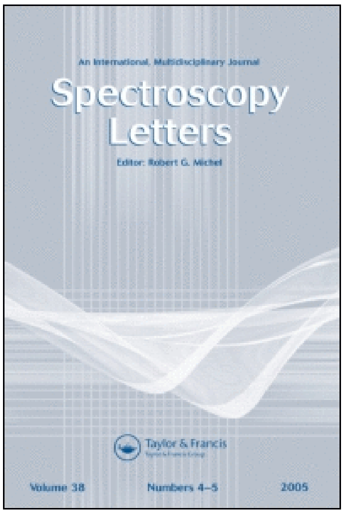

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Characterizing Low Light Level Signals with the Triggered Delayed Photocount Distribution

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CHARACTERIZING LOW LIGHT LEVEL SIGNALS WITH THE TRIGGERED DELAYED PHOTOCOUNT DISTRIBUTION

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ABSTRACT

The theoretical expression of the first-order factorial moment of a triggered delayed photocount distribution and a description of its SNR have been developed. We explain the adventages of this thecnique, in comparison with the second-order correlation function, when we measured a temporal signal under low light level. We derived the theoretical errors involved in determining a parameter by measuring both functions for a signal with a periodically modulated intensity, since this kind of signals usually appear in spectroscopy. We conclude that the first-order factorial moment of a triggered delayed photocount distribution is a useful tool for characterizing a signal at low light level conditions.

INTRODUCTION

The measurement of the first-order factorial moment (FOFM) of a triggered photocount distribution (TPCD)[1] is used for the analysis of a light beam because it can be easily measured and it contains the same information about the signal to be analyzed as the autocorrelation function $g^{(2)}(\tau)$. In a standard TPCD , where the measurement time (T) stars immidiately one pulse is registred , the FOFM only provide the information contained in $g^{(2)}(0)$[2] . But if we want to obtained the information about $g^{(2)}(\tau)$ for every value of τ ,we have to evaluate the FOFM of a triggered delayed photocount distribution (TDPCD).

A TDPCD is a TPCD in which a time or space interval (θ) is introduced between the ocurrence of one photoevent and the beginning of the counting time[3]. The triggering pulse which starts the countig process can be obtained from the signal to be analyzed (Auto-trigger) or from a different signal (Cross-trigger). The aim of this work is to characterize the use of the FOFM of a TDPCD as a method for signal characterization at low light level.

THEORY

In order to compare the results obtained by using the FOFM of the TDPCD with the autocorrelation function,consider a temporal signal I(t)

The photocount distribution $P(n,\theta,T)$ of registrered n photoelectrons during the time interval (T), when the counting time is delayed by a time θ from the occurrence of one process point, can be expressed as follows[3]:

$$P(n,\theta,T) = \langle I(t)\ [w(t+\theta,T)]^n \exp(-w(t+\theta,T)) \rangle / (\langle I \rangle n!) \quad [1]$$

where the mean value corresponds to a random average of $w(t+\theta,t)$, and

$$w(t+\theta,T) = \int_{t+\theta}^{t+\theta+T} I(t')\,dt' \quad [2]$$

It can be shown[5] that the expresion of the experimental FOFM of a TDPCD is:

$$N^{[1]}(\theta,T) = \langle I(t)\ w(t+\theta,T) \rangle / \langle I \rangle \quad [3]$$

The normalized FOFM will be:

$$n^{[1]}(\theta,T) = N^{[1]}(\theta,T) / \langle w \rangle \quad [4]$$

If we use a TPCD the value of θ in Eq.(3) becomes zero.

The expression of the experimental autocorrelation function is:

$$g^{(2)}(\tau,T) = \langle w(t,T)\, w(t+\tau,T) \rangle / \langle w \rangle^2 \quad [5]$$

which is very similar to Eq.(4) for small counting times, where $w(t,T) \cong I(t)\,T$. Therefore, Eq. (4) are related with the expression of the theoretical autocorrelation function by a temporal derivate [2].

We have developed an expresion for the variance of $n^{[1]}(\theta,T)$, by the same way that Saleh [4] used for evaluating the variance of the FOFM of a standard PCD :

$$\mathrm{Var}[\,n^{[1]}(\theta,T)\,] = (1/\bar{n})^2\ \mathrm{Var}(N^{[1]}) + (N^{[1]}/\bar{n}^2)^2\ \mathrm{Var}\,\bar{n} +$$

$$+ \quad 2\,(-N^{[1]}/\bar{n}^3)\,[\,\langle N^{[1]}\,\bar{n}\rangle - \bar{n}\langle N^{[1]}\rangle\,] \qquad [6]$$

For small values of $\bar{n}$ (mean number of photoevents per counting time) we obtain an aproximate equation :

$$\mathrm{var}\,(n^{[1]}) \cong n^{[1]}\ /\ (\,N\,\bar{n}\,) \qquad [7]$$

where N is the number of experiments used to evaluate it. Under the same conditions the following expresion of the variance of $g^{(2)}(\tau,T)$ can be obtained[4]:

$$\mathrm{Var}\,(\,g^{(2)}) \cong g^{(2)}\ /\ (\,N\,\bar{n}^2\,) \qquad [8]$$

The SNR derived from Eqs.(7) and (8) will be :

$$\mathrm{SNR}_n = (n^{[1]}\,N\,\bar{n}\,)^{1/2} \qquad [9]$$

$$SNR_g = (q N \bar{n}^2)^{1/2} \qquad [10]$$

For small values of $\bar{n}$ SNR_n will be greater than SNR_g. So we can obtain a statistical function which contains the same information about the signal as the autocorrelation function but has the advantages of a easier processing procedure and better SNR.

We suggest a new experimental way for measuring the FOFM of a TDPCD. It is to use a multichannel annalyzer , auto or cross-triggered, and so , for each trigger pulse , we obtain a set of values of $n^{[1]}(\theta,T)$ for diferent values of θ.

If we want to know the error in determining a parameter α from the mesurament of a function $f(\alpha,\tau)$ for various values of the delay interval τ, we have to use the expresion :

$$Var\,\alpha = \left(\sum_{i=1}^{L} \left[(df(\alpha,\tau_i)/d\alpha)^2 / Var\,f(\alpha,\tau_i) \right] \right)^{-1} \qquad [11]$$

APLICATION

We shall now evaluate the relative errors obtained,when the measured function is $n^{[1]}(\theta,T)$ and $g^{(2)}(\tau,T)$ respectively, in determining the parameter α=M for the light signal whose intensity is periodically modulated :

$$I(t) = \bar{I}\,(1 + M \cos\omega t) \qquad [12]$$

where $\omega = 2\pi/P$, P is the period of the signal, M is the modulation factor and $\bar{I}$ the mean value of the intensity.

Taking into account the fact that

$$w(t,T) = \bar{I}\,T\,[1 + \cos((t+T/2)\,\omega)] \qquad [13]$$

and using Eqs. (4) and (5) we obtain :

$$g^{(2)}(\tau,T) = 1 + (A^2/2)\ \cos\omega\tau \qquad [14]$$

$$n^{[1]}(\theta,T) = 1 + (M\,A/2)\ \cos\omega(\theta+T/2) \qquad [15]$$

where

$$A = M \sin(\omega T/2) \,/\, (\omega T/2) \qquad [16]$$

By using Eqs. (7) and (8) , and by evaluating the derivatives which appear in Eq. (11) , we have represented the relative error in percent involved in determining M by measuring $n^{[1]}(\theta,T)$ as function of:

a) the number of channels $L = P/\tau$ ranging from 5 to 35 in steps of 5 , and the value of M varying from 0.1 to 0.7 with steps of 0.1. The value of the mean number of photocounts per counting time is fixed : $\bar{n} = 10^{-3}$ counts (Fig (1)).

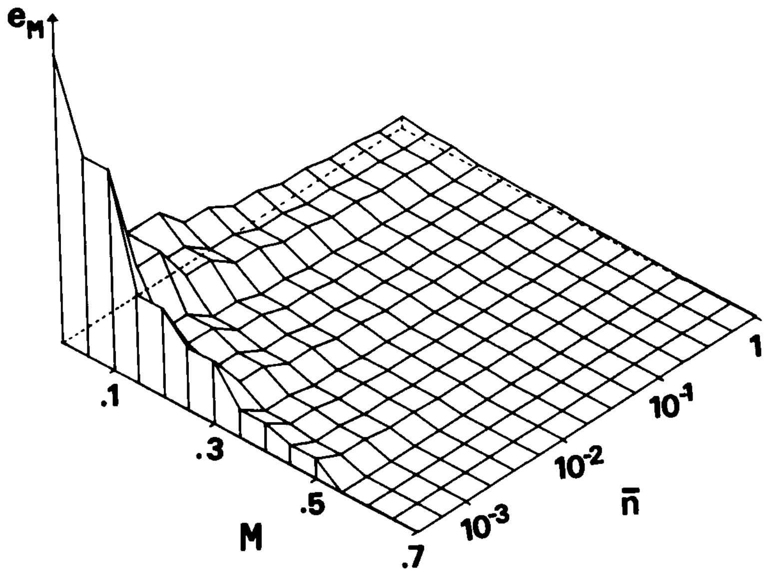

Fig. 1.- Relative error (e_M) in percent involved in determining the parameter M of the signal $I(t)= \bar{I}\ (1+M \cos(\omega t)\ )$ by measuring $n^{[1]}(\theta,T)$ versus the number of channels (L) , and the modulation factor (M) for a value of $\bar{n}=10^{-3}$ photocounts per counting time

b) the number of photocounts per counting time $\bar{n}$ ($\bar{n}$ from 10^{-3} to 1) and M (M in the range from 0.1 to 0.7 in steps of 0.1), fixed L=50 channels (Fig (2)).

It can be seen that the behaviour of the error involved in obtaining M by measuring $n^{[1]}(\theta,T)$ and $g^{(2)}(\tau,T)$ is the same , but the values for $g^{(2)}(\tau,T)$ is greater than those obtained for $n^{[1]}(\theta,T)$: 10 times in the case (a) and up to 30 times in the case (b) for small values of $\bar{n}$.

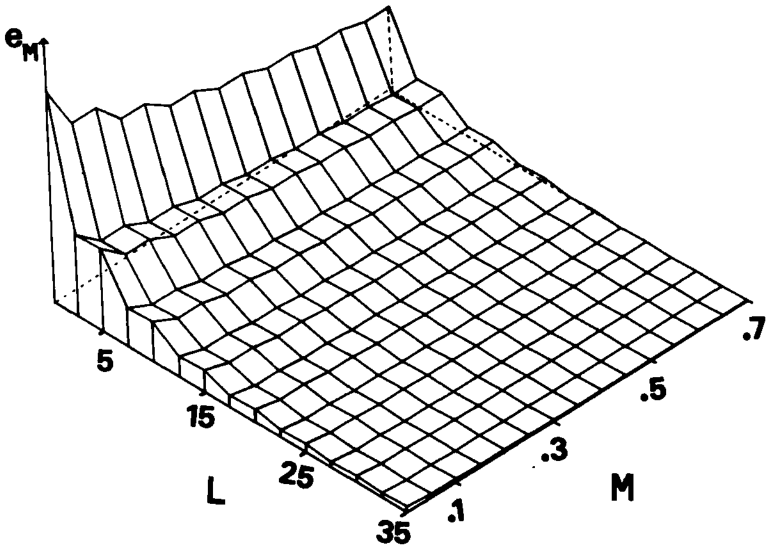

Fig. 2.- Relative error (e_M) in percent involved in determining the parameter M of the signal $I(t)= \bar{I}\ (1+M\ \cos(\omega t))$ by measuring $n^{[1]}(\theta,T)$ versus the number of photocounts per counting time ($\bar{n}$),and the modulation factor (M) for a value of L=50 channels.

CONCLUSIONS

In analizing a deterministic light signal at low light level , the normalized FOFM of a TDPCD contains the same information as the normalized second-order autocorrelation function, but its measurement produce smaller errors in the determination of the characterizing parametrers of the light beam . We can conclude that the measurement of $n^{[1]}(\theta,T)$ is an useful method for characterizing low light level signals, since, in this case, it presents betters results than $g^{(2)}(\tau,T)$

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