Frontiers in Computing and Intelligent Systems
ISSN: 2832-6024 | Vol. 8, No. 1, 2024

Research on Atmospheric Attenuation Compensation Technology of High-Frequency Band Microwave in Long-Distance Transmission

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Abstract: With the rapid development of wireless communication technology, high-frequency band microwaves (e.g., millimeter-wave and terahertz wave) show great potential in the field of high-speed data transmission due to their huge bandwidth resources. However, high-frequency band microwaves are seriously affected by atmospheric attenuation during transmission, especially at long distances, and this attenuation significantly reduces the signal strength and quality. Therefore, the study of accurate modeling of atmospheric attenuation as well as effective compensation techniques is crucial for improving the performance of long-distance transmission of high-frequency band microwaves.

Keywords: High-band Microwave; Long-distance Transmission; Atmospheric Attenuation; Compensation.

1. Context

High-frequency band microwave occupies an important position in the field of communication with its high bandwidth and high speed. It effectively alleviates the tension of spectrum resources, meets the demand for high-speed services such as high-definition video and big data transmission, and promotes the rapid development of wireless communication technology.

High-frequency band microwave faces the serious challenge of atmospheric attenuation during long-distance transmission. Atmospheric gas molecules, water vapor, raindrops and other particles on the microwave signal absorption and scattering effect, resulting in signal energy with the distance gradually weakened. This attenuation is affected by multiple factors such as weather, season, altitude, etc., which not only reduces the signal strength, but also may introduce noise and interference, seriously affecting the communication quality.

An in-depth study of the accurate modeling and effective compensation techniques for the atmospheric attenuation of high-frequency band microwaves [1]is crucial for enhancing the performance of long-distance transmission. Through the development of new compensation methods, it is expected to provide strong support for the reliable transmission of high-frequency band microwave and promote the continuous progress of communication technology.

Based on this, the purpose of this paper is to analyze the different factors leading to the atmospheric attenuation encountered in microwave long-distance transmission, to analyze the degree of influence under different factors, and to explore the future direction of microwave long-distance transmission compensation technology.

2. Atmospheric Attenuation Mechanism and Impact Analysis

In communication engineering, atmospheric attenuation [2] is a physical process that cannot be ignored, and it is directly related to the quality and efficiency of high-frequency band microwave signals in long-distance transmission. Atmospheric attenuation is mainly caused by the absorption and scattering effects of atmospheric components on electromagnetic waves [5], and these effects lead to the gradual loss of electromagnetic wave energy in the propagation process.

Absorption occurs mainly when specific atmospheric components match the frequency of the electromagnetic wave. For example, water vapor, oxygen, and ozone have a strong absorption capacity for certain frequency bands of microwaves, which results in significant energy loss of microwave signals in these bands as they propagate through the atmosphere.

Scattering is caused by the irregular reflection and refraction of electromagnetic waves by particles in the atmosphere (e.g. aerosols, water droplets, ice crystals, etc.). The size, shape and concentration of these particles affect the strength of the scattering and hence the propagation characteristics of the electromagnetic waves.

The degree of atmospheric attenuation[3] is also affected by other factors such as the length of the transmission path, meteorological conditions, and the composition of gases and aerosols in the atmosphere. Longer transmission paths mean that electromagnetic waves need to pass through more layers of the atmosphere, thus increasing the likelihood of attenuation. Changes in meteorological conditions such as temperature, humidity and barometric pressure also affect the state and distribution of atmospheric constituents, which in turn affects the degree of attenuation.

For high-frequency band microwave signals, they are more susceptible to atmospheric attenuation due to their shorter wavelength. This attenuation not only leads to a reduction in signal strength, but also may introduce noise and interference, affecting the quality and stability of signal transmission. Therefore, in the high-frequency band microwave communication system, it is necessary to pay special attention to the impact of atmospheric attenuation and take corresponding compensation measures to reduce its impact.

3. Example of Atmospheric Attenuation Experiment

The moisture content of the atmosphere has a significant effect on the attenuation of microwaves in the higher frequency bands. The presence of water vapor leads to increased absorption of microwave signals, especially in some specific frequency bands. The degree of attenuation of microwave signals increases significantly in environments with high humidity. The exact amount of attenuation depends on the amount of humidity and the frequency of the microwave signal.

The following are comparative test data on microwave attenuation by rainwater for which experiments have been conducted:

Table 1. Attenuation experimental data

Frequency band	28 GHz
Distance	10Km
Climatic conditions	clear
Temperature	25°C
Humidity	50%
Atmospheric pressure	Standard

The equipment's used in this experiment are the market common high-frequency band microwave transmitter, high-frequency band microwave receiver, and signal power measurement equipment. After testing, the results are as follows:

Table 2. Attenuation experimental data

Radiant power	**100mW**
Receiving power	75mW
Atmospheric attenuation decibels	2.32 dB

From the experimental data, it can be seen that the total attenuation for this experiment is 2.32dB at a distance of 10KM and in a clear weather condition.

The decibel value of attenuation (dB) is a unit of measure used to quantify the loss of signal strength. In communications and signal processing, the decibel value provides a convenient way to compare and characterize the degree of signal attenuation under different conditions.

The decibel value is defined based on the logarithmic scale, which represents the logarithm of the ratio of two powers or intensities. Specifically, if P1 and P2 represent the signal power at two different points, then the decibel value of attenuation (A) can be expressed by the following equation:

$$A = 10 * \log10(P1 / P2) \quad (1)$$

Where log10 represents a logarithmic operation with a base of 10. This formula tells us that the decibel value of attenuation is 10 times the logarithm of the ratio of the original signal power (P1) to the attenuated signal power (P2).

The advantage of decibel value is that it can compress a wide range of power variations into a smaller range of values, making comparisons and descriptions more intuitive and easier. For example, a 3 dB attenuation means that the signal power is reduced by half (since $10^{(3/10)} \approx 0.5$), while a 10 dB attenuation means that the signal power is reduced to one-tenth of its original value (since $10^{(10/10)} = 0.1$).

Below are the experimental data under rainfall conditions:

Table 3. Attenuation experimental data

Frequency band	28 GHz
Distance	5Km
Climatic conditions	Light rain (rainfall rate of 2 mm/h)
Temperature	20°C
Humidity	80%
Atmospheric pressure	Standard

Table 4. Attenuation experimental data

Radiant power	**100mW**
Receiving power	75mW
Atmospheric attenuation decibels	8.68 dB

Based on the above experimental data, it can be seen that the atmospheric attenuation is significantly enhanced under rainy conditions[4]. Compared with the attenuation under clear weather, the atmospheric attenuation under light rain increased by about 6 dB or so. This is mainly due to the strong absorption and scattering effect of rain on the microwave signal, resulting in a significant loss of signal energy. According to the definition of decibel value, 8.68 dB attenuation, the basic signal attenuation is about 80%, the signal attenuation is very serious, basically does not meet the basic requirements of continuous data transmission.

4. Conclusion

The atmospheric attenuation problem faced by high-frequency band microwaves in long-distance transmission has always been a research hotpot and difficulty in the field of wireless communication. Especially under precipitation conditions, atmospheric attenuation poses a serious challenge to the transmission efficiency and stability of microwave signals. In terms of mechanism research, this paper focuses on analyzing the atmospheric attenuation characteristics of microwave signals under precipitation weather conditions, revealing that the scattering and absorption effects of raindrops on microwave signals under precipitation conditions lead to significant signal attenuation.

By optimizing the transmit power and modulation method, the anti-interference ability and transmission distance of the signal can be improved. Meanwhile, with the help of advanced signal processing techniques and algorithms, such as adaptive equalization and channel coding, the impact of atmospheric attenuation on signal quality can be effectively reduced. In addition, the application of MIMO technology and beam fouling technology in microwave signal transmission further improves the efficiency and stability of signal transmission. The atmospheric attenuation compensation technology of high-frequency band microwave in long-distance transmission will continue to develop with the continuous progress of artificial intelligence, machine learning and other technologies, and is expected to realize intelligent prediction and adaptive compensation of atmospheric attenuation in the future. This will provide a more reliable and efficient data transmission solution for the field of wireless communication and promote the further development and application of wireless microwave data transmission technology.

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