Analysis of tracking-pointing error and platform vibration effect in inter-satellite terahertz communication system

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***Abstract*—Combining the current development of high-gain antenna technology, the inter-satellite terahertz communication system's demand for acquisition pointing and tracking (Acquisition Pointing Tracking, APT) technology are analyzed based on the inter-satellite terahertz communication application. The tracking-pointing error has a major influence on the received power of the communication system by simulating and calculating the tracking-pointing error of APT subsystem. The higher the terahertz wave frequency, the greater influence of the tracking-pointing error. The influence of the vibration of the satellite platform on the terahertz communication are analyzed by simulation calculation. There is almost no influence on the terahertz communication when the frequency is 0.34THz, while the influence becomes larger when the frequency increases to 1.5 THz and above. The signal-to-noise ratio of the system changes periodically with the vibration of the satellite platform. This research provides the basis for the design of beam tracing and platform vibration controller of space terahertz communication system.**

Keywords*—*APT system; Tracking-pointing error; Platform vibration; Terahertz communication

I. INTRODUCTION

Terahertz wave has the characteristics of high frequency bandwidth, high speed, small scattering, high penetrability, good directivity and high security. It is another communication band between microwave communication and laser communication. In recent years, the development of terahertz communication technology has become the hotspot of high-speed and large-capacity communication research in developed country. Many countries, such as China, Germany, Japan, France and the United States, even successfully conducted terahertz communication system test [1]. In 2012, NTT company in Japan set up a 0.3THz wireless communication demonstration system, it was achieved a short distance (0~0.5m) 24Gbps error-free transmission (bit error rate less than 10-9) using amplitude shift keying (ASK) modulation [2, 3]. In the same year, the German Fraunhofer Institute for Application of Solid State Physics (IAF) built a 0.22 THz wireless communication demonstration system and conducted communication demonstration experiments (20m, 15Gbps and 10m, 25Gbps) [4]. In 2013, the communication capacity achieved a seamless connection with optical fiber communication when the transmission rate reached 40Gbps with the 1km communication experiment distance [5]. In 2015, Lille University completed the terahertz wireless data link experiment with the operating frequency of 0.3THz and communication distance of 25m [6]. So far, most of the terahertz communication systems' transmission distance are less than 1km, and these systems are restricted to indoor short-distance transmission experiments.

Long-distance and large-capacity THz communication requires high gain antenna and high power transmission system, and also needs the guarantee of capture, alignment, tracking subsystem. In this paper, based on the technical requirements of inter-satellite terahertz communication application and the existing high-gain antenna, the demand of APT technology in terahertz communication system are analyzed. By analyzing the simulation results, the APT tracking error and affection of the satellite platform vibration to the system's signal noise ratio are calculated.

II. THE DEMAND FOR APT TECHNOLOGY IN INTER-SATELLITE TERAHERTZ COMMUNICATION SYSTEM

While some new reflective antenna designs make long-range free-space terahertz communication possible, it is also required to increase the frequency of terahertz waves. However, with the increase in frequency, inter-satellite terahertz communication system on the APT subsystem requirements will be increased. Terahertz communication has the advantage of laser communication in that APT subsystems are relatively easier to be achieved. So by the proven APT technology in laser communication, beam tracking and locating high gain antenna become possible.

Terahertz wavelength is between microwave and laser. Cassegrain antenna, one meter in diameter, for example, whose 0.3THz~30THz band are corresponding to 0.22mrad ~12.2μrad diffraction limit angle, transmits 100km and then its beam diameter turns into about 22cm~1.22m [7]. So, its accuracy requirements of the spatial alignment are lower in comparison to optical communication. However, the impact of satellite platform vibration can't be ignored. The vibration of the satellite platform will have a direct impact on the tracking error, and the vibration of the transmitter

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will make the receiver to produce the alignment deviation. As the current satellite communication system generally use direct strength modulation, which will lead to the increase in bit error rate, the adverse impact on the quality of communication, and even lead to communication link disruption. To solve this problem, it is necessary to calculate system's launch tracking error and reception tracking error, analyze the influence of tracking error on the signal-to-noise ratio of the system, basing on the requirements of space terahertz communication application to the APT technology. We also need to analyze the vibration performance of the satellite platform and its influence on the terahertz communication, which provides the basis for the beam tracing design and the platform vibration controller design of the space terahertz communication system.

III. TRACKING-POINTING ERROR OF ATP SYSTEM

A. *Tracking-pointing error*

When the transmission signal is a Gaussian distribution, the reception area of the antenna is less than the cross-sectional area of the beam. It is considered that the light field distribution is uniform within the reception area of the antenna.

Definition: $G(\psi)$ is the signal power loss coefficient caused by the tracking-pointing error of the transmitter, $G'(\varphi)$ is the signal power loss coefficient caused by the receiver. Among them, ψ is the tracking-pointing error of the transmitter (μrad), φ is the tracking-pointing error of the receiver (μrad), and θ_0 is the main beam width of the radio (μrad). So the formula of $G(\psi)$ is:

$$G(\psi) = \exp\left(-\frac{8\Psi^2}{\theta_0^2}\right) \tag{1}$$

$$G'(\varphi) = \cos(\varphi) \tag{2}$$

In the formula, $G(\psi)$ and $G'(\varphi)$ are in the range of 0 to 1, the value of 1 means no power loss, and the value of 0 means the maximum loss. when both ψ and φ are not zero, the received signal power drops. The antenna beam angle of the main lobe is proportional to the operating wavelength and is inversely proportional to the antenna diameter. The formula is as follows:

$$\theta_0 = 2\theta_{p/2} \approx 1.03\frac{\lambda}{D_a} \tag{3}$$

The formula (1) can be converted to:

$$G(\psi) = \exp\left(-\frac{8\Psi^2 f^2 D_a^{\ 2}}{1.03^2 c^2}\right) \tag{4}$$

Combined with the above formula, when the platform vibrates, the terminal receives the optical signal power $P_R^{'}$:

$$P_R^{'} = G^{'}(\varphi) P_R G(\psi) \tag{5}$$

From formula (1) to (5) available:

$$\begin{aligned} P_R^{'} &= \cos(\varphi) P_T \eta_T^{\ 2} \pi^2 \frac{D_a^{\ 4} f^2}{16c^2 d^2} \exp\left(-\frac{8\Psi^2 f^2 D_a^{\ 2}}{1.03^2 c^2}\right) \\ &= \cos(\varphi) P_T \frac{D_a^{\ 4} f^2 C_0^{\ 2}}{d^2} \exp\left(-\frac{8\Psi^2 f^2 D_a^{\ 2}}{1.03^2 c^2}\right) \end{aligned} \tag{6}$$

In this paper, based on the formula (6), it can get the relationship between the normalized power loss coefficient and the tracking-pointing error of the receiver, as shown in Fig.1. The ordinate is normalized received power loss of the system reduced by 1. From the figure, when φ is less than 100μrad, the tracking-pointing error of the receiver almost has no effect. Therefore, it only needs to consider the impact of the tracking-pointing error of the transmitter.

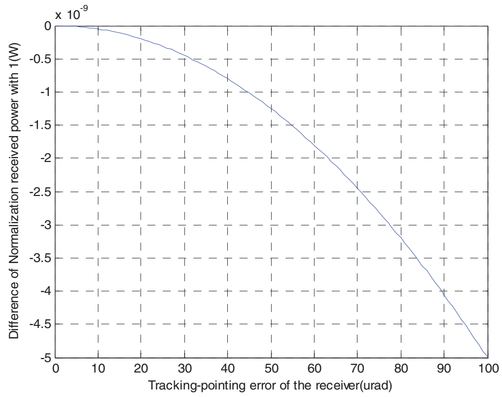


Fig.1 The normalized received power loss coefficient and the tracking-pointing error of the receiver

Similarly, based on the formula (6), the paper gets the relationship between the normalized power loss coefficient and the tracking-pointing error of the transmitter, as shown in Fig. 2. It can be seen from the figure that for a fixed frequency, with the increase of the tracking-pointing error of the transmitter, not only the power of the received signal but also the SNR gradually decrease. What's more, the bit error rate increases and the communication quality decreases. For the same the tracking-pointing error, when the frequency is higher, the tracking-pointing error of the transmitter has the more serious impact on the power received by the receiver. However, when the platform vibration is less than 100μrad, the influence of platform vibration on the 0.3THz communication system can be neglected. And when the frequency increases to 10THz, the normalized received power loss coefficient reaches -65dB. Therefore, the higher frequency of the satellite platform is, the higher the demand for APT technology is, and the slight vibration of the platform may have an impact on the system. APT subsystems is designed to making the greatest possible to avoid or reduce the impact caused by the vibration of the platform.

B. *Impact on the tracking-pointing error of the transmitter for SNR*

First, when the vibration of the platform is not considered, the influence of platform vibration on the SNR of the system is analyzed in the presence of the tracking-pointing error. Figure 3 and Figure 4 show the relationship not only between the SNR of the system and the tracking-pointing error of the transmitter at different frequencies, but also between the SNR and the frequency in different tracking-pointing errors of the transmitter.

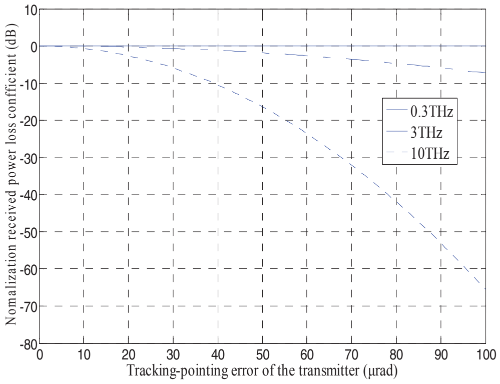
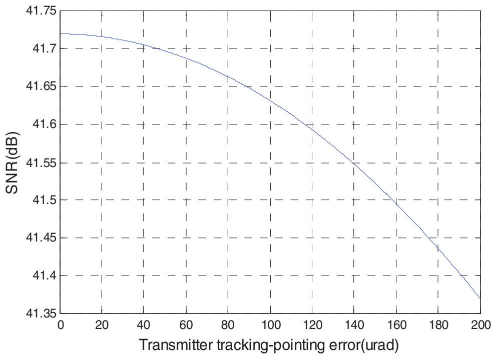
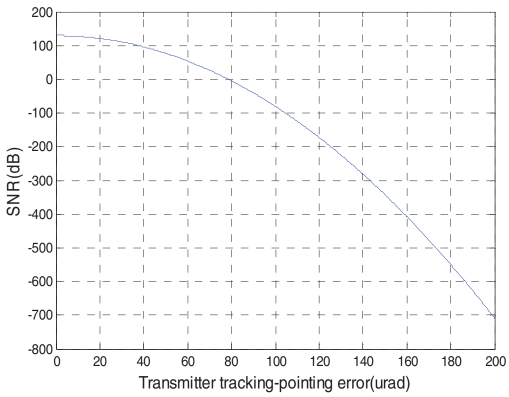


Fig.2 The normalized received power loss coefficient and the tracking-pointing error of the transmitter



(a) 0.34THz



(b) 10THz

Fig.3 Relationship between the SNR of the system and the tracking-pointing error of the transmitter

It can be seen from Fig. 3 (a) that the SNR of 0.34THz system decreases gradually with the increase of tracking-pointing error. The greater the tracking-pointing error is, the more the SNR decreases. The SNR decreases by less than 1 dB when the error is 200μrad.It can be seen: tracking-pointing errors of the transmitter and receiver have little effect on the SNR of 0.34THz communication system, which can be ignored. However, from Fig. 3 (b), when the transmission frequency is 10THz and the tracking-pointing error of the transmitter increases to more than 80μrad, the system exhibits a negative SNR.

The simulation results in Fig.3 show that the terahertz communication frequency is higher, the tracking-pointing error of the transmitter has the more serious impact on the SNR of system.

It can be seen from Fig. 4 that when there is no tracking-pointing error, the SNR of the system increases with the increase of the frequency.When there is tracking-pointing error, the SNR of the system still shows an increasing trend at the low frequency.Nevertheless, with the frequency increasing, the SNR of the system does not increase and changes the downward trend. What's more, the greater the tracking-pointing error of the transmitter is, the more obvious the trend is.When the tracking-pointing error of the transmitter is 15μrad, the SNR of system starts to decrease behind 20THz. When the tracking-pointing errors of the transmitter are respectively 20, 25, 30μrad, the SNR of system starts to decrease at about 10THz.

The simulation results in Fig.4 show that the effect of communication frequency on the SNR is different in the different tracking-pointing error of the transmitter.When there is no tracking-pointing error,the increase of communication frequency can improve the SNR of the system.When there is tracking-pointing error and it increases to 15μrad or more, the increase of communication frequency does not always improve the SNR of the system. Although the frequency increases to 10THz or more, the SNR of the system decreases.

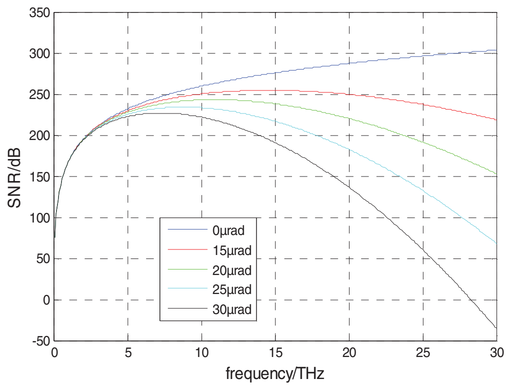


Fig.4 Relationship between the SNR and the frequency in different tracking-pointing errors of the transmitter

IV. THE INFLUENCE OF SATELLITE PLATFORM VIBRATION ON THE SYSTEM

The vibration of the satellite platform is mainly caused by the noise generated by the elecyro-optical tracking device and the mechanical vibration of the satellite [8]. According to the ESA spatial measurements of the satellite platform's vibration in the early 1990s, the mechanical vibration of the satellite platform caused by the stretching of solar panels is similar to the triangular wave vibration, and its vibration form is more regular, while the mechanical vibration of the satellite platform is caused by the propeller ignition, whose vibration form is more complex, but similar to the combination of some simple vibration such as sine wave vibration, triangular wave vibration, sawtooth vibration, and square wave vibration. Though the vibration of the satellite platform is complex, it can be approximately seen as several simple vibrations or their combinations. This section will analyze the influence of the platform vibration on the spaceborne terahertz communication system through studying several simple vibrations.

According to the NDSAT orbit measurement vibration data provided by the United States NASA/GSFC, the satellite vibration spectrum expands from low frequency to high frequency (about 125Hz), and at 1Hz the solar array drive will produce 100μrad vibration, and the satellite reaction wheel's fundamental wave and second harmonics will produce 100Hz, 4μrad and 200Hz, 0.6μrad vibration. The whole vibration stochastic model is composed of continuous vibration power spectrum and three harmonic vibration components [9, 10]. To this end, assuming that the satellite platform's vibration rule in the direction of communication beam angular is:

$$q_1 = 100\sin(2\pi t) \tag{7}$$

The fundamental wave and the second harmonics of the satellite reaction wheel are:

$$q_2 + q_3 = 4\sin(200\pi t) + 0.6\sin(400\pi t) \tag{8}$$

Figure 5 is a schematic diagram which shows the system SNR changing with the frequency and the vibration of the satellite platform when the inter-satellite distance d is 100 km, the antenna effective aperture D_a is 0.3 m, and the antenna efficiency is 0.55.

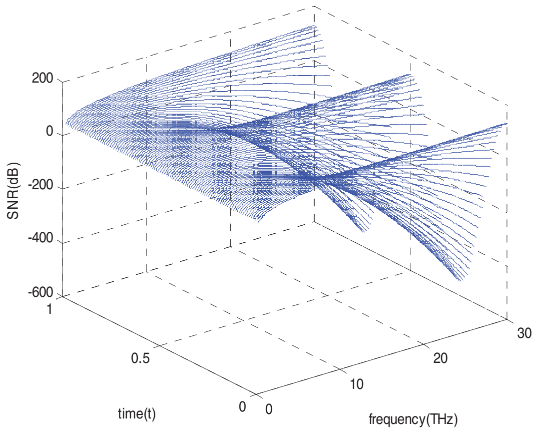


Fig.5 Influence of sinusoidal vibration and communication frequency on signal to noise ratio of the system

From this figure, it can be seen that the system's SNR is proportional to the frequency, that is, the SNR gradually increases with the frequency increasing. At the same time, the system SNR is changing periodically with the vibration of the satellite platform, and the periodic change is more and more significant as the frequency increases.

In addition, it can be found that the changing trend of the system SNR with the frequency while the platform is vibrating is as followed: the signal-to-noise ratio of the low frequency band increases obviously, but as the frequency increases, the rising trend in the high frequency band becomes slow and the change is not significant; the vibration of the satellite platform has little influence on the 0.34THz inter-satellite communication, but this influence on the 1.5 THz and above inter-satellite communication becomes larger and can't be neglected. In practical application, though the design of the communication system keeps every parameter in accordance with the requirements of the system on the signal to noise ratio or bit error rate, it only can meet the system needs sometimes, not always, and can't work continuously. Meanwhile, it will cause a great waste of resource, and will easily cause other interference, which can affect the received signal.

When the platform is vibrating, the numerical changes of the system signal to noise ratio is shown in Fig. 6, at this time, the communication frequency f is 0.34THz, antenna size D_a is 0.6m, distance d is 100km. It can be seen that when the satellite platform is in the sinusoidal vibration, the system's signal to noise ratio is smaller than no vibration.

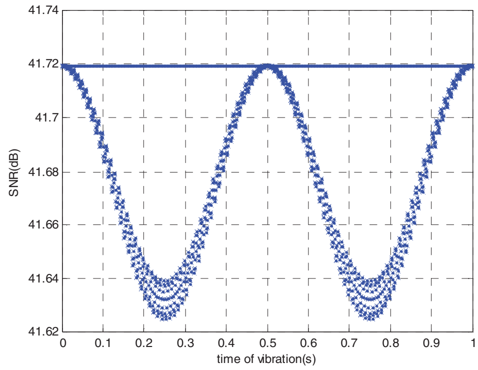


Fig.6 Relationship between system platform vibration and SNR

Figure 7 shows the relationship between the vibration of the system platform under different antenna diameters and signal-to-noise ratio. At this time, the communication frequency f is 1.5THz, and the distance d is 100km. It can be seen that when the satellite platform is vibrating, the larger the effective antenna diameter D_a is, the higher the signal-to-noise ratio of the system is; the change of the signal-to-noise ratio of the system is not only related to the frequency but also increasing with the expanding of effective antenna diameter; the bigger the D_a is, the greater the SNR fluctuation is, and when D_a is 3m, the maximum value of the amplitude differs by 150 dB or more from the minimum value.

The simulation results show that the vibration of the satellite platform has little effect on 0.34THz inter-satellite terahertz communication, and the influence on 1.5 THz and above interstellar communication becomes larger, and the vibration of the transmitter is the most important factor. In the same vibration amplitude, the higher the communication frequency is, the greater the change of system SNR is; the signal-to-noise ratio of the system changes cyclically with the vibration of the satellite platform, and the periodic variation is becoming more and more significant as the frequency increases, and the change form is directly related to the vibration rule.

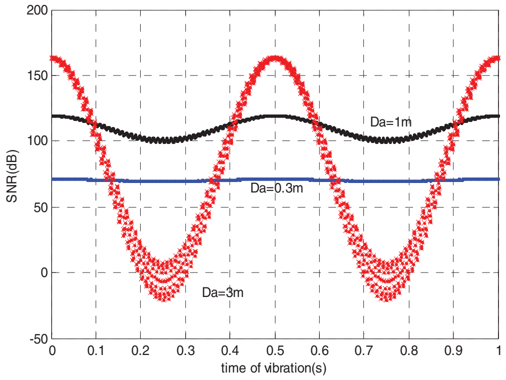


Fig.7 Relationship between system vibration and SNR under different aperture antennas

V. CONCLUSION

In order to achieve high-speed, large-capacity and long-distance inter-satellite terahertz communication, the system needs high-gain antenna and high-power transmission, and also needs APT technology protection. Based on the application of inter-satellite terahertz communication, combining with the developing situation of the current high-gain antenna technology, the APT technology requirements of the inter-satellite terahertz communication system is analyzed, and the transmitting and receiving tracking-pointing error of the system is discussed by the simulate calculation, it is found that the transmitting tracking-pointing error mainly affect the received power of the system, while the receiving tracking-pointing error is almost no impact; with the increase of the transmitting tracking-pointing error, the received signal power of the system gradually decreases; for the same tracking-pointing error, the higher the terahertz wave frequency is, the greater influence on the system's signal-to-noise ratio the transmitting tracking-pointing error cause, and at this time, the slight vibration of the satellite platform may have a great impact on the system, and the requirements of the terahertz communication on APT technology are also becoming higher.

In this paper, the influence of the satellite platform vibration on the terahertz communication is analyzed. It is concluded that the vibration of the platform has little effect on the signal-to-noise ratio when the frequency is 0.34THz, but this influence will be increasing when the frequency increases to 1.5 THz and above. In the same platform vibration amplitude, the higher the communication frequency is, the greater the change of system SNR is the signal-to-noise ratio of the system changes periodically with the vibration of the satellite platform, and the periodic variation is becoming more and more significant as the frequency increases, and the change form is directly related to the vibration rule of the platform.

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