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RESEARCH ARTICLE

Evaluation of Direct Terahertz Radiation on Prospective Communication Applications

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Abstract

The continuous development of information and communication technology has brought rapid changes, especially developments in cellular technology, starting with 1G and reaching the fifth development in 2020, 5G. This development continues, as evidenced by the start of 6G technology development in early 2020. The Terahertz (THz) spectrum, which has not been used optimally so far for communication technologies, is one candidate to support the next cellular technology developments. THz Waves offers far wider bandwidth than the existing technologies. Apart from the advantages of THz wave radiation, this research studies THz wave radiation intensity and its potential for communication. By calculating the Atmospheric Attenuation, FSPL and considering the minimum received power of user equipment (UE), THz wave radiation characteristics will be more optimal for use less than 500 meters at 0.1 THz and less than 100 meters at 3 THz. The highest Power density of THz radiation is 7.99 × 10-11 Watt/m2 when using 0.1 THz as frequency and a power transmitter of 10 Watts. The results show that exposure to THz waves in communication applications is safe and acceptable for practical communication use.

Keywords: Terahertz radiation, communication, application, technology

1. Introduction

Information and communication technology continues to grow rapidly. This development began with the first generation (1G), second generation (2G), third generation (3G), and the fourth generation (4G) in 1980,1990, the 2000s and the end of 2020, respectively. In early 2020, fifth-generation (5G) technology was rolled out worldwide [1]. In many countries, such as Europe, USA and Korea, 5G technology was launched commercially in 2019 [2]. Indonesia plans to roll out 5G technology in 2021 [3]. The

5G technology offers three potential use case applications, namely: eMBB (enhanced mobile broadband), URLLC (ultra-reliable and low latency communication), and mMTC (massive machine type communication).

The development of the sixth generation has also begun in early 2020. Even though 5G technology has just been launched and developed, researchers have started to conduct research for the development of 6G [4]. 6G technology is expected to concentrate on use cases for communication and other fields beyond 5G technology [5]. Developing 6G Technology is refining 5G Technology and adding new technologies such as Artificial Intelligence (AI), Terahertz (THz) Communication, Optical Wireless Technology, Free Space Optics (FSO) fronthaul / backhaul Networks, Massive Multi Input Multi Output (MIMO), Blockchain, 3D Networking, Quantum Communication, Cell-Free Communications, Big Data Analysis, etc. [6]. It is expected to increase and maximize user Quality of Services (QoS) several folds than 5G New Radio (NR). 6G is expected to be a global communication facility. Some research on 6G targets key performance indicators (KPIs) such as data rate up to 1 Tbps, latency below 1 ms, higher reliability, cheaper energy and cost, wider coverage, and increasingly massive connectivity [6]. Especially to realize the increasing/expanding capacity KPI, THz gap, and Spectrum Between 100 GHz to 10 THz, this technology is proposed for use in sixth-generation (6G) wireless communication [1].

THz band has micrometers of wavelength with path loss dependency and unique channel characteristics. One is a human blockage in which loss increases and areas decrease with increasing frequency [1]. THz propagation characteristic of human blockage loss was measured. Four phenomena occur in the propagation of radio waves, namely: path-loss, scattering, diffraction, and reflection [7]. In an Indoor environment, the main signal will propagate in the Line of Sight (LoS) path and also can arrive in the receiver via a different path (multipath) or NLOS (Non-Line of Sight) [8]. This multipath will cause physical effects such as reflection, scattering, and diffraction. The indoor environment has its characteristics depending on room size, building material, and properties of another object [9]. The dependency and characteristics of the room will lead to how the radio waves propagate.

The telecommunications system uses the electromagnetic wave spectrum as a carrier to transmit information. Due to technical and regulatory challenges, the THz gap, which lies between 100 GHz to 10 THz, has not been maximized for their use in telecommunications. Meanwhile, the 6G technology is expected to reach 1 Tbps [6]. THz waves are projected to be carriers that are expected to be able to meet those expectations because the THz wave has a potential with a large bandwidth [10] [11]. Another characteristic is non-ionizing radiation, which has potential medical applications [12].

THz bands have a large bandwidth that allows for high data rates. However, THz technology is still developing and must be addressed before implementation. One of the challenges or things in developing the THz band is the aspect of radiation produced by the THz band [1]. Understanding the power density of terahertz radiation is critical for assessing potential health risks, ensuring compliance with safety standards, optimizing system performance, ensuring device safety, and implementing appropriate risk mitigation strategies. It enables the responsible and safe use of terahertz technology for humans and the environment. This research studies THz wave radiation intensity and its potential for communication.

2. Methodology

Figure 1 is a schematic for the radiation propagation model. It consists of a directional antenna, tower, and serving Area. The directional antenna can be characterized by resonant frequency, beamwidth, and power. This research considers the beamwidth of 6.1 degrees. The antenna direction can also be adjusted with electrical tilting, often featured by commercial antenna products. Another component of the tower provides a determined height for the antenna placement. In the antenna installment on the tower, it is also possible to conduct mechanical tilting. The total tilting considered in this research is from one degree to 30 degrees.

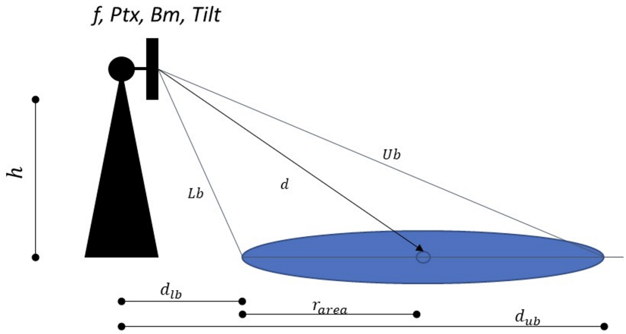

Figure 1. Schematic for radiation propagation Model

A transmission tower forms the service area. The service area is determined by the tower height or antenna location (h), tilt (θ) and antenna beamwidth (β). The upper bound and lower bound distances are obtained using that parameter. It is assumed that the service area is a circle, so Equation 1 can be used to calculate the serving area.

$$ServingArea = \frac{\pi h^2}{4}\left(\frac{1}{tan(\theta - 0.5\beta} - \frac{1}{\theta + 0.5\beta}\right)^2 \tag{1}$$

After obtaining the serving Area, power density modeling is continued by considering the transmit power used in each scenario. The research considers 4 height scenarios: 12, 32, 52, and up to 72 m. The transmit power scenarios are 2-Watts and 4-Watt. These numbers are often used in telecommunication industries. A power of 10 watts is also considered to predict future technology in which the maximum power emitted can exceed 4G technology [13][14].

Losses in propagation are also important factors that must be considered in the propagation of electromagnetic waves, especially in the THz spectrum. Besides the common loss factor of free space path loss in propagation that is frequency dependent, atmospheric attenuation must also be considered in THz wave propagation. Therefore, this research considers the factors of Free Space Path Loss (FSPL) and atmosphere attenuation in modeling the THz wave propagation.

In the propagation of electromagnetic waves in a vacuum or on the line-of-sight (LOS) path, this attenuation or loss is often referred to as FSPL. The Free Space Path Loss equation is derived from the Friis equation [15]. Equation 2 is necessary to calculate the THz wave propagation in free space by considering frequency (f), distance (d), and the speed of light (c).

$$FSPL = \left(\frac{4\pi df}{c}\right)^2 \tag{2}$$

Figure 2 shows the atmospheric attenuation of electromagnetic waves. THz frequency attenuates higher than the microwave spectrum in the atmospheric environment [16]. The attenuation occurs due to gas molecules, rainfall, snow or fog [17]. This paper considers specific attenuation on 15^oC of a water-vapor density 7.5 g/m3 or standard environment as 0.5, 10, 100, and 1000 dB/km for 0.1, 0.3, 3, and 10 THz Spectrum. The Atmospheric Attenuation can be obtained by calculating specific attenuation (α) and distance (d) as mentioned by equation 3.

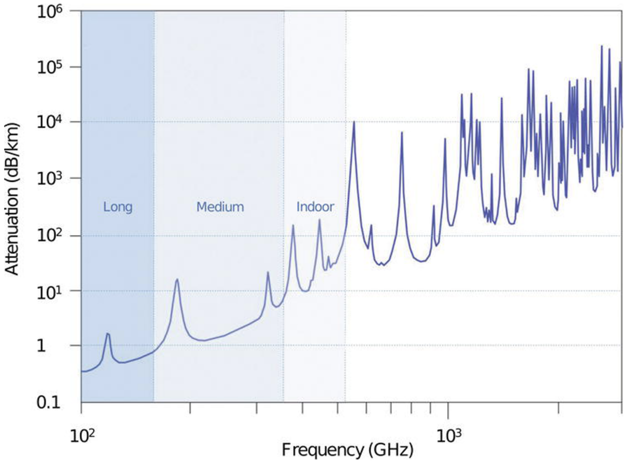

Figure 2. Atmospheric attenuation up to 10THz [16]

$$Attenuation = \alpha \times d \tag{3}$$

The FSPL and attenuation decrease the power transmitted along propagation to UE. UE minimum Reference Signal Received Power (RSRP) on 4G technology is -140 dBm [19]. The Synchronization Signals (SS) RSRP for 5G technology in Non-Stand Alone (NSA) scenario is between -40 dBm to -139 dBm with a potential of up to -156 dBm since 6G has not had standard, so -156 dBm is considered as the threshold in this research [17].

Transmit power is calculated by Equation 4 [15]. It is determined by input power (P), the number of Resource Blocks (RB) (N) and Antenna Gain (G). Input power and antenna gain are obtained from the Radio Remote Unit (RRU) and antenna specifications. Meanwhile, the number of RB is determined by the width of the bandwidth.

$$P_{Tx} = 10log_{10}P - 10log_{10}(N \times 12) + G \tag{4}$$

Power Received can be obtained by considering transmit power, FSPL, and atmospheric attenuation. Equation 5 shows the calculation for received power by UE. It shows that other factors will reduce the transmit power as a function of distance until reaching the receiver.

$$P_{Rx} = (P_{Tx} - Attenuation - FSPL)_{dBm} \tag{5}$$

Another parameter to analyze the received power is power density which indicates the level of power strength that can be compared to the safety standard of radiation hitting the human body. Equation 6 is the formula for calculating the power density considering a circle area. The power density calculation results will be compared with the ICINRP (International Commission on Non-Ionizing Radiation Protection) guideline mentioning that the safe level of radiation is 2 watts per square meter [18]. ICINRP is an independent non-profit organization that provides scientific advice and guidance on the health and environmental effects of non-ionizing receiving electromagnetic wave radiation.

$$P_{density} = \frac{P_{Rx}}{Serving\ Area} \tag{6}$$

3. Result and Discussion

Figure 3 shows the FSPL calculation with a frequency of 0.1 THz to 10 THz at a distance range from 1 meter to 1 kilometer. The smallest and greatest loss value occurs at a frequency of 0.1 and 10 THz at a distance of 1 km, respectively, 132.44 dB and 232.44 dB. Despite the distance, the calculation results show that the frequency increases contribute to the loss increase.

Figure 4 shows the power received by varying transmitter power of 2, 4, and 10 watts. This calculation indicates that the THz frequency in the 0.1 to 0.3 THz range can be received up to 500 meters with a power level threshold above -156 dBm. Meanwhile, the radiation at 3 THz and 10 THz suffers below -150 dBm at 400 and 100 meters, respectively. It indicates that radiation at the THz spectrum is affected by atmospheric attenuation when considering the whole spectrum.

Table 1 shows the power density results where the distance of serving cells is up to 5 kilometers depending on the height antenna. Towers with a height of 12 meters have a maximum serving area of 0.3 km2 with a serving radius of 4.3 km. The calculation is conducted on power transmit of 2 and 4 watts. The calculation results

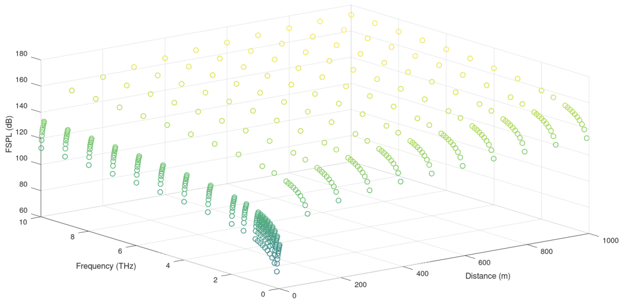

Figure 3. THz wave FSPL

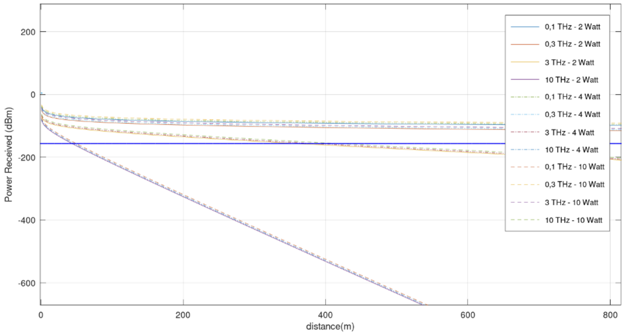

Figure 4. THz received power by transmit power variation

of power density using 2-watt transmit power at 0.1 THz are in the range of 3.30 x 10-22 to 1.60 x 10-11 Watt/m2 at the height of 12 m to 72 m. At 0.3 THz and 3 THz, as in the 0.1 THz frequency with the same antenna height scenario, the power density calculation of the use of 2 watts at the 0.3 THz and 3 THz frequencies are in the range 2.30 × 10-68 Watt/m2 to 1.77 × 10-12 Watt/m2. The minimum power density is calculated at a power transmission of 2 watts and radiation frequency of 10 THz is close to 0 watts/m2 at the height antenna on 52 and 72 m.

The maximum result of the power density calculation of 4-watt transmit power is 3.20 x 10-11 watts/m2 at a frequency of 0.1 THz with an antenna height of 12 meters. Meanwhile, the minimum power density value of the 4-watt scenario is close to 0 watts/m2 at 52 and 72 m antenna heights. The increase in power transmission from 2 to 4 watts increases the power density of THz radiation, which is still safe for the human body.

Table 2 shows using 10 watts as transmit power. The highest power density value is 7.99 × 10-11 Watt/m^2 with a high antenna of 12 meters at a frequency of 0.1 THz. Conversely, the lowest power density value is 0 Watt/m^2 with antenna heights of 52 and 72 meters at a frequency of 10 THz. Tables 1 and 2 show that the calculation results of power density from THz wave propagation are lower than standards from ICINRP, which is 2 watts/m2.

Table 1. Power density on THz spectrum calculation on transmit power of 2 and 4 watt

Power Tx (watt)	Frequency (THz)	Antenna Height (meter)	Upper bound (meter)	Max serving Area (m²)	Power Density (watt/m²)
2	0.1	12	723.67	308530.29	6.49E-19 to 1.60E-11
		32	1929.98	2193993.19	1.12E-20 to 3.15E-13
		52	3135.90	5793513.26	1.39E-21 to 4.50E-14
		72	4342.01	11107090.51	3.30E-22 to 1.22E-14
	0.3	12	723.67	308530.29	6.63E-20 to 1.77E-12
		32	1929.98	2193993.19	9.93E-22 to 3.48E-14
		52	3135.90	5793513.26	1.08E-22 to 4.95E-14
		72	4342.01	11107090.51	2.22E-23 to 1.34E-15
	3	12	723.67	308530.29	4.54E-29 to 1.16E-14
		32	1929.98	2193993.19	7.80E-43 to 1.13E-16
		52	3135.90	5793513.26	9.72E-56 to 8.01E-18
		72	4342.01	11107090.51	2.30E-68 to 1.07E-18
	10	12	723.67	308530.29	3.03E-95 to 2.29E-17
		32	1929.98	2193993.19	1.46E-217 to 3.82E-22
		52	3135.90	5793513.26	0 to 4.63E-26
		72	4342.01	11107090.51	0 to 1.06E-29
4	0.1	12	723.67	308530.29	1.30E-18 to 3.20E-11
		32	1929.98	2193993.19	2.23E-20 to 6.30E-13
		52	3135.90	5793513.26	2.79E-21 to 9.00E-14
		72	4342.01	11107090.51	6.60E-22 to 2.44E-14
	0.3	12	723.67	308530.29	1.33E-19 to 3.54E-12
		32	1929.98	2193993.19	1.99E-21 to 6.96E-14
		52	3135.90	5793513.26	2.16E-22 to 9.91E-15
		72	4342.01	11107090.51	4.45E-23 to 2.68E-15
	3	12	723.67	308530.29	9.08E-29 to 2.33E-14
		32	1929.98	2193993.19	1.56E-42 to 2.27E-16
		52	3135.90	5793513.26	1.94E-55 to 1.60E-17
		72	4342.01	11107090.51	4.59E-68 to 2.15E-18
	10	12	723.67	308530.29	6.06E-95 to 4.58E-17
		32	1929.98	2193993.19	2.93E-217 to 7.65E-22
		52	3135.90	5793513.26	0 to 9.25E-26
		72	4342.01	11107090.51	0 to 2.21E-29

Table 2. Power density on THz spectrum calculation on transmit power of 10 watt

Power Tx (Watt)	Frequency (THz)	Antenna Height (meter)	Upper bound (meter)	Max serving Area (m²)	Power Density (Watt/m²)
10000	0.1	12	723.67	308530.29	3.24E-18 to 7.99E-11
		32	1929.98	2193993.19	5.58E-20 to 1.57E-12
		52	3135.90	5793513.26	6.97E-21 to 2.25E-13
		72	4342.01	11107090.51	1.65E-21 to 6.10E-14
	0.3	12	723.67	308530.29	3.32E-19 to 8.86E-12
		32	1929.98	2193993.19	4.97E-21 to 1.74E-13
		52	3135.90	5793513.26	5.39E-22 to 2.48E-14
		72	4342.01	11107090.51	1.11E-22 to 6.69E-15
	3	12	723.67	308530.29	2.27E-28 to 5.82E-14
		32	1929.98	2193993.19	3.90E-42 to 5.67E-16
		52	3135.90	5793513.26	4.86E-55 to 4.01E-17
		72	4342.01	11107090.51	1.15E-67 to 5.37E-18
	10	12	723.67	308530.29	1.51E-94 to 1.15E-16
		32	1929.98	2193993.19	7.32E-217 to 1.91E-21
		52	3135.90	5793513.26	0 to 2.31E-25
		72	4342.01	11107090.51	0 to 5.31E-29

Attenuation and loss of the THz spectrum are quite high. The frequencies of 0.1 to 0.3 THz are acceptable for communication standards for UE minimum Received Power in 500 meters. For frequency above 1 THz, the loss and attention are too high, making it too short in distances. The power density of this spectrum is safe because it is still below the threshold standard issued by ICINRP. THz Spectrum will be more effectively used in indoor Areas where the distance antenna and the object is below 5 meters. It also can be used in urban areas, with a site distance of 500 meters suggested with complex consideration. Due to its characteristics, this spectrum will be more challenging to use in Rural Areas.

With the advantage of wide bandwidth and unique characteristics, the challenge for THz spectrum when implemented in 6G technology is coverage or serving area.

6G technology must optimize power usage. Regardless of the channel model, research on transmit power, gain and antenna technology will greatly assist in developing 6G technology with THz. In addition, the feasibility of investing in 6G technology with THz also needs to be discussed further.

4. Conclusion

The frequencies of 0.1 to 0.3 THz are still acceptable for communication standards for UE minimum Received Power for distances less than 500 meters. The power density of this spectrum is safe because it is still below the threshold standard issued by ICINRP. This research can contribute as fundamentals for practitioners observing the perspective of THz radiation in communication applications.

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