Analysis of THz space communication link based on STK

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Abstract: The characteristics of terahertz communication technology, such as large capacity, high speed and high security, make it stand out among many wireless communication technologies. For future space communication application scenarios, the link performance and beam pointing accuracy of the terahertz communication system were analyzed. The beam adjustment angular acceleration index were analyzed through STK.

1. Introduction
Terahertz usually refers to electromagnetic waves with a frequency in the range of 0.1THz~10THz, and the wavelength range is 0.03mm~3mm. The special position on the electromagnetic spectrum and the special physical properties that it possesses make terahertz technology unique in the field of communications[1-5]. At present, research on terahertz technology is mainly concentrated on devices[6-8], ground applications[9]. In terms of space communications, the International Telecommunication Union has reserved resources near the 200 GHZ frequency band for the next step of satellite communications[10]. With the further development of satellite communications, there is a tendency to enter the communication range above 300 GHz. Because the terahertz beam is narrow, its beam adjustment angular acceleration index will affect the performance of the inter-satellite link. Therefore, this article carried out link analysis for the GEO-LEO communication scenarios, and proposed pointing accuracy indicators. The STK software was used to analyze the beam adjustment angular velocity and angular acceleration indicators of the low and high orbit satellites. A theoretical basis was provided for the future terahertz inter-satellite link beam indicators.

2. THz space communication link analysis
In terms of frequency band selection, according to China’s 2019 "Regulations of the People’s Republic of China on Wireless Point Frequency Allocation", the highest frequency band that can be used for inter-satellite communication is 191.8~200GHz[11]. This study set the communication frequency band as the current highest frequency 200GHz.

In terms of system selection, at present, terahertz technology has formed a parallel development trend of three types of terahertz systems: photoelectric combination method, all-solid-state electronics method and laser direct modulation method[12-14]. The all-solid-state electronics terahertz communication system has the advantages of high integration and does not rely on high-precision optical devices. At present, there is a lot of research on all-electronic terahertz systems. Due to the characteristics of space communication, it is closer to the all-electronic system. This article chose the all-solid-state electronics system as the research object.

In terms of application scenarios, space communication application scenarios can be divided into satellite-ground communication and inter-satellite communication. Because the absorption and
scattering of water vapor and oxygen have a great impact on THz waves[15], and the current terahertz radiation power is limited, this research focused on the application of terahertz communication technology to inter-satellite communication scenarios. In inter-satellite communication, there are mainly six communication links: GEO-GEO, LEO-LEO, MEO-MEO, GEO-MEO, MEO-LEO and GEO-LEO. Because the relative position and angular velocity dynamic range between low and high orbit satellites are relatively large, this research was aimed at the analysis of GEO-LEO.

In order to meet the requirements of high-speed inter-satellite communication in the future, a 200GHz communication system was designed according to the development status of existing system devices in THz [16]. Table 1 summarized the specific parameters of the designed system.

| Parameter                          | Value   | Parameter                          | Value   |
|------------------------------------|---------|------------------------------------|---------|
| Frequency (GHz)                    | 200     | Feeder thermodynamic temperature (K)| 290     |
| Bandwidth (GHz)                    | 10      | Equivalent input noise temperature (K)| 1100    |
| Distance (km)                      | 45871.58| Mixer conversion loss (dB)         | 10      |
| Antenna diameter (m)               | 1       | Amplifier gain (dB)                | 35      |
| Antenna efficiency                 | 0.55    | LNA noise temperature (K)          | 50      |
| Antenna feeder loss (dB)           | 1       | Polar loss (dB)                    | 2       |
| Transmit power (dBW)               | -10     | Boltzmann constant (dB)            | -228.6  |
| Receiver noise figure (dB)         | 1       | Modulation mode                    | BPSK    |

Table 1. Specific parameters of the design system

Through the link analysis algorithm, without considering the pointing error, it can be concluded that the SNR of the system at the farthest inter-satellite distance of 45871.58km in a specific scenario is 15.79dB, which meets the BER requirement of $1 \times 10^{-6}$. However, due to the perturbation force in the space orbit in practical applications, the influence of the pointing error loss on the link is inevitable. Therefore, it is necessary to analyze the influence of the pointing error on the link performance.

Pointing error loss refers to the loss caused by the direction of the maximum gain of the transmitting antenna beam that is not aligned with the target. Due to the operation of the spacecraft and the tracking accuracy of the antenna tracking system, the antenna pointing often deviates from the theoretical direction, causing a certain pointing error. The general pointing error is:

$$L_T = L_R = \exp \left( 2.77 \left( \frac{\theta_T}{\theta_{3dB}} \right)^2 \right)$$

(1)

$\theta_{3dB} = 70 \left( \frac{\lambda}{B} \right)$ is the 3dB bandwidth of the parabolic antenna beam, $\theta_T$ is Pointing error.

Introduce the influence of pointing error into the above system and analyze it. As shown in Figure 1, the pointing error from 0 to 0.3° causes a huge change in the SNR. Only when the pointing accuracy is less than 0.078° can the SNR meet the BER requirement. It can be seen that the space terahertz communication link has relatively strict requirements on the pointing accuracy of the terahertz wave.
3. **STK simulation example**

Satellite tool software STK is an advanced system analysis software in the aerospace field, used to analyze complex land, ocean, aviation and aerospace missions[17]. It can provide realistic two-dimensional, three-dimensional visual dynamic scenes and accurate charts, reports and other analysis results.

In inter-satellite communications, the acquisition and tracking of terahertz beams will affect the performance of terahertz communications. In order to explore the beam pointing requirements of the satellite servo system in space terahertz applications, this paper used STK to simulate the GEO-LEO link model in terahertz space application scenarios, and analyzed the GEO satellite antenna beam adjustment angular velocity and angular acceleration. The scene parameters are set as follows: the scene time is from 4:00:00 on April 27, 2021 to 4:00:00 on April 28, 2021, and the orbit model adopts the HPOP high-precision orbit prediction model. The parameter settings of the two satellites are shown in Table 2.

![Graph of pointing error vs. SNR](image)

**Figure 1. The relationship between pointing error and SNR**

| Orbital elements         | LEO        | GEO        |
|--------------------------|------------|------------|
| Semimajor axis α(km)    | 7626.14    | 42166.3    |
| Eccentricity e           | 1.01037e-15| 7.0006e-16 |
| Inclination Ι(deg)       | 37         | 9.48783e-16|
| RAAN Ω(deg)              | 0          | 0          |
| Argument of Perigee ω(deg)| 0          | 0          |
| Mean Anomaly (deg)       | 1.44952e-17| 161.444    |

**Table 2. GEO and LEO satellite parameters (see Figure 2 for interpretation)**
The changes of GEO to LEO beam's azimuth angle $\alpha$, elevation angle $\beta$ and angular velocity were analyzed through Report & Graph Tools, as shown in Figure 3.

![Figure 2. GEO-LEO orbit model](image)

The first-order derivative of the angular velocity data with respect to time can be used to obtain the beam angular acceleration index, as shown in Figure 4.

![Figure 3. GEO-LEO beam azimuth and elevation angle and their angular velocity](image)

(a) Changes in Azimuth  
(b) Changes in Elevation  
(c) Changes in Azimuth rate  
(d) Changes in Elevation rate
The simulation data shows that the beam azimuth acceleration of GEO to LEO is between $-4.555 \times 10^{-4}$ to $0.072 \text{deg} \cdot \text{s}^{-2}$, and the elevation angle velocity is between $-0.03308$ to $0.64028 \text{deg} \cdot \text{s}^{-2}$. Due to the lack of a suitable flexible connection structure, the current terahertz system transceiver channel and the antenna are rigidly connected. The disadvantages of large servo system load, high impulse required, and slow response of the steering mechanism make the beam adjustment angular acceleration put forward higher requirements on GEO's satellite antenna pointing. In the future, it can be considered to seek breakthroughs from the lightweight scanning mechanism[18], terahertz phased array antenna[19], etc. At present, extensive research has been carried out on these key technologies.

4. Conclusion
Terahertz's special position on the electromagnetic spectrum and its special physical properties make it of great application value in the field of space communication. This paper designed a 200GHz space terahertz communication system and analyzed its space link performance. In addition, STK was used to analyze the beam changes in a specific scene. According to the analysis, the terahertz beam is narrow, and the requirements for the acquisition and tracking performance of the satellite antenna are relatively strict.

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