The study on THz wave propagation feature in atmosphere

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Abstract. THz wave has many applications, such as space communication, Earth environment observation, atmosphere science, remote sensing and so on. The atmospheric propagation of terahertz waves now rank among the most critical issues in the societal implementation of terahertz technology. In this paper we introduce the constitution of THz wave atmosphere propagation system, decay, then analyze the decay, turbulent and enhancement effects about THz wave atmosphere propagation, then carry out atmospheric propagation measurement system based on THz-TDS.

1. Importance of terahertz-wave propagation in atmosphere
Terahertz (THz) region (0.1-10 THz; 3mm-30um) plays important role for the Earth’s radiation budget, the atmospheric transmittance of terahertz waves now rank among the most critical issues in the societal implementation of terahertz technology[1]. THz atmospheric propagation technology is expected to open new opportunities for the accurate prediction of the natural disaster, such as localized torrential rain and extraordinarily heavy snowfall.due to the climate change, THz atmospheric technology is suitable to observe humidity, ice cloud, and the temperature simultaneously with high spatial resolution. Despite its importance, due to the difficulty of generating and detecting waves in this region, we did not yet reach a good understanding of the behaviour of THz-wave in the atmosphere. Moreover, there still exist large difficulties in developing appropriate observation technology for THz-wave[2].

2. THz wave atmosphere propagation system
THz wave atmosphere propagation system includes emission, propagation, detector, amplifier and processing systems(Fig.1).
THz propagation is an important application technology, THz wave has a very wide unallocated band, which transfer rate is high, direction is good, and security is high, and diffused antlers is small. In the 90's, because of lacking effective THz source and detection technology, people's knowledge on THz is very limited, so called "unexplored" range between visible light and radio wave. Recently, with the reliable source and detection technology developing, THz will be used to short distance, wireline and wireless communication. In communication and propagation, THz wave transmission is a bond, which associates wave THz launch and receiving two parts, it is of vital importance on the whole THz applications. During propagation, various media and amplifier technologies can be adopted to overcome the absorption, for example, water absorption.

3. THz wave atmosphere propagation effects

There are three main effects in THz wave atmosphere propagation, including decay, turbulent and enhancement effects.

3.1 The decay effect of THz propagation in atmospheric

3.1.1 Absorption process about THz propagation in atmospheric

About the THz radiation, the absorption and the scattering are the basic decay effects in atmosphere propagation. When THz radiation goes through atmosphere, its total or part energy transfer to the atmosphere, this process is called absorption. Some terahertz wave-lengths can be used for communications between locations separated several hundred kilometers on the ground, other terahertz waves propagate less than 1m due to significant, it is essential to know the applicable attenuation characteristics under different atmospheric condition.

Atmospheric absorption of THz waves is commonly divided into two components. One is the line contribution, which arises mainly from the resonance absorption of water vapour in atmosphere. One of the absorption line is comprised mostly of the absorption lines of water vapour present in air. The absorption lines of water vapour are characterized by spectroscopic parameters, including the center frequency of the absorption line, oscillator intensity, and the pressure broadening coefficient. These spectroscopic parameters are generally determined through precise, careful measurement in laboratory experiments. Common spectrum parameter in the atmosphere may find in existing database (for instance JPL, GEISA database, HITRAN and so on), at present the most commonly used database is HITRAN the database. With the spectrum parameter precision's developing, the atmospheric propagation model's accuracy will enhance.

The other component of atmospheric absorption is the "continuum absorption" (Fig.2), which in practice is defined as the excess of absorption unaccounted for by the resonance water vapour spectrum. The major contribution to the THz-wave propagation is in total the water vapour lines and their wing absorption. It is well known that the results of simulation under the assumption that the atmospheric absorption spectrum corresponds to the accumulation of water vapour absorption lines do not agree with experimental observation of atmospheric absorption. Continuum absorption cannot be described by water vapour absorption lined and it may be observed in very wide electromagnetism wave frequency scope (from microwave to infrared).
Absorption coefficients strongly depend on pressure broadening of water vapour lines, which is caused by collision between a water molecule itself and the other atmospheric molecule like $\text{N}_2$, $\text{O}_3$, or $\text{H}_2\text{O}$. In Fig. 1 atmospheric $\text{H}_2\text{O}$ line-by-line and continuum absorption coefficients calculated on the basis of several spectroscopic models are shown. It demonstrates that there are significant discrepancies among the models. One of the reasons of the discrepancy is due to the small number of laboratory spectroscopic measurements made so far. The accuracy of atmospheric parameters derived based on the model directly depends on the accuracy of the spectroscopic parameters$^8$.

But so far, we can not solve completely the continuous absorption physical machine-made question. The water vapour continuous absorption is the biggest question in THz radiation. Until now people find three kinds theories, which can explained the water vapour continuous absorption: Far wing absorption, collision induced absorption and double syndrome absorption. The corresponding processing method includes: CKD$^9$ continuous absorption method; M&T continuous absorption theory method; MT-CKD continuous absorption theory; Semiempirical processing methods and so on. Without a doubt, the water vapour continuous absorption originates interaction between the syndrome, but how to describe these interactions, is still the question which waits for solving. We must have experimental data to verify these predictions. At same time, we can adopt various media and amplify technologies to overcome the absorption shortcoming in space applications.

3.1.2 Scattering process about THz propagation in atmospheric

It is well known, scatters including the Rayleigh scattering and the Mie scattering. To THz wave band, because its wave length is much bigger than the wave length of visible light and the ultraviolet ray, therefore in general we do not consider the Rayleigh scattering$^{10}$. During THz propagation process, the main scattering granule are aerosol and the water vapour coagulum. The aerosol (refers to multi-disperse systems from small granule constitution) and the water vapour coagulum (cloud, rain, snow and so on). Aerosol radiative transfer is a difficulty question because of its big change in the space and time. The criterion distribution is an important concept in describing aerosol, the different criterion's granule has different scattering wave length. At present, the aerosol criterion spectrum pattern commonly include$^{11}$:

1) Revision spectrum:

$$\frac{dN(r)}{dr} = ar^\alpha \exp(-b^\gamma)$$

(1)

Where $N$ is granule number in the unit volume, $r$ is the radius of particle, $a$, $b$, Alpha, Gamma is the constant which depends the resource. But the origin of aerosol can be divided into: Mainland (Haze L), sea (Haze M) and high stereotype (Haze H)$^{12}$.
2) Junge spectrum

\[ \frac{dN}{d \log r} = cr^{-v} \]

In the formula (2), \( v \) is the spectrum parameter, \( v \) takes 2~4, \( c \) related to the total density in general.

3.2 The turbulent effect of THZ propagation in atmospheric

The atmospheric physical property is dissimilar in different position and different height. Even if at one place, the property can have the change with different time. The turbulent motion is the most important characteristic usually, the turbulent motion causes the atmospheric refractive index to fluctuate stochastic \[^{[13]}\].

The atmospheric turbulent cause the atmospheric refractive index to fluctuate unceasingly, thus causes the THz wave amplitude and the phase to fluctuate stochastic, so the THz beam will twinkle, curve, fission, expand, polarization condition will fluctuate \[^{[14]}\], even the spatial coherence is reduced and so on.

The influence may divide into three kinds according to the turbulent criterion: When the turbulent criterion is bigger than the THz beam diameter, the THz beam deflects stochastic, causing THz beam drifting on receiving end\[^{[15]}\]; When the turbulent criterion is equal to the THz beam diameter nearly, the light beam will also have the deflection stochastic, main performance is arrival angle fluctuating, image point vibrating \[^{[16]}\]; When the turbulent criterion is smaller than the THz beam diameter, the light beam has the diffraction, the coherence character dropping, the main performance is expanding, the luminous intensity fluctuating and the luminous intensity reducing. The atmospheric turbulent has critical affection to THz wave propagation, this will also be our research direction later.

3.3 The enhancement effect of THz propagation in atmospheric

Atmospheric and the THz radiation interact during THz wave propagation in atmospheric, it will experience the enhancement process. Usually we introduce the source function \( J \) item to describe THz radiation enhancement. The scattering and the heat radiation cause the enhancement. These two machine relative importances depend on the difference wave length . The expression of source function \( J \) is defined:

\[ J = J_B + J_{SS} + J_{MS} \]

\( J_B \) described the heat radiation, the definition as follows\[^{[17]}\]:

\[ J_B = (1 - \omega_0)B(T) \]

Where \( B \) is the Planck function, represents blackbody heat radiation at temperature \( T \). The mono frequent Planck function can be written:

\[ B_v(T) = \frac{2hv^3c^2}{e^{hv/kT} - 1} \]

Where \( \nu \) is a wave number, \( c \) is the speed of light, \( k \) and \( h \) on behalf of the Boezriman constant and the Planck constant separately

\( J_{SS} \) comes from the source (e.g.: Sun) sole scattering on direct radiation condition

\[ J_{SS} = \omega_0 \frac{1}{4\pi} P(\Theta)F^\theta T^\theta \]
Where $P$ is the phase function, $F_\Theta$ represents sun radiance from the exterior land, $F_\Theta = \exp(-\tau_\Theta)$ is transmissibility on condition of the crown atmosphere to the scattering perpendicular way\textsuperscript{[18]}, $\omega_0$ is the sole scattering albedo:

$$\omega_0 = \frac{\beta_{sp}^{par}}{\beta_s + \beta_a^{par} + \beta_s^mol}$$  \hspace{1cm} (7)

$s$ and $a$ is the scattering and the absorption coefficient, the superscript “mol” and “par” represents molecular and the granule material characteristics.

$J_{MS}$ item of multiple scattering source comes from multiple scattering radiative\textsuperscript{[19]}

$$J_{MS} = \omega_0 \frac{1}{4\pi} \int_0^{4\pi} P(\Theta) I(\Omega') d\Omega'$$  \hspace{1cm} (8)

Where $I(\cdot)$ represents the incident scattering radiation field.

4. Atmospheric propagation measurement scheme based on THz-TDS

THz-TDS spectroscopic system includes Pumping laser, optical delay, THz emitter, detector sample, THz detector locking-amplifier and computer, and so on. Sub-ps THz pulse penetrate sample, the detector receive the signal after free space propagation. THz-TDS is a pulsed terahertz wave to the sample, measures the time variation of the electric field of the transmitted wave, and obtains the amplitude magnitude and phase information of the electric field of the terahertz wave at each wavelength by Fourier transformation(\textsuperscript{[20]}). The time-domain spectrum measured transform Fourier transformed into a frequency spectrum and then modified to an absorbency spectrum using the background spectrum measured directly prior to the main measurement.

Fig.3 THz-TDS spectroscopic system

Fig.4\textsuperscript{[20]} shows the measurement results of atmosphere propagation characteristics based on THz-TDS, the time-domain spectrum and frequency spectrum by Fourier transformation, as an spectroscopic parameters required to construct an appropriate model.
4. Conclusion

Terahertz (THz) radiation is extensively applied in diverse fields, such as space communication, earth environment observation, atmosphere science, remote sensing and so on. And the research on propagation features of THz wave in the atmosphere becomes more and more important. In this paper we introduce the constitution of THz wave atmosphere propagation system, decay, then analyze the decay, turbulent and enhancement effects about THz wave atmosphere propagation, then carry out atmospheric propagation measurement system based on THz-TDS.

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