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Near-field propagation of a flat-topped gaussian beam: Analysis in weakly turbulent atmospheres

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Abstract: We investigate the analysis of optical communication employing the shape beams, definitely concentrating on the effect of factors on the physical characteristics of a Flat Top Gaussian (FTG) beam. The propagation of a beam of laser light in the atmosphere layer is disposed to being affected by many optical phenomena such as scattering, absorption, and turbulence. These phenomena arise from differences in the scintillation index and the intensity modes realized in the source and receiver planes. This work is a numerical investigation of the FTG laser beam as it beams trekking through a zone of low turbulence using open-source software. This simulation will be conducted using a mathematical model derived from the split-step beam propagation technique. The intensity distributions of the source plane and the average intensity is received in air turbulence are computed, with an extra contour at the transducer plane. The Rytov approach to develops the scintillation index, structural constant, source size, and supplementary parameters to measure the weak turbulent model. Furthermore, these factors are studied in the context of near-field propagation. Also, the impression of the scintillation and wander of the beam is assessed. All simulated results are analyses and contrasted with the TEM00 Gaussian beam. At last, these discoveries are compared with the data obtained in the experimental piece of the study, additionally by applied in laser applications.
Keywords: *Flat Topped Gaussian (FTG), Near field analysis, Weak Turbulence.*

1. Introduction

The beam of Flat-top (also called top-hat) laser beams was characterized by having a homogeneous distribution of beam intensity in the center with nearly sharp beams at two edges[1,3]. These kinds of beams are very helpful for diverse applications including laser engraving, selected laser melting, laser micro-fabrication, laser radar, and optical metrology[4], [5]. By using an optical beam shaper the Gaussian ray laser can be turned into a flat-top laser beam [6] such as holograms[7], Binary Phase Plate[4], and hybrid grating[8] for example but not limited. The atmospheric effects on laser beam propagation can be categorized as attenuation of the laser power and fluctuation caused by beam distortion. The photons of laser light can be attenuated by absorption and scattering due to interaction with aerosols and gaseous molecules in the atmosphere. On the other hand, Small-scale dynamic variations in the atmosphere's index of refraction cause laser beam distortion. As a result, the laser beam wanders, spreads, and distorts the wave front or exhibits scintillation. For short-range propagation ns, the laser beam undergoes fewer fluctuations is and less distorted. The deformation of a beam using a method of small perturbing actions is often referred to as the Rytov Method and laser applications [9-

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13]. As a laser beam travels across several kilometers, it experiences strong fluctuations causing the deformity cross-sections section of that beam into a speckled pattern. The investigations of this work aimed at modeling A flat-top Gaussian beam, the field as it propagates via atmospheric turbulence, causes to producing beam scintillation and wander are established in order to make a comparison with experimental results.

2. Effect of Flat-Topped Gaussian Beamwidth on Average Intensity

The intensity diffusion of the proportional FTG beam at the sender plane (U_T) is found in z = 0, and the parataxis presented by [14] can be used as given by Eq. 1

$$U_T(\mathbf{s},0) = Aexp\left(-\frac{(N+1)\mathbf{s}^2}{w_0^2}\right)\sum_{m=0}^{N}\frac{1}{m!}\left(\frac{\sqrt{N+1}\,\mathbf{s}}{w_0}\right)^{2m} \quad (1)$$

Here U_T is Intensity spread at the source plane, A is the field scattering amplitude, s is the cross vector at the sender plane, w_0 are middle of the spectrum and the *N* integer number represents superficies ranking. Density spreading at the receiver level U_R They will be able to choose to use the Huygens - Fresnel integral as beneath [15].

$$U_R(\mathrm{r},\mathrm{z}) = \frac{-ik}{2\pi z}exp(ikz)\iint_{-\infty}^{\infty}U_T(\mathrm{s},0)\exp\left(\frac{ik}{2z}|s-r|\right)ds^2 \quad (2)$$

Wherever the parameters of the equation above, z are defined as the space amidst the planes T (transmitter) and R (receiver), *r* is the slope vector in the R plane, and wave number *k*. Moreover, the outdo spread of the FTG beam, and convolution of Eq. (2) and Eq. (3) without turbulent plenty enlargement function is required as given by [16].

$$U_R(\mathrm{r},\mathrm{z}) = U_T(\mathrm{s},0) * \left(\frac{-ik}{2\pi z}exp\left(ikz + \frac{ik}{2z}|s-r|\right)\right) \quad (3)$$

Turbulence affects laser radiation, causing temporal and spatial changes in irradiance that are visible at the receiving plane. The scintillation index of the phase is related to beam fluctuation and is usually measured in space.

$$\sigma_I^2 = \frac{\langle I^2\rangle}{\langle I\rangle^2} - 1 \quad (4)$$

where σ_I is denoted scintillation index and *I* refer to the light intensity. The Rytov variance can be used to characterize scintillation. σ_I when a model of an unobstructed flat wave or circular wave is utilized.

$$\sigma_I^2 = KC_n^2k^{7/6}L^{11/6} \quad (5)$$

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The refractive index fluctuations and the Kolmogorov power-law spectrum only occur among inertia-band vortices K (rad m^{-1}). It is isotropic and limited to homogeneous.

$$\Phi_n(\kappa) = 0.033C_n^2K^{-11/3} \qquad 2\pi/L_0 \ll K \ll 2\pi/l_0 \quad (6)$$

The parameter C_n acts as a deflective index of structure constant (m$^{-2/3}$) and the l_0, L_0 is the inner and outer turbulence measure, correspondingly. The direction along which light propagates depends on whether its medium is homogeneous or not and heterogeneous. Moreover, the degree of refractive index structure constant governs to that the refractive index of a medium vacillates. In the fact of the values order of 10^{-17} m$^{-2/3}$ is accompanying occurred in weak turbulence to up it, consequently, the section of reasonable turbulence is $10^{-17} < C_n^2 < 10^{-17}$. The grade of turbulence is advanced at minor elevations as mentioned above. Additionally, the higher values of C_n^2 results are nearer to the ground level. Eq.7 defines the refractive index of structure constant as below.

$$C_n^2 = \left[79.0 * 10^{-6}\left(\frac{P}{T^2}\right)C_T\right]^2 \quad (7)$$

Somewhere the factors C_T, P, and T, are delighted with the temperature (K) of structure constant, the pressure (m bar) indoors of the turbulence model, we can compared with refs [17- 20].

3. Results and Analysis

In this Sector, we are using some numerical examples of the different intensity developments of FTG for dissimilar distances in a turbulence atmosphere accomplished according to Eqs. (1&2). Furthermore, to explain the outcomes of several figures like intensity, scintillation index, contour, and so on, moreover, to apply these parameters, for example, the wavelength λ= 1550 nm, source size. $\omega_{gx} = \omega_{gy} = 1.0\ cm$, and structure constant parameter $C_n^2 = 0.5 \times 10^{-13} m^{-2/3}$ of the Gaussian beam, additionally, to added other factors have been displayed in all figures.

Figure 1. The contour for flat top Gaussian ray of the basic field, we observed the lines in the center are dissimilar on the other line that's back to equality of source size (x&y) axis, conclusively, Figure 2. source intensity of flat top Gaussian beam in the oblique coordinate structure, thereby like the previous figure but applied colour and referring to values of boundary lines. Similarly, Figures 3 and 4 illustrate the average intensity of FTG Beam in 2-D and 3-D Transverse Coordinate systems Interetingly for different distances. Besides, Figure 5 refers to the 3D of average Intensity for the FTG beam in the transmitter plan, in addition to besides, spreads in atmospheric space with distribution as propagation distance rises. On the other hand, the intensity shape will adopt a bright center core comparable to the flat-top Gaussian profile.

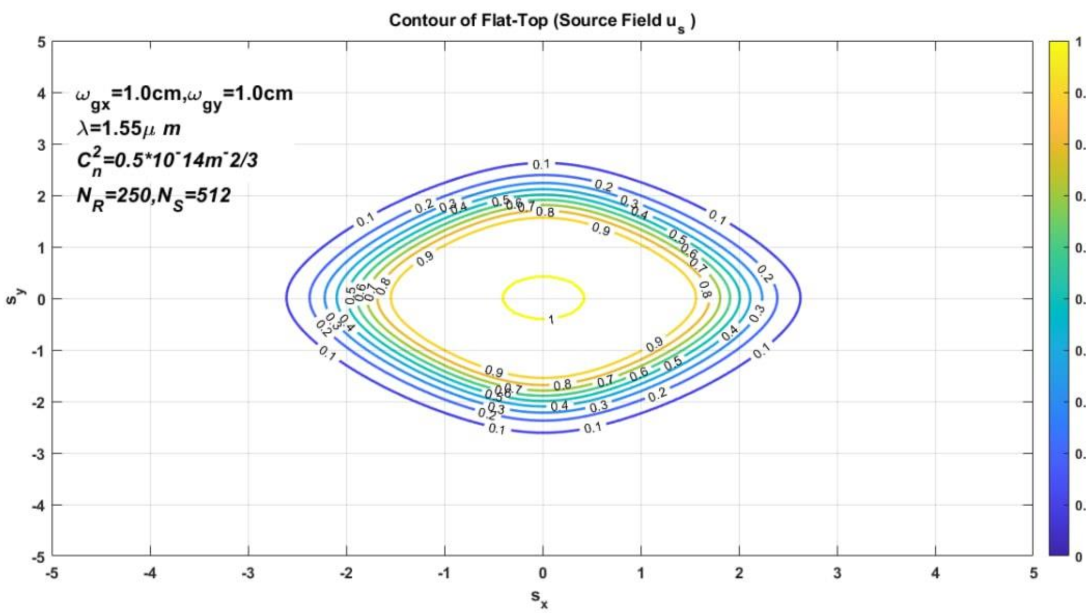

Figure 1.
The contour for flat top gaussian beam of source field.

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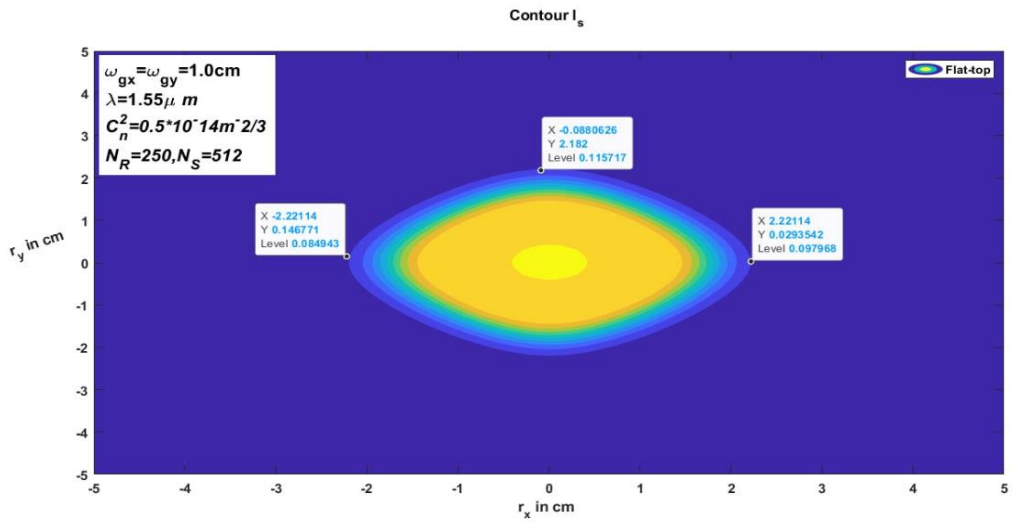

Figure 2.
In Diagonal direct system of source intensity related to flat top Gaussian beam.

In this perspective, Figure 2 provides the source intensity of the flat-top Gaussian ray in the slanting coordinate system dependent on the parameters mentioned earlier, intensity contour loops describe the constant distance between two circles. So, the constant construction structure, wavelength, is usage. In addition, Figure 3 and Figure 4 show the variation of source intensity with different propagation distances L= (0.5, 1.5, 2.5, 3.5) km in the oblique coordinate classification of two and three dimensions respectively.

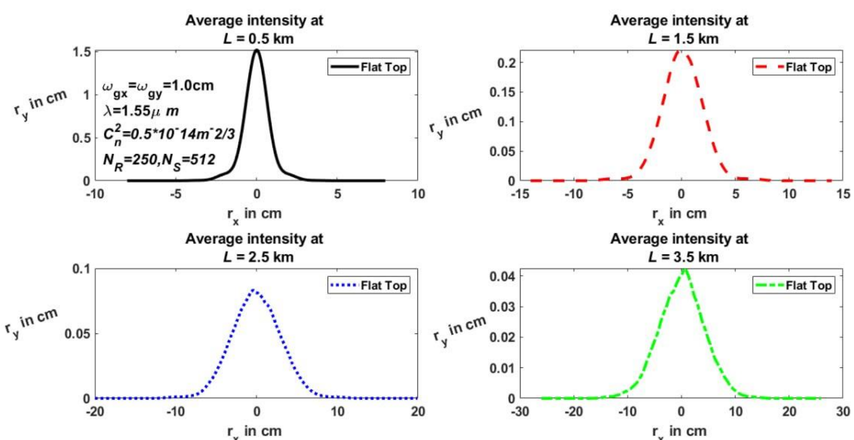

Figure 3.
Average Intensity of FTG beam in 2-D transverse coordinate system.

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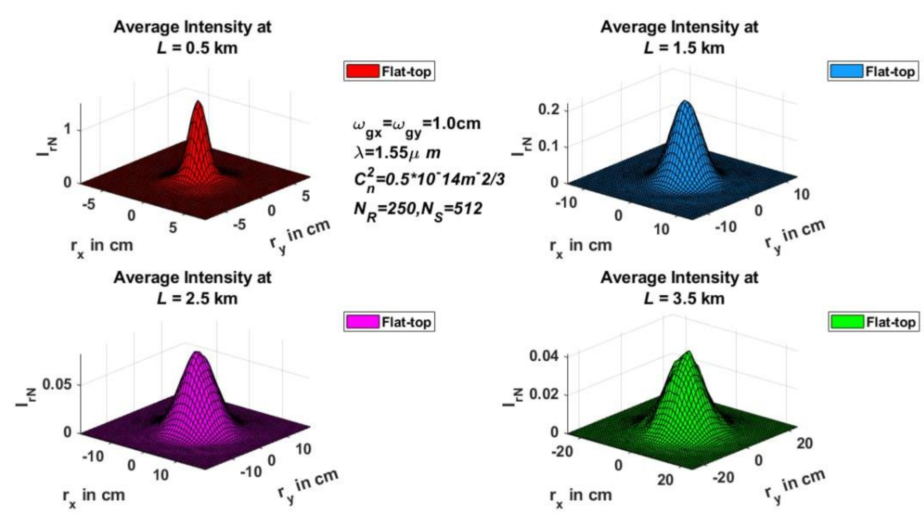

Figure 4.
Picture of 3D for changed proliferation distances of FTG beam.

Figure 4. Illustrate the receiver field, indicating a reduction in receiver intensity in comparison with the amplitude of the source as the beam diffusion is passing the far distance of 3.5 km from the source to the receiver plane. Similarly, representative simulated results concerning the variation of source amplitude at different propagation distances and contour rings at the receiver plane are displayed in Figures 6 and 7. Specifically, Figure 8 focuses on the variation of the scintillation index with fixed wavelength FTG beam versus propagation distance which shows the scintillation increases linearly to the far 2.5 km and for up that's raised high scintillation. As the initial wave front of the laser beam propagates via turbulence zones it would undergo variance in irradiance causing temporal and spatial changes in irradiance that are visible at the receiver. The on-axis scintillation index calculated by Eq. 3 is commonly used to assess the degree of variation in the received signal.

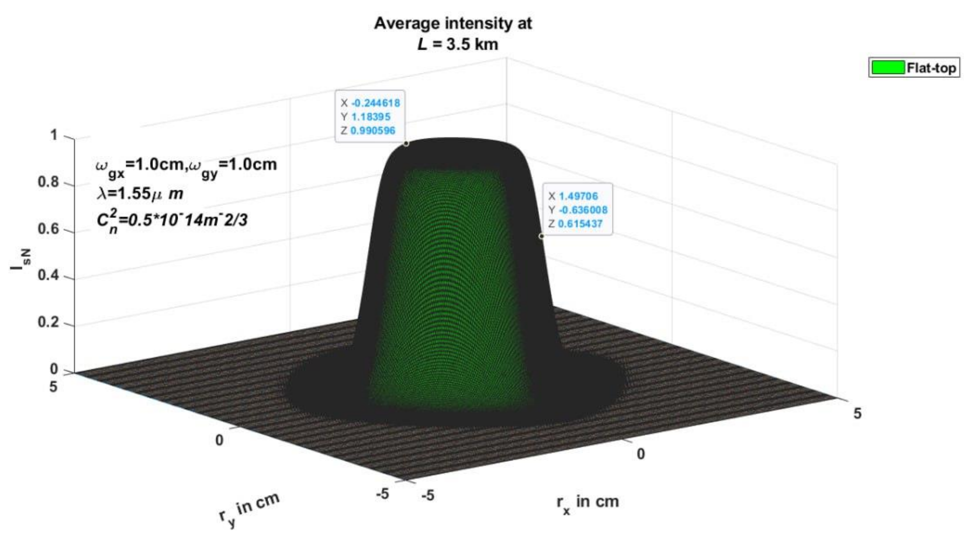

Figure 5.
The 3D of average intensity for FTG beam in transmitter plan.

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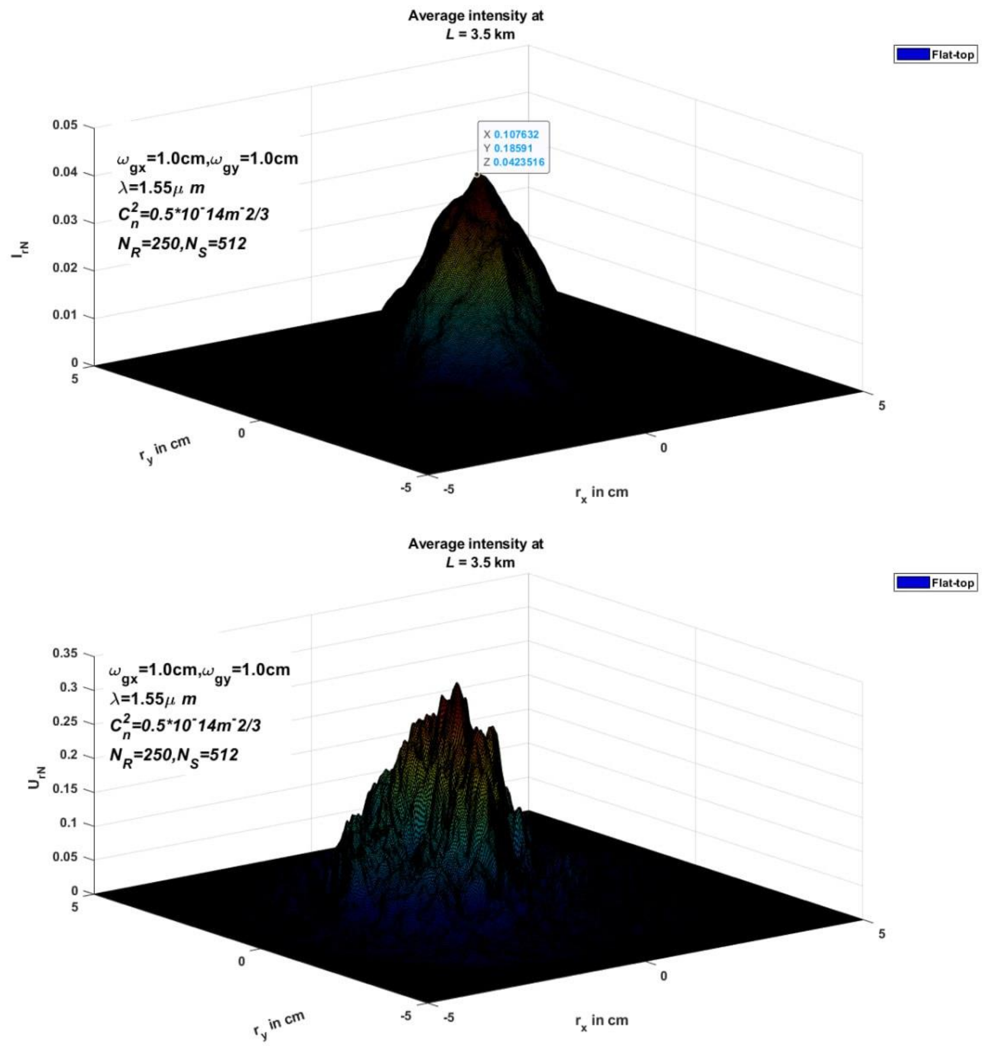

Figure 6.
Image of 3D for dissimilar dissemination distances of FTG beam and the shape of average intensity and receiver field.

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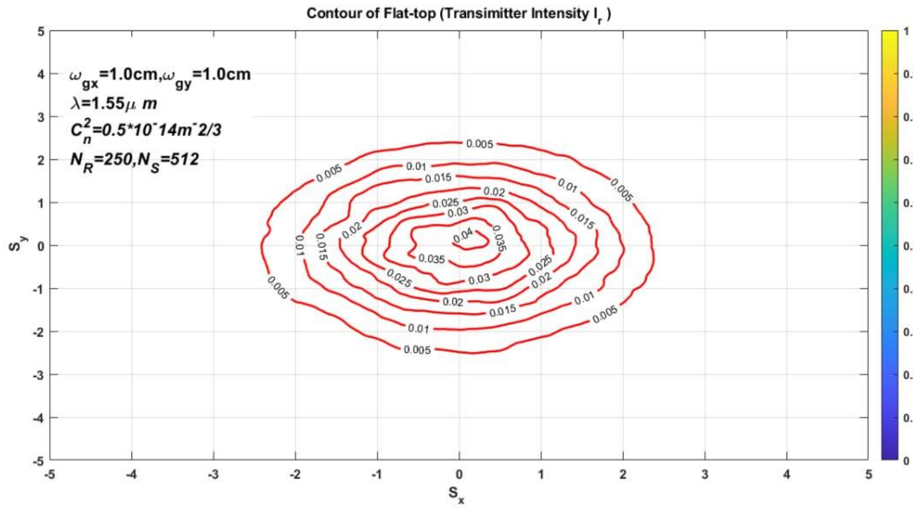

Figure 7.
The 3D source intensity for FTG beam at different parameters.

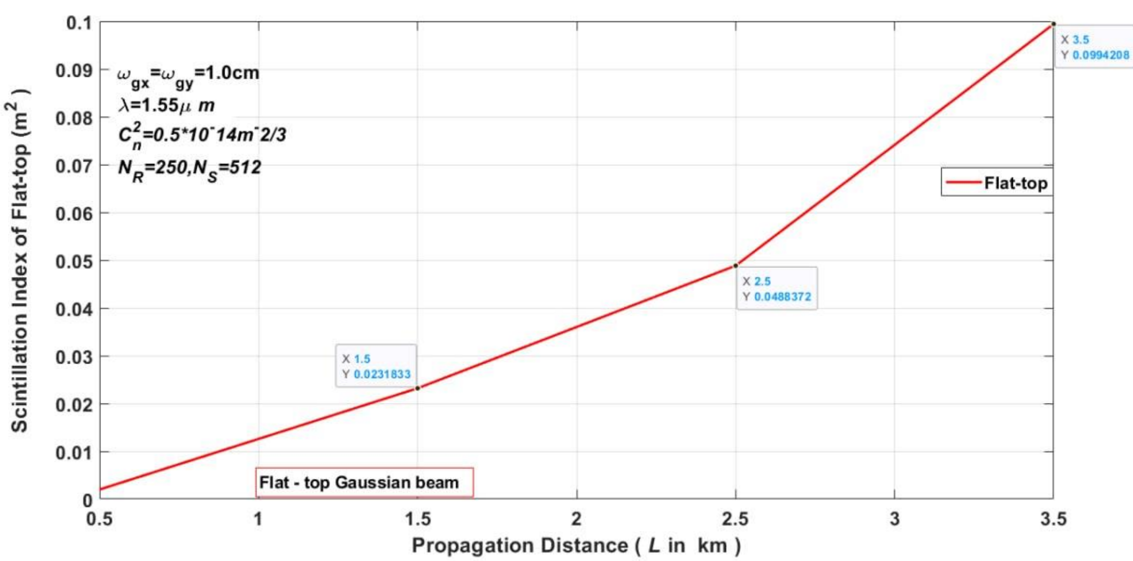

Figure 8.
Dissimilarity of the propagation distance versus scintillation index with fixed wavelength FTG beam.

4. Conclusions

In this paper, the near-field proliferation of the FTG beam through a puny atmosphere is mathematically simulated. The analysis was performed with the help of the fragmented beam propagation technique. It is shown that the propagation of an FTG beam with a high uniformity parameter can be analyzed as the deflection of a plane wave occurrence on a spherical gap with an extent equivalent to that of the FTG beam at the T plane. The two and three-dimension intensity possessions were accurately held. The rising scintillation index proportion constant produced a larger distortion in receiver intensity. The finding is valuable for applications in not only optical communication systems but also in laser material collaboration practically.

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