Backscatter amplification effect for a reflected partially coherent Gaussian beam in turbulent medium

Ning-Jing Xiang\textsuperscript{a,b}, Zhen-Sen Wu\textsuperscript{b,*}, Qiu-Fen Guo\textsuperscript{a}, Ming-Jun Wang\textsuperscript{a}

\textsuperscript{a} School of Science, Xidian University, Xi’an 710071, China
\textsuperscript{b} School of Physics and Electronic Engineering, Xian Yang Normal College, Xianyang 712000, China

\textbf{A R T I C L E I N F O}

\textbf{Article history:}
Received 6 December 2014
Received in revised form
15 April 2015
Accepted 16 April 2015
Available online 4 May 2015

\textbf{Keywords:}
Atmospheric turbulence
Enhanced backscatter
Gaussian Schell-model

\textbf{A B S T R A C T}

The extended Huygens–Fresnel principle is used to develop a formulation for the backscattered intensity enhancement of a Gaussian Schell-model source beam through a weak turbulence. The results are shown that backscattered intensity enhancement factor of the reflected GSM beam is concerned with the coherence length of source, the wavelength, the size of target and wave structure function. In addition, the closed-form expressions can interpret backscattered intensity enhancement of plane and spherical wave scattered from a diffuse target. The results are illustrated by examples and compared with the previous work.

\copyright 2015 Elsevier Ltd. All rights reserved.

1. Introduction

The lidar beam is propagated through the atmospheric turbulence to a target and back through exactly the same atmospheric turbulence, but in the opposite direction, which can lead to an enhancement in the mean irradiance near the optical axis of the return beam. This phenomenon is known as enhanced backscatter (EBS), also called the backscatter amplification effect (BSEE) [1]. For a turbulent medium, the BSE effect was first predicted by Belen’kii and Mironov [2] for an incident spherical wave on a finite specular target. Vinogradov et al. indicated that this increase in the mean irradiance was dependent upon reflection characteristics of the target [3]. Later many researchers have been doing theoretical and experimental work on this topic in U.S.S.R. They have focused on plane, spherical wave reflected by a point scatterer, retroreflective, diffuse target, and mirror for a monostatic lidar [4–8]. A detailed review of the results is presented by Banakh and Mironov which also includes an extensive list of references [9]. Their results are too obsolete to understand physically and an updated review was presented by Barabanenkov et al. [10]. In that follows, Tapster et al. and Welch et al. simulated and analyzed enhanced backscatter by a phase screen [11,12]. Andrews et al. used ABCD matrix to characterize propagation path and develop a model of the target to deal with BSE of the spherical wave and plane wave [1]. For the incident Gaussian beam, they deduce that the size of the diffuse surface can play a significant role on EBS effects. Holmes calculated the enhanced backscattered intensity for a bistatic lidar operating with Gaussian beam and a diffuse target in weak turbulence [13]. His result implies enhancement is due to incoherent perturbation effects. Amzajerdian et al. derived the time-delayed mutual intensity function of echo wave considering the dependent effects of turbulence on outgoing and return paths [14]. Yeh calculated mutual coherence functions and the aperture-averaged intensities of the backscattered signal under the saturated regime [15]. Hung et al. [16] used a linear interpolation method to obtain backscattered intensity enhancement effect in the Fresnel zone. Banakh discussed that the edge diffraction on a reflector has a profound effect on intensity distribution of the reflected...
wave and on the manifestation of backscatter amplification in a regime of weak turbulence[17]. Gurvich proposes scheme of a lidar for BSE measurement. With the use of models it is shown that regions of increased turbulence can be detected with such a lidar [18]. In 2013, Banakh analyzed the backscattered radiation mean power enhancement in a strong turbulent atmosphere and Smalikho proposed a numerical simulation-based algorithm. Using this algorithm, the BSA coefficient is analyzed for different conditions of laser radiation propagation in the atmosphere [19,20].

Recently, much work demonstrates that the partially coherent beams are less sensitive to the effects of turbulence than fully coherent ones [21–23]. As yet, only a few papers deal with EBS effect of partially coherent beam reflected by a target. Most papers discuss average intensity and beam size of different types of partially coherent propagating through the turbulence. Xiang and Wu et al. discussed statistic of a partially coherent Gaussian–Schell beam reflected from a diffuse target in turbulence. They took into account the fluctuations of log-amplitude and phase neglecting the correlation of forward and backward scattering channel [24,25].

In this paper, we extend our analysis to the more practical case of finite-size object defined by Gaussian reflectivity function. Using the extended Huygens–Fresnel formulation and reciprocity principle, we develop a formulation for the backscattered intensity of the reflected GSM beam propagating through double-passage turbulence. We studied the effect of target size on backscattered enhancement effect and compared enhancement factor of the partially coherent beam with that of the Gaussian beam. The main results are illustrated by numerical examples and interpreted physically.

2. Statement of the problem

Let the single-mode amplitude distribution \( u_0(\mathbf{r}) \) be the same as that of a single-mode collimated Gaussian beam

\[
\begin{align*}
\Delta u_0(\mathbf{r}) &= \Delta u_0 \exp \left[ -\frac{r^2}{w_0^2} - \frac{ikr^2}{2F} \right] \\
\end{align*}
\]

where \( w_0 \) and \( F \) are the characteristic beam radius and focal length, respectively. \( \mathbf{r} = (x^2 + y^2)^{1/2}, \mathbf{r} = (x, y) \) denotes a two-dimensional transverse vector perpendicular to the direction of the beam propagation in the transmitter plane. The value of \( k = 2\pi/\lambda \) is the optical wave number in free space.

Consider that a phase diffuser is placed over the laser transmitter aperture, so that the emitted field can be modeled as

\[
\Delta u_0(\mathbf{r}) = u_0(\mathbf{r}) \exp[i\varphi_d(\mathbf{r})].
\]

The quantity \( \exp[i\varphi_d(\mathbf{r})] \) represents the small random perturbation due to the diffuser.

Under the assumption that the ensemble average of random phases induced by the diffuser is Gaussian and depends only on the separation distance, the cross spectral density at the transmitter can be expressed as

\[
W_0(\mathbf{r}_1, \mathbf{r}_2) = \langle \Delta u_0(\mathbf{r}_1, 0) \Delta u_0^*(\mathbf{r}_2, 0) \rangle
\]

where \( \Delta u_0(\mathbf{r}_1, 0) \) is the complex random field at the transmitter plane, and \( \mathbf{r}_1 \) and \( \mathbf{r}_2 \) are two-dimensional transverse vectors. The quantity \( \varphi_d(\mathbf{r}) \) is the small random perturbation due to the diffuser.

Using Eq. (7) the second moment of the scattered field is expressed as follows:

\[
\langle u_0(\mathbf{p}) u_0^*(\mathbf{p}) \rangle = \beta \langle l_1(\mathbf{p}_1) \rangle \Delta \varphi_d(\mathbf{p}_1 - \mathbf{p}_2) \exp \left( -\frac{\mathbf{p}_1^2}{\alpha^2} \right)
\]

where \( \mathbf{p} \) is a two-dimensional transverse vector in the target plane and \( L \) is the distance from the source to the target. The propagation geometry is shown in Fig. 1. The value of \( \psi_d(\mathbf{p}, \mathbf{r}) \) describes the effects of the random medium on the propagation of a spherical wave from a point \( r \) located in the transmitter plane to point \( \mathbf{p} \) in the target plane, and \( L \) is the path length, \( \mathbf{p} \) is in the receiver.

Assuming the reflector has a Gaussian reflectivity function

\[
T(\mathbf{p}) = -\exp(-\mathbf{p}^2/2\sigma^2_0),
\]

where \( \sigma_j \) represents the size of the reflector.

For a diffuse target the statistics \( T(\mathbf{p}) \) are described by a complex random function with the zero mean value and correlation function, respectively

\[
\langle T(\mathbf{p}) \rangle = 0,
\]

\[
\langle T(\mathbf{p}_1) T^*(\mathbf{p}_2) \rangle = |T(\mathbf{p}_1)|^2 \delta(\mathbf{p}_1 - \mathbf{p}_2),
\]

where \( |T(\mathbf{p})|^2 = \exp(-\mathbf{p}^2/2\sigma^2_0) \). \( \delta(\mathbf{p}) \) is the Dirac delta function.

Using Eq. (7) the second moment of the scattered field is expressed as follows:

\[
\langle u_0(\mathbf{p}) u_0^*(\mathbf{p}) \rangle = \beta \langle l_1(\mathbf{p}_1) \rangle \Delta \varphi_d(\mathbf{p}_1 - \mathbf{p}_2) \exp \left( -\frac{\mathbf{p}_1^2}{\alpha^2} \right)
\]

Fig. 1. The geometry of the double passage wave through a turbulence.
Download English Version:


Download Persian Version:

https://daneshyari.com/article/5427926

Daneshyari.com