavelength in such situation approaches the size of dust, rain, or snow. Beside that terahertz band was harmfully affected by significant signal absorption due to the resonance's phenomena of hydrogen, oxygen, and other gases already exist in the atmospheric media. By adding the atmospheric loss to the free space path loss(FSPL), the terahertz propagation distance becomes limited to a few meter and to extend this range to around 100-150m an advance technology should be integrated in the 6G system [36]–[38]. So, lack of technology, which is out of the scope of this paper, will represent another important challenge in the realization and construction of the 6G system. For the moment been this technology is not ready and will need many years to reach the commercial state.

A. Free Space Path Loss (FSPL)

Considering two communication nodes separated by a distance (d) in Km and operating at carrier frequency ( $f_s$ ) in MHz , the FSPL in (dB) unit is given by equation (1) [1], [27], [37].

$$FSPL_{dB} = 32.44 + 20\log_{10}(f_s) + 20\log_{10}(d) \tag{1}$$

Equation (1) can be manipulated as:

$$FSPL_{dB} = 152.44 + 20\log_{10}(f_s) + 20\log_{10}(d) \tag{2}$$

where  $f_s$  is in THz unit and d is the LOS distance in Km.

Using (2), the FSPL was plotted against distance as shown in Fig. 6 for one of the licensed frequencies (800 GHz) in the terahertz-band allocated for 6G mobile cellular system depending on Table II and for one of the nominal millimeters-wave frequency of 28 GHz actually employed in 5G system.

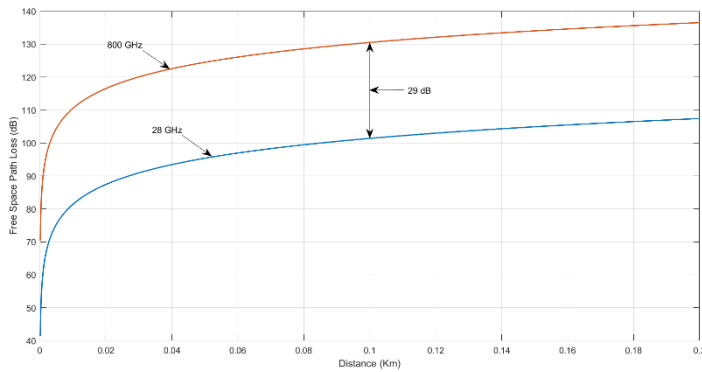


Fig. 6 Free Space Path Loss (FSPL)

The above Figure clearly show that FSPL becomes one of the major path loss challenges in the terahertz band applications. For a distance of 100m the FSPL of the terahertz frequency (800 MHz) is (29) dB more than that of the millimeter-wave frequency (28GHz). So the 6G mobile system need a base station with a very high antenna gain at the base station to overcome the high FSPL and the high atmospheric absorption loss [30], [39].

### B. Atmospheric Absorption

The atmospheric absorption at the sea level versus frequency for different humidity environment is depicted in Fig.7 [2], [36], [38]. Due to atmospheric absorption, certain selective frequencies belong to the sub-terahertz band was harmfully attenuated (see Table II). One of these frequencies, as an example, is the 450 GHz which is attenuated by 1000 dB/ Km. By adding the FSPL to the atmospheric loss, these frequencies will be so attenuated which making this portion of spectrum suitable for secure communications and short range communication[4], [9], [12], [24], [40], [41]. On other hand the portion of the spectrum between 600 and 800 GHz was attenuated by 100 to 200 dB/km respectively, and for a 6G base station with radius of 100mm, this attenuation was reduced to a value between 10 to 20 dB  $\left\{ \left( \frac{200}{1000} \right) \times 100 = 20\text{dB} \right\}$ . For the 6G mobile system the atmospheric attenuation can be practically overcome by using an adaptive array high gain antenna. Depending on Fig.3, the Sub-THz frequency band, with an approximated transmission window of 454 GHz and manageable losses will be so efficient for establishing a wireless communication system with ultra-high data rate and ultra-low latency which make this band ideal for 6G wireless mobile communications system.

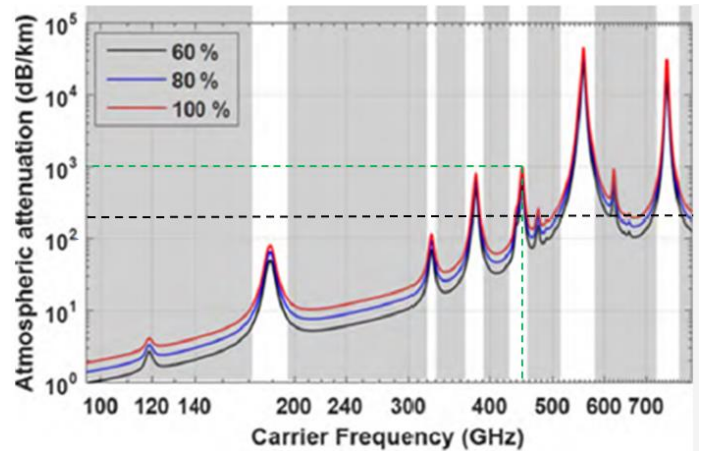


Fig. 7 Atmospheric absorption loss of electromagnetic waves [2].

## VII. RAIN ATTENUATION

Figure 8 represent the Rain attenuation for the sub-Terahertz band. It is clear from this figure that the portion of spectrum between 100 GHz to 800 GHz has a nearly flattens shape with 20 dB/km of rain attenuation for a rain rate of 50 mm/h. For a 6G cell sizes of 100m, this attenuation will be reduced to 2dB  $\left\{ \left( \frac{20}{1000} \right) \times 100 = 2\text{ dB} \right\}$ , which can be easily compensated by introducing more gain using adaptive antenna at the base station. We can conclude that at sub-terahertz band the rain situation will have minor effect on the wave propagation compared with the atmospheric absorption loss and the FSPL, so the band of sub-terahertz between 100GHz to 800GHz can be well allocated for the future 6G mobile system application [2].

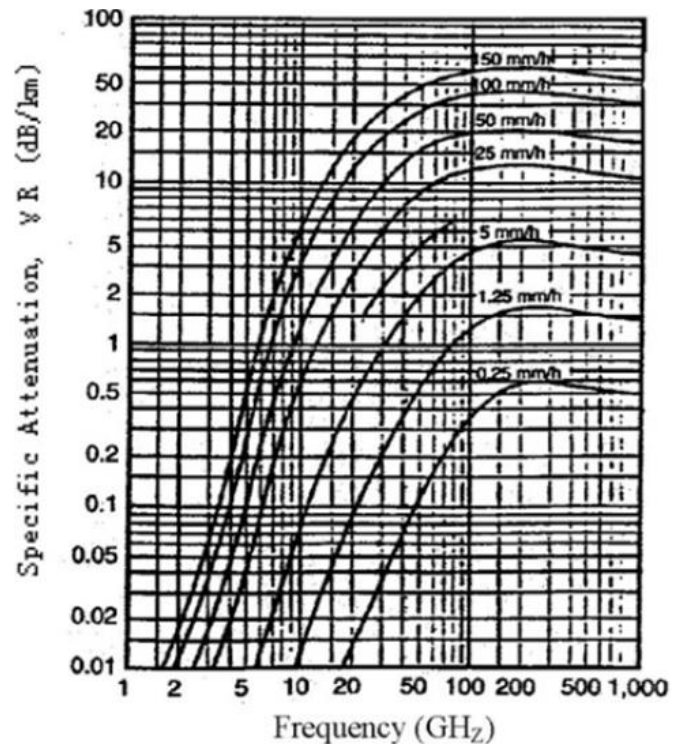


Fig. 8. Rain attenuation for sub-terahertz band [2]

## CONCLUSION

Further upgrading for the actual employed 5G mobile system, working at millimeter band, are still in progress, on other hand, researches activity on the next 6G mobile system, working at terahertz-band, have been already started by academics and industries. 6G system will be expected to be introduce in services at 2030. 6G is not just faster than 5G system, but its fully artificial intelligent (AI) based. Propagation path-loss represent by the free space path loss (FSPL) and the atmospheric absorption loss are one of the most challenges which effecting the wave propagation at the terahertz band. By additional antenna gain using beam forming technique, sub-terahertz band between 100 GHz to 800 GHz can be well allocated for the future 6G mobile system. It was found that the sub-terahertz band had a potential available bandwidth of 454 GHz, which get great attention by researchers to initiate the 6G project.

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