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Echo-wave scattering characteristics of the diffuse target in the slant atmospheric turbulence

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ABSTRACT

The extended Huygens–Fresnel principle is utilized to make analysis of the received intensity for laser beam propagation through the atmospheric turbulence in the slant path. For a diffuse target, the effects of the turbulence on the statistical parameters such as the mutual coherence function and the mean intensity are studied in detail. The influence of the incident wave radius and the distance of the incident beam on these parameters are discussed.

1. Introduction

Optical wave propagation in random media, in addition to the random distribution of discrete scattering, is the most important which is affected by random medium refractive index of continuous transformation. When the target, even a simple target, appears in the transmission path, which will greatly influences the random field, then it will appear the speckle phenomenon. So, the influence of atmospheric turbulence on the scattering characteristics of the target in the random medium wave propagation and scattering, target feature extraction and calibration, and radar analysis of signal-to-noise ratio, remote sensing, atmospheric coherent imaging, optical correlation of radar and optical adaptive imaging system has an important significance.

Recently, because of the requirement of atmospheric communication, detection and remote sensing, the characteristics of the laser beam propagation in the slant path become very important. Work on reflection field scattering character by other researchers has primarily been concentrated on the horizontal path [1–5]. There are many correlative researches [6–13] and application of turbulent model. Later, Wei Hong-Yan et al. [14], based on the extended Huygens–Fresnel principle and ITU-R atmospheric turbulence model [15], studied the scattering problem from a diffuse target which is non-glint.

We have utilized the extended Huygens–Fresnel principle to make an analysis of the scattering characteristics of the laser beam propagation through the atmospheric turbulence in the slant path for a diffuse target. This paper discussed the effect of atmospheric turbulence to the field mean intensity, the mutual coherence function, the intensity covariance function and the intensity variance. The treatment includes the effects of the atmospheric turbulence on the laser beam as it propagates to the target and on the scattering field as it propagates back to the receiver. The source, the target and the receiver are assumed to be located in planes transverse to the propagation direction with positions in each plane described by $\vec{r}$, $\vec{\rho}$ and $\vec{p}$, respectively.

The schematic diagram of optical wave transmission through the double path in the atmospheric turbulence is shown as Fig. 1. In Fig. 1, laser beam propagates from the transmitter to the target, and the echo propagates along with the same path back to the receiver. L is the propagation distance in the slant path. H is the vertical distance of the target and the receiver.

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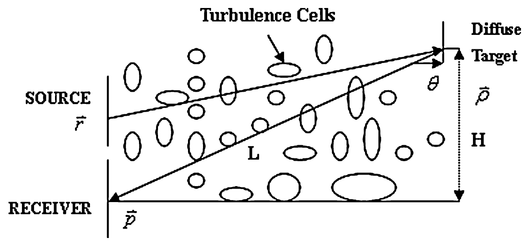

Fig. 1. Schematic diagram for optical wave transmission with double slant path in turbulent atmosphere.

2. The scattering characteristics of the diffuse target in atmospheric turbulence in the slant path

The initial distribution of source field is expressed as

$$u_0(\vec{r}) = \bar{u}_0 \exp\left[-\frac{r^2}{2W_0^2} - \frac{ikr^2}{2F_0}\right] \tag{1}$$

where $\vec{r}$ is the two-dimensional coordinate vector in the transmitter plane, W_0 is the beam characteristic radius, k is the free space wave number and F_0 is the radius of curvature of the wave front. Assuming that the target size is much larger than the beam aperture, and application Huygens–Fresnel principle, the field in the target plane is show that

$$u_i(\vec{\rho}) = \frac{k\,e^{ikL}}{2\pi iL}\int d\vec{r}\,u_0(\vec{r})\exp\left[\frac{ik|\vec{\rho}-\vec{r}|^2}{2L} + \psi_1(\vec{\rho},\vec{r})\right] \tag{2}$$

where $\vec{\rho}$ is the two-dimensional coordinate vector in target plane. $\psi_1(\vec{\rho},\vec{r})$ is random disturbance of spherical wave complex phase when laser beam propagation from transmitter $\vec{r}$ to $(L, \vec{\rho})$ in the target plane. It consists of amplitude disturbance and phase disturbance and can be expressed as

$$\psi_1(\vec{\rho},\vec{r}) = \chi(\vec{\rho},\vec{r}) + iS(\vec{\rho},\vec{r}) \tag{3}$$

Regarding the illuminating target as the source, the field $u_s(\vec{\rho})$ in the target plane, is changing to be source field. The distribution of receiver field $\vec{p}$ is expressed as

$$u_r(\vec{p}) = \frac{k\,e^{ik(L+p^2/2L)}}{2\pi iL}\int d\vec{\rho}\,u_s(\vec{\rho})\exp\left[\frac{ik}{2L}(\rho^2 - 2\vec{p}\cdot\vec{\rho}) + \psi_2(\vec{p},\vec{\rho})\right] \tag{4}$$

The relationship between the incident field $u_i(\vec{\rho})$ and the scattering field $u_s(\vec{\rho})$ in the target plane is expressed by reflection coefficient as

$$u_s(\vec{\rho}) = u_i(\vec{\rho})T(\vec{\rho}) \tag{5}$$

where $T(\vec{\rho})$ shows the target reflected intensity, surface shape and material feature through its amplitude and phase. For pure diffuse target, the coherent component $T_g(\vec{\rho}) \equiv 0$. The statistical properties of incoherent component $T_d(\vec{\rho})$ are shown as [16]

$$\langle T_d(\vec{\rho})\rangle = 0 \tag{6}$$

$$\langle T_d(\vec{\rho}_1)T_d(\vec{\rho}_2)\rangle = 0 \tag{7}$$

$$\langle T_d(\vec{\rho}_1)T_d^*(\vec{\rho}_2)\rangle = \frac{\lambda^2 R_d}{\pi}\delta(\vec{\rho}_1 - \vec{\rho}_2) \tag{8}$$

$$\langle T_d(\vec{\rho}_1)T_d^*(\vec{\rho}_2)T_d(\vec{\rho}_3)T_d^*(\vec{\rho}_4)\rangle = \left(\frac{\lambda^2 R_d}{\pi}\right)^2[\delta(\vec{\rho}_1-\vec{\rho}_2)\delta(\vec{\rho}_3-\vec{\rho}_4) + \delta(\vec{\rho}_1-\vec{\rho}_4)\delta(\vec{\rho}_3-\vec{\rho}_2)] \tag{9}$$

Eqs. (6)–(9) show that the space coherent incident wave scattered by pure diffuse target becomes complete incoherent scattering wave. R_d is the equivalent average reflectivity in diffuse plane. The establishment condition of above equations is that lateral correlation length of incident wave is very larger than correlation distance of the target's rough surface. The second and fourth moments of the target scattering field are expressed by above equations as

$$\langle u_s(\vec{\rho}_1)u_s^*(\vec{\rho}_2)\rangle = \frac{\lambda^2 R_d}{\pi}\langle I_i(\vec{\rho}_2)\rangle\delta(\vec{\rho}_1 - \vec{\rho}_2) \tag{10}$$

$$\langle u_s(\vec{\rho}_1)u_s^*(\vec{\rho}_2)u_s(\vec{\rho}_3)u_s^*(\vec{\rho}_4)\rangle = \left(\frac{\lambda^2 R_d}{\pi}\right)^2[\langle I_i(\vec{\rho}_1)\rangle\langle I_i(\vec{\rho}_3)\rangle\delta(\vec{\rho}_1-\vec{\rho}_3)\delta(\vec{\rho}_3-\vec{\rho}_4) + \langle I_i(\vec{\rho}_4)\rangle \times \langle I_i(\vec{\rho}_2)\rangle\delta(\vec{\rho}_1-\vec{\rho}_4)\delta(\vec{\rho}_3-\vec{\rho}_2)] \tag{11}$$

where $\langle I_i(\vec{\rho}_m)\rangle$ is average intensity of incident wave in the target plane $\vec{\rho}_m$ ($m = 1, 2, 3, 4$).