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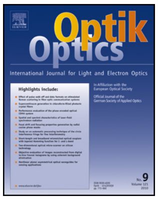

Full length article

Nonparaxial propagation of a partially coherent Lorentz-Gauss beam

Dajun Liu*, Hongming Yin, Yaochuan Wang*

Department of Physics, Dalian Maritime University, Dalian, 116026, China

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ABSTRACT

Based on the Rayleigh-Sommerfeld diffraction integral, the analytical propagation equations of nonparaxial propagation and far field propagation for a partially coherent Lorentz-Gauss beam in free space are derived. The results show that the far field propagation is in agreement with nonparaxial propagation as the propagation distance z increases. And the beam with smaller coherence length for nonparaxial propagation of partially coherent Lorentz-Gauss beam will spread faster in free space.

1. Introduction

With the development of the laser technology, laser beams have been applied to many instruments, and the propagation properties of laser beam have been widely investigated by many researchers [1–7]. And in the application of near field, the nonparaxial properties of laser beams have been studied, such as spirally polarized optical beam [8], elliptical Gaussian beam [9], radially polarized light beam [10], four-petal Gaussian beam [11], hollow Gaussian beam [12], partially coherent dark hollow beam [13], rotating Cosh-Gaussian beam [14], flat-topped vortex hollow beam [15,16], Gaussian optical vortex beam [17], partially coherent flat-topped beam [18], partially coherent anomalous hollow beam [19], Lorentz-Gauss beam [20,21], multi-Gaussian Schell-model beam[22,23] and partially coherent four-petal Gaussian beam [24]. However,new laser beams called Lorentz beams have been given to describe the propagation of laser diode, and the propagation properties of Lorentz and Lorentz-Gauss beam have been widely studied [25–30]. To the best of our knowledge, the nonparaxial propagation properties and far field propagation properties of a partially coherent Lorentz-Gauss beam in free space have not been illustrated in the past years. In order to investigate the near field propagation properties of partially coherent Lorentz-Gauss beam, in this paper, the nonparaxial propagation properties and far field propagation properties of a partially coherent Lorentz-Gauss beam in free space are studied by using the generalized Rayleigh-Sommmerfeld diffraction.

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* Corresponding authors.
E-mail addresses: liudajun@dlmu.edu.cn (D. Liu), ycwang@dlmu.edu.cn (Y. Wang).

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2. Theory analysis

Based on the generalized Rayleigh-Sommerfeld diffraction integral equation, the propagation function of partially coherent beams propagating in free space at the receive plane z can be written as [13]:

$$W(\mathbf{r}_1, \mathbf{r}_2, z) = \left(\frac{z}{\lambda}\right)^2 \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} d\mathbf{r}_{10} d\mathbf{r}_{20} W(\mathbf{r}_{10}, \mathbf{r}_{20}, 0) \frac{\exp\left[ik(R_2 - R_1)\right]}{R_1^2 R_2^2} \tag{1}$$

where $\mathbf{r}_1 = (x_1, y_1)$ and $\mathbf{r}_2 = (x_2, y_2)$ are the position vectors at the receiver plane z; $\mathbf{r}_{10} = (x_{10}, y_{10})$ and $\mathbf{r}_{20} = (x_{20}, y_{20})$ are the position vectors at the source plane z = 0; $W(\mathbf{r}_1, \mathbf{r}_2, z)$ and $W(\mathbf{r}_{10}, \mathbf{r}_{20}, 0)$ are the cross spectral density function of partially coherent beam at the receiver plane z and source plane z = 0; $k = 2\pi/\lambda$ is the wave number with λ being wavelength. R_1 and R_2 of Eq. (1) are the distance between the source plane and receiver plane and can be expressed as:

$$R_1 = \sqrt{(x_1 - x_{10})^2 + (y_1 - y_{10})^2 + z^2} \tag{2a}$$

$$R_2 = \sqrt{(x_2 - x_{20})^2 + (y_2 - y_{20})^2 + z^2} \tag{2b}$$

And, a partially coherent Lorentz-Gauss beam generated by a Schell-model source at the source plane z = 0 can be expressed as [31]:

$$\begin{aligned} W(\mathbf{r}_{10}, \mathbf{r}_{20}, 0) = {} & \frac{1}{w_{0x} w_{0y}\left[1 + \left(\frac{x_{10}}{w_{0x}}\right)^2\right]\left[1 + \left(\frac{y_{10}}{w_{0y}}\right)^2\right]} \exp\left(-\frac{\mathbf{r}_2^{10}}{w_0^2}\right) \\ & \times \frac{1}{w_{0x} w_{0y}\left[1 + \left(\frac{x_{20}}{w_{0x}}\right)^2\right]\left[1 + \left(\frac{y_{20}}{w_{0y}}\right)^2\right]} \exp\left(-\frac{\mathbf{r}_2^{20}}{w_0^2}\right) \\ & \times \exp\left[-\frac{(x_{10} - x_{20})^2 + (y_{10} - y_{20})^2}{2\sigma^2}\right] \end{aligned} \tag{3}$$

where w_0 denotes the waist of the Gaussian part for partially coherent Lorentz-Gauss beam; w_{0x} and w_{0y} are the parameters related to beam widths of Lorentz part for partially coherent Lorentz-Gauss beam in x-axis and y-axis, respectively; σ are the transversal coherence length of partially coherent Lorentz-Gauss beam.

When the nonparaxial propagation properties of partially coherent beam are investigated, the R_1 and R_2 in Eq. (1) can be expanded as:

$$R_1 = r_1 + \frac{x_{10}^2 + y_{10}^2 - 2x_1 x_{10} - 2y_1 y_{10}}{2r_1} \tag{4a}$$

$$R_2 = r_2 + \frac{x_{20}^2 + y_{20}^2 - 2x_2 x_{20} - 2y_2 y_{20}}{2r_2} \tag{4b}$$

with

$$r_1 = \sqrt{x_1^2 + y_1^2 + z^2} \tag{5a}$$

$$r_2 = \sqrt{x_2^2 + y_2^2 + z^2} \tag{5b}$$

By considering the relationship of Lorentz function and Hermite-Gauss function in Eq. (3) of partially coherent Lorentz-Gauss beam [32]

$$\begin{aligned} \frac{1}{\left(x_0^2 + w_{0x}^2\right)\left(y_0^2 + w_{0y}^2\right)} = {} & \frac{\pi}{2w_{0x}^2 w_{0y}^2} \sum_{m=0}^{N}\sum_{n=0}^{N} a_{2m} a_{2n} H_{2m}\left(\frac{x_0}{w_{0x}}\right) H_{2n}\left(\frac{y_0}{w_{0y}}\right) \\ & \times \exp\left(-\frac{x_0^2}{2w_{0x}^2} - \frac{y_0^2}{2w_{0y}^2}\right) \end{aligned} \tag{6}$$

And recalling the following formulae [33]

$$\int_{-\infty}^{+\infty} x^n \exp\left(-px^2 + 2qx\right) dx = n! \exp\left(\frac{q^2}{p}\right)\left(\frac{q}{p}\right)^n \sqrt{\frac{\pi}{p}} \sum_{k=0}^{\left[\frac{n}{2}\right]} \frac{1}{k!(n-2k)!}\left(\frac{p}{4q^2}\right)^k \tag{7}$$