Physics Letters A 378 (2014) 1687–1690

Contents lists available at ScienceDirect

Physics Letters A

www.elsevier.com/locate/pla

The control of pulse profiles with tunable temporal coherence

Chaoliang Ding [a], Olga Korotkova [b], Liuzhan Pan [a,*]

[a] Department of Physics, Luoyang Normal University, Luoyang 471022, China
[b] Department of Physics, University of Miami, Coral Gables, FL 33146, USA

ARTICLE INFO

Article history:
Received 11 February 2014
Received in revised form 14 April 2014
Accepted 16 April 2014
Available online 24 April 2014
Communicated by C.R. Doering

Keywords:
Pulse shaping
Coherence and statistical optics
Pulse propagation

ABSTRACT

A new class of partially coherent pulse sources with Multi-Gaussian Schell-model (MGSM) correlations is proposed. The expression for the intensity distribution for the MGSM pulses generated by such sources on propagation through the dispersive media is derived. It is demonstrated that the pulse intensity profile, in particular, the width of the flat center of pulse intensity profile and the peak intensity, can be controlled by adjusting the source temporal coherence. The obtained results have potential applications in pulse shaping for communication and media sensing or pulsed laser material processing.

1. Introduction

It is well known that the far-field intensity distribution of a partially coherent source is closely related to the structure of the correlation function of the field in the source plane [1]. Traditionally, most of the characterizations on the correlation function of the field in the source plane are confined to the Gaussian Schell-model correlations [2]. Recently, the classic family of Gaussian Schell-model sources has been augmented by other models, such as, the J_0-correlated Schell-model sources [3,4], the non-uniformly correlated sources [5,6], the Bessel–Gaussian Schell-model sources, the Laguerre–Gaussian Schell-model sources [7], the cosine-Gaussian Schell-model sources [8–11], and the Multi-Gaussian Schell-model sources [12–16]. The beams generated by these sources have revealed many interesting and useful features in propagation. For instance, the intensity profile of beams originated by J_0-correlated Schell-model sources have properties analogous to those of the Bessel–Gaussian beams but the degree of coherence does not preserve the $J_0(x)$ profile nor shift-invariance [4]; the beams generated by non-uniformly correlated light sources hold self-focusing and lateral shifts of the beam intensity maxima in free-space propagation [5]; the Bessel–Gaussian and Laguerre–Gaussian Schell-model sources are capable of producing far fields with ring-shaped intensities [7]; the far-field spectral density produced by the cosine-Gaussian Schell-model sources takes on the dark-hollow profile [8,11]; both the Multi-Gaussian Schell-model (MGSM) beams in free-space propagation and MGSM beams scattered by random media can generate far fields with tunable flat profiles, whether circular [12,15] or rectangular [17]. The vast majority of above investigations have been concerned with stationary beams or light sources.

On the other hand, based on the theory of coherence for non-stationary light fields, statistical optical pulses represent a wide class of partially coherent fields that find numerous applications in optical imaging, fiber optics, optical telecommunications, etc. [18]. In recent years, the influence of the temporal coherence properties on the evolution of pulses upon propagation has received widespread attention [19–32]. It was revealed that the pulse duration increases upon propagation with decreasing temporal coherence in dispersive media [26], the temporal coherence affects extent of variations of the degree of polarization in optical fibers [28] and the ghost interference can be achieved using temporally partially coherent light pulses [29]. However, in most of the above studies concerning the coherence properties of pulses, the classical Gaussian Schell-model correlations have been adopted to describe the temporal coherence of optical pulse. Only a few papers have been devoted to the propagation of partially coherent pulses with non-Gaussian Schell-model correlations distribution, in which some interesting characteristics have been presented [33–35].

In this Letter, we consider the propagation of the MGSM pulses in dispersive media, where the temporal degree of coherence of the pulses does not satisfy Gaussian distribution and is modeled

* Corresponding author. Tel.: +86 379 65526002; fax: +86 379 65526002.
E-mail addresses: dingchaoliang2006@126.com (C. Ding), panliuzhan@263.net (L. Pan).

http://dx.doi.org/10.1016/j.physleta.2014.04.029

by Multi-Gaussian distribution. Our aim is to explore the influence of Multi-Gaussian Schell-model distribution of temporal coherence on the pulse intensity profile on propagation. We have found that the pulse intensity profile, i.e. the width of the flat center of the pulse intensity profile and the peak intensity, can be controlled by adjusting the summation index M in the Multi-Gaussian function.

2. Theoretical model

In the space–time domain the coherence properties of the pulses can be defined by their mutual coherence function $\Gamma(t_1,t_2)=\langle E^*(t_1)E(t_2)\rangle$, where $E(t)$ represents the complex analytic signal of pulse realizations at time t, and the angle brackets denote the ensemble average. In general, for a mutual coherence function to be genuine, i.e. physically realizable, $\Gamma(t_1,t_2)$ must correspond to a non-negative definite kernel [2]. As has been shown for the correlation functions in the spatial domain [36], a sufficient condition for the non-negative definiteness is that the mutual coherence function must be expressed as a superposition integral of the form

$$\Gamma(t_1,t_2)=\int p(v)H^*(t_1,v)H(t_2,v)dv. \tag{1}$$

In order to introduce an ensemble of MGSM pulses, we choose $p(v)$ and H as follows

$$p(v)=\frac{T_c}{\sqrt{2\pi}}\frac{1}{C_0}\sum_{m=1}^{M}(-1)^{m-1}\binom{M}{m}\exp\left[-\frac{mT_c^2v^2}{2}\right], \tag{2}$$

$$H(t,v)=\exp\left[-\frac{t^2}{4T_0^2}\right]\exp[-ivt], \tag{3}$$

where T_c is the r.m.s. source correlation determining the temporal coherence of the pulses, $C_0=\sum_{m=1}^{M}\frac{(-1)^{m-1}}{\sqrt{m}}\binom{M}{m}$ is the normalization factor, $\binom{M}{m}$ denotes binomial coefficient, and T_0 represents the pulse duration. Substituting Eqs. (2) and (3) into Eq. (1), we obtain the mutual coherence function of the Multi-Gaussian Schell-model pulses as follows

$$\Gamma^{(0)}(t_1,t_2)=\exp\left\{-\frac{t_1^2+t_2^2}{4T_0^2}\right\}\times\gamma(t_1,t_2), \tag{4}$$

where

$$\gamma(t_1,t_2)=\frac{1}{C_0}\sum_{m=1}^{M}\binom{M}{m}\frac{(-1)^{m-1}}{\sqrt{m}}\exp\left\{-\frac{(t_2-t_1)^2}{2mT_c^2}\right\}. \tag{5}$$

Eq. (5) denotes the temporal degree of coherence of the MGSM pulses at two instants of time, t_1 and t_2, in the source plane. It is a kind of extension from traditional Gaussian degree of coherence $\gamma(t_1,t_2)=\exp[-(t_2-t_1)^2/2T_c^2]$ which can be derived by letting $M=1$ in Eq. (5). Formally, Eq. (5) is similar with the spectral degree of coherence of stationary MGSM beams proposed by S. Sahin and O. Korotkova in Ref. [12]. As is illustrated in Fig. 1, the profile function defined by Eq. (5) visually resembles a Bessel-correlated source or a Lambertian source; however, it is defined by a different functional form, i.e. Multi-Gaussian function.

We will now investigate the propagation of the MGSM pulses in a second-order dispersive medium. Propagation of the mutual coherence function in the dispersive media can be characterized by the generalized Collins formula in the temporal domain [20,37]

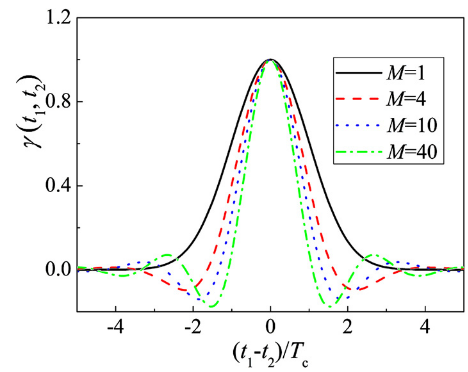

Fig. 1. (Color online.) Illustration of the temporal degree of coherence of the MGSM pulses calculated from Eq. (5) as a function of the non-dimensional parameter $(t_1-t_2)/T_c$ for several values of M: $M=1$ (solid curve); $M=4$ (dashed curve); $M=10$ (dotted curve), and $M=40$ (dotted–dashed curve).

$$\Gamma(t_1,t_2,z)=\frac{\omega_0}{2\pi B}\iint\Gamma(t_{10},t_{20})\times\exp\left\{\frac{i\omega_0}{2B}\left[A\left(t_{10}^2-t_{20}^2\right)+D\left(t_1^2-t_2^2\right)-2(t_{10}t_1-t_{20}t_2)\right]\right\}dt_{10}\,dt_{20}, \tag{6}$$

where A, B, C, and D are the elements of the temporal matrix of the dispersive media. Here we have assumed that the time coordinate is measured in the reference frame moving at the group velocity of the pulses.

The temporal matrix for the second-order dispersive medium of length z is given as [20,37]

$$\begin{pmatrix}A & B\\ C & D\end{pmatrix}=\begin{pmatrix}1 & \omega_0\beta_2z\\ 0 & 1\end{pmatrix}, \tag{7}$$

where β_2 represents the group velocity dispersion coefficient.

On substituting from Eqs. (7) and (4) into Eq. (6), after tedious integral calculations we obtain the following analytic formula of the mutual coherence function of the MGSM pulses propagating in dispersive media

$$\Gamma(t_1,t_2,z)=\frac{1}{C_0}\sum_{m=1}^{M}\binom{M}{m}\frac{(-1)^{m-1}}{\sqrt{m}}\frac{1}{\Delta_m(z)}\exp\left[-\frac{(t_1+t_2)^2}{8T_c^2\Delta_m^2(z)}\right]\times\exp\left[-\frac{(t_1-t_2)^2}{2Q_m^2\Delta_m^2(z)}\right]\exp\left[i\frac{(t_2^2-t_1^2)}{2\beta_2R_m(z)}\right], \tag{8}$$

$$Q_m^2=\left(\frac{1}{4T_0^2}+\frac{1}{mT_c^2}\right)^{-1},\qquad \Delta_m^2(z)=1+\frac{\beta_2^2z^2}{T_0^2Q_m^2},$$

$$R_m(z)=z\left(1+\frac{T_0^2Q_m^2}{\beta_2^2z^2}\right). \tag{9}$$

Thus, the pulse intensity can be obtained by the expression

$$I(t,z)=\Gamma(t,t,z)=\frac{1}{C_0}\sum_{m=1}^{M}\binom{M}{m}\frac{(-1)^{m-1}}{\sqrt{m}}\frac{1}{\Delta_m(z)}\exp\left[-\frac{t^2}{2T_0^2\Delta_m^2(z)}\right]. \tag{10}$$

The analysis of Ref. [12] describes the evolution of the wide-sense statistically stationary fields that are radiated by a source with the 2D MGSM spatial coherence function. In this paper the novel random pulse is proposed, in which case the 1D temporal coherence function is imposed in the source, while the spatial characteristics of the field can be chosen at will. It is seen that