

Analysis of Inter-Satellite Terahertz Communication Link

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Abstract—The domestic and foreign status of terahertz wireless communication is introduced, and the paper analyzes the feasibility of ultra high speed short range and high speed long range inter-satellite terahertz communication. The capacity of inter-satellite terahertz communication system under the ideal additive white Gaussian noise (AWGN) channel is studied. It simulates the inter-satellite terahertz communication link and calculates high gain antenna design parameter requirements by analyzing more than 100Gbps capacity of short range inter-satellite communication and more than 2.5Gbps capacity of long range inter-satellite communication.

Keywords—satellite communication; terahertz communication; inter-satellites link

I. INTRODUCTION

Terahertz wave has many features, such as wide frequency band, high speed, small scattering, high penetrability, good directionality, high security and so on. It is another communication frequency band between microwave communication and laser communication. In recent years, the development of terahertz communication technology has become the hot topics in the study of high speed large capacity communications in developed countries. China, Japan, Germany, France, the United States, Canada and other countries also successfully carried out terahertz communication system research and experiment.

A. Japan

In 2004, Japan's NTT company for practical application of terahertz wireless communication system, in 0.12THz carrier, realized the remote (more than 1km) communication in 6HDTV signals 10Gbps wireless transmission link. In 2012, the company set up 0.3THz wireless communication demonstration system, using the amplitude shift keying (ASK) modulation way, realized the short distance (0~0.5m) 24Gbps error-free transmission (bit error rate is better than ten of negative nine power)[1].

B. Germany

In 2011 year, Germany's Fraunhofer institute for applied solid state physics (IAF) designed 0.3THz wireless communication system in which the modulation systems were ASK and BPSK. When transmission distance was 5m, transmission rate was 10Gbps. In the same year, IAF set up 0.22THz wireless communication demonstration system, when the output power is about 1.4mW, the institute adopted 16/64 /128/256QAM modulation system, which conducted a 2m transmission distance, 12.5Gbps experiment, and completed the pure atmosphere, heavy rain and heavy fog weather conditions of THz wave attenuation testing [2]. In 2012 year, the system was improved, which conducted 20m, 15Gbps and 10m, 25Gbps communication demonstration

experiments. In 2013 year, when the communication experiment distance was 1km, transmission rate reached 40Gbps, implemented on communication capacity and the seamless connection of optical fiber communication [3]. The physikalisch technische bundesanstalt (PTB) and the federation technische bundesanstalt (FTB) built a transmitting and receiving modules independent system used in 0.3THz measurement and transmission system of communication channel experiment.

C. China

In 2011 year, China academy of engineering physics (CAEP) developed a set of 0.14THz communication system based on the structure of super-heterodyne. It adopted 16QAM advanced digital modulation, completed the 500m and 10Gbps experimental verification [4]. In 2013 year, the CAEP also developed a set of 0.34THz system based on the SSB modulation system, in which the transmission rate was 3Gbps and transmission power was 14.58dBm, but it can only achieve 0.25m short distance transmission [5]. In 2013 year, the China academy of sciences Shanghai micro system set up a 3.9THz system with the communication rate of 1Mbps which achieved 2.4m video wireless transmission. In 2015 year, it also carried out wireless communication system research based on terahertz quantum cascade lasers (QCL) and completed the real-time video transmission experiment [6].

In addition, the city university of Hong Kong and university of electronic science and technology also designed terahertz communication experiment systems. Currently, the transmission distance of the before-mentioned terahertz communication experiment system is within 1km, mostly confines to the indoor short distance transmission experiment.

D. Other Countries

In 2009 year, the university of Toronto set up 0.14THz communication demonstration system using ASK modulation system and proceeded the short distance (0~1.15m) of 4Gbps transmission experiment [7]. In 2011 year, the United States Bell laboratory set up a 0.625THz communication demonstration system, used for short distance (0~0.5m) transmission experiment, when the output power was about 1mw, transmission rate was 2.5Gbps [8]. In 2015 year, Lille university completed the terahertz wireless data link experiment, which is 0.3THz working frequency, and 25m communication distance [9].

Reference [10] is on the background of long distance satellite terahertz communication applications, it simulates and analyzes transmission performance of inter-satellite communication link. It is concluded that the electron

emission system has a higher signal to noise ratio (SNR) and lower error rate than photoemission system, which can choose BPSK and 16QAM modulation system for variable rate transmission. Nevertheless, when the communication distance between the satellite increases to 100km, space transmission loss reaches hundreds of dB. This suggests that the long distance terahertz communication link need higher antenna gain. Therefore, it is necessary to further analyze the feasibility of terahertz satellite long distance communication for terahertz communication applications to explore new ways. At the same time, in the design of launch system of inter-satellite terahertz communication, we also must consider the space transmission characteristics of terahertz wave through link design to compensate for transmission loss.

Reference [11] researches potential space applications of the terahertz wireless communication system, through the analysis of wireless communication link about spacecraft indoor WLAN and the planet's surface wireless communication application. It is concluded that each 1GHz channel bandwidth can be obtained maximum data rate more than 10Gbps, pointing out that the high gain antenna and high power transmitter used in long distance communication between satellites is feasible. Terahertz spectrum of state-of-the-art antenna technology can reduce the design cost and improve the system performance, higher antenna gain can also increase the system capacity. References [12] and [13] separately designed the high gain reflective antenna system and mechanical scanning confocal elliptical antenna system. However, with the increasing antenna gain and terahertz frequency, narrow beam width for terahertz applications is a challenge, because it needs antenna tracking and locating accurately.

Long range between the satellites of the large capacity terahertz communication need high gain antenna and high power launch system, at the same time, also need acquisition pointing tracking (APT) subsystem safeguard. This paper, based on the existing high gain reflective antenna, analyzes capacity of inter-satellite terahertz communication system. It calculates satellite communication parameters of high gain antenna design requirements which are more than 100Gbps high capacity, short distance and 2.5Gbps high capacity, long distance.

II. TERAHERTZ SATELLITE COMMUNICATION SYSTEM CAPACITY

When terahertz satellite communication system is assumed to be the additive white Gaussian noise (AWGN) channel, the system capacity can be calculated by the Shannon theorem:

$$C = B \log_2(1 + SNR) \quad (1)$$

In the formula, SNR is signal to noise ratio, B is channel bandwidth. SNR's formula is:

$$SNR = \frac{P_R}{FkTB} \quad (2)$$

In the formula, P_R is received power, K is Boltzmann constant, T is environment temperature, F is additional noise receiver.

According to the electromagnetic wave transmission model, system's received power P_R is:

$$P_R = \frac{P_T \eta_T \eta_R G_T G_R}{L_f} \quad (3)$$

In the formula, P_T is transmitter power, G_T and G_R separately are transmitting antenna and receiving antenna gain, L_f is free space transmission loss, η_T and η_R separately are transmitting antenna and receiving antenna efficiency. When the integration of the sending and receiving antenna is used, the efficiency of the antenna is $\eta_T = \eta_R$, antenna gain is:

$$G_T = G_R = \left(\frac{\pi D_a}{\lambda} \right)^2 \quad (4)$$

λ is wavelength, D_a is antenna diameter, L_f is free space propagation loss.

$$L_f (dB) = 10 \lg \left(\frac{4\pi d}{\lambda} \right)^2 \quad (5)$$

Here d is receiving distance, the unit is km.

Hence, without considering the satellite platform vibration effect, system power for the receiver to receive is:

$$\begin{aligned} P_R &= P_T \eta_T^2 \left[\pi \left(\frac{D_a}{2} \right)^2 \right]^2 \left(\frac{f}{cd} \right)^2 \\ &= P_T \eta_T^2 \pi^2 \frac{D_a^4 f^2}{16c^2 d^2} \end{aligned} \quad (6)$$

When $C_0 = \sqrt{\eta_T^2 \pi^2 / 16c^2}$, the above formula can be converted to:

$$P_R = P_T \eta_T \frac{C_0^2 D_a^4 f^2}{d^2} \quad (7)$$

When formula (2) and (7) substitute into formula (1), terahertz satellite communication link which is calculated under ideal AWGN channel can reach the maximum capacity.

III. TERAHERTZ SATELLITE COMMUNICATION LINK SIMULATION ANALYSIS

In the following simulation analysis and calculation, the assumed parameters are as follows: 0.34THz frequency, bandwidth of 10GHz and 50GHz respectively, choice of transmitted power of 10mw and 1w respectively, 300K environment temperature.

A. Short Range Satellite Communication

When the satellite communication distance is within 1km, maximum communication capacity of terahertz communication system is shown in Fig.1 and Fig.2. Figure 1 is the maximum capacity of the short distance communication system, communication frequency is 0.34THz, system transmission power is respectively selected for 10mW and 1W, bandwidth is 50GHz. Known from the figure, when the antenna gain is more than 40dB, the system's maximum communication capacity increases significantly. The antenna gain raises more than 50dB, communication capacity of 1W transmitted power is higher 70Gbps than that of 10mW. When the system communication bandwidth increases from 10G to 50G, the system largest communication capacity increases significantly, as shown in Fig.2.

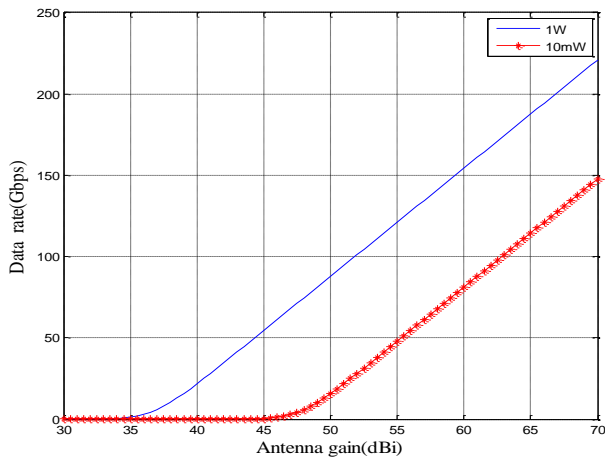


Figure 1. The maximum capacity of short distance communication system.

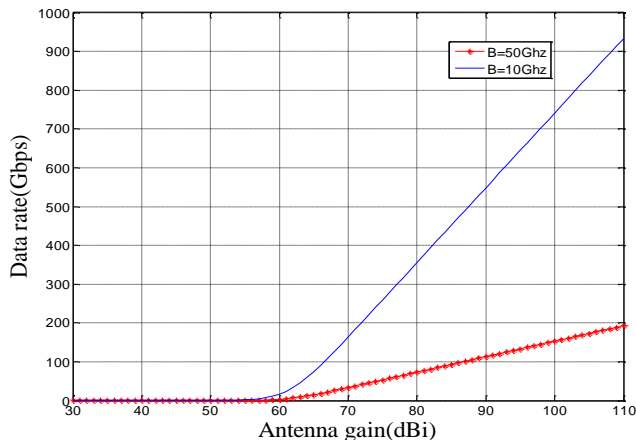


Figure 2 The maximum capacity of short distance communication system under different bandwidth

Based on the design given by [14], the antenna gain is closely related to the aperture size. As shown in Fig.3, when frequency is 0.34THz and gain is 70dB, antenna needs 1.2m aperture. Then, according to Fig.1 and Fig.3, to achieve 100Gbps or higher communication capacity, it requires 10mW system transmission power, 65dB antenna gain and 68cm antenna aperture. If the channel bandwidth increases to 50GHz, it can get higher communication capacity more than 500Gbps. The traditional microwave frequency wireless communication system is impossible to achieve.

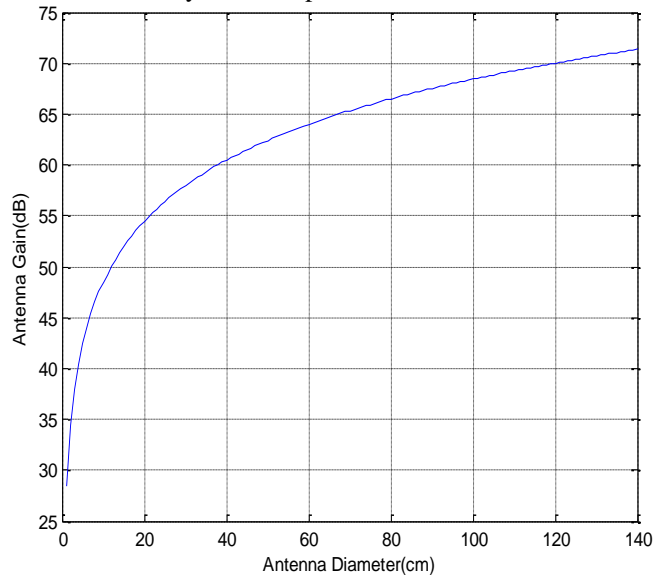


Figure 3. The relationship between antenna gain and aperture size

B. Long Range Satellite Communication

In the Fig.4, communication distance is 100km, it analyzes different transmission power relationship between communication capacity and antenna gain. As shown in Fig.4 (a), when system transmission power is 10mW, reaching 2.5Gbps or higher communication capacity needs antenna gain increased to 71dB, then the corresponding antenna aperture is 120cm. As shown in Fig.4 (b), if the system transmission power can be increased to 1W, it only needs to design a antenna of 62dB gain, 50cm aperture and can reach 2.5Gbps or higher communication capacity.

Combining the existing antenna design, the paper analyzes inter-satellite communication capacity between short distance of 1km and long distance of 100km. The results show that in order to realize the short distance 0.34THz ultra-fast communication application, system design has low requirements to the antenna size, but it has higher demands for long range communication antenna. For example, the bandwidth is the premise, in the short range communication, to reach 100Gbps or higher data transmission rate, it requires 10mW system transmission power, 65dB antenna gain, 68cm aperture. To achieve 2.5Gbps, 100km long range inter-satellite terahertz communication, it needs to design 62dB gain and 50cm antenna aperture, and demands that the system transmission power reaches 1W. Therefore, long distance and large capacity are feasible for terahertz satellite communication.

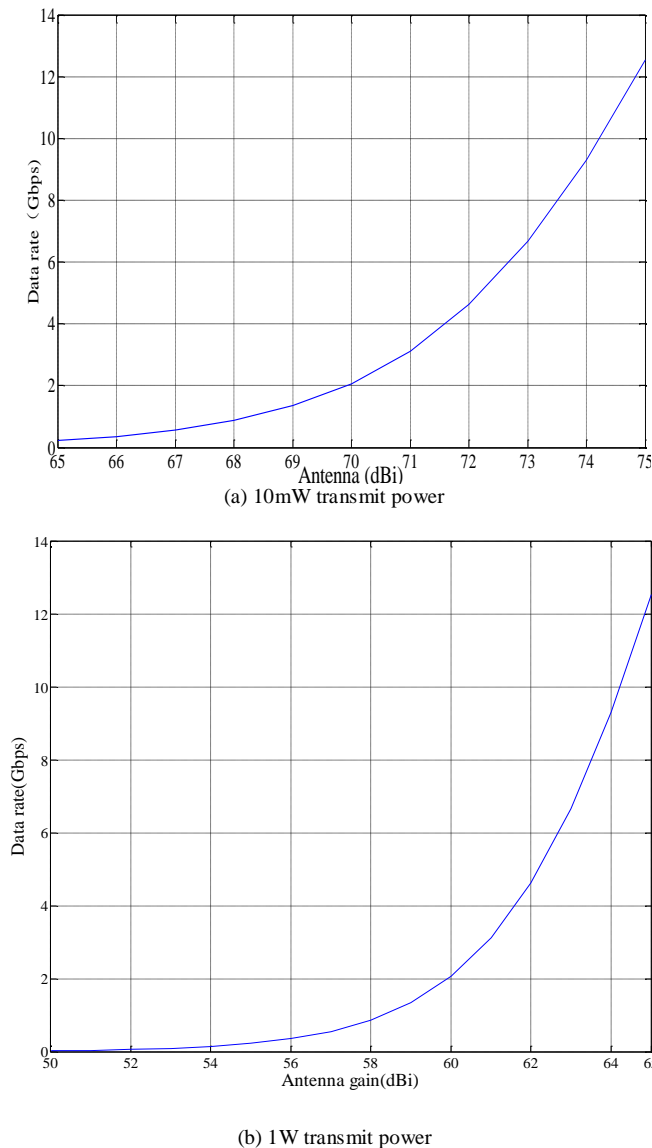


Figure 4. The relationship between the communication capacity of different transmit power and antenna gain (100km long distance communication).

IV. CONCLUSION

Combining the current status of the development of antenna technology, this paper analyzes the feasibility of ultra high speed short distance and high speed long distance inter-satellite terahertz communication. The results show that the short distance between satellites within 1km and 0.34THz communication applications for antenna size requirement is lower, but has the higher demand for long distance communication antenna. To reach 2.5Gbps, 100km inter-satellite terahertz communication, it needs to design 62dB gain, 50cm antenna aperture, and demands that the system transmission power reaches 1W. Distributed clusters terahertz communication application system, to realize the technology advantage of high speed, long distance, large

capacity, demands high gain antenna, high power transmission system and the guarantee of APT system. Therefore, as the future research, it is necessary to analyze the demand for APT technology and satellite platform vibration influence on inter-satellite terahertz communication, further design inhibiting platform vibration feedback control system.

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