TIME DISTRIBUTION OF PHOTONS FROM COHERENT AND GAUSSIAN SOURCES *

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The statistics of a radiation field is investigated by measuring the time distributions of photoelectrons from a single-photon counter. The statistics of a Gaussian field, a single-mode and a two-mode laser field are studied and compared.

It is known from a theoretical analysis [1, 2] that the second order statistical properties of a stationary radiation field can be deduced by the photoelectron time distribution from a single-photon counter. This letter reports the first experimental analysis of these time distributions.

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Two kinds of distributions have been examined: a) the conditional probability $p_c(\tau)$ of a count occurring at a time τ after another one has occurred at $\tau = 0$; b) the time intervals distribution between two successive pulses.

Let us first examine experiment a). For a Gaussian light the conditional probability $p_c(\tau)$ is given by [2]:

$$p_c(\tau) = \alpha \bar{I}(1 + |\gamma_{11}(\tau)|^2) \tag{1}$$

where $\bar{I}$ is the average light intensity, α the photocathode efficiency and $\gamma_{11}(\tau)$ the first order correlation function of the field. For a completely coherent field, $p_c(\tau) = \alpha \bar{I}$ = constant.

The experimental set up for measuring this distribution consists of a variable delay generator triggered by a photoelectron pulse which operates a gate of a short fixed duration $\Delta\tau$ after a time interval τ. The number of pulses occurring in $\Delta\tau$ is counted and recorded in the memory of a pulse-height analyzer. The source used was either a Gaussian source obtained by randomization of a laser light [3] by means of a rotating ground glass disc and observed within a coherence area, or the laser light itself coming from a single axial mode of a He-Ne laser (with a cavity length of 20 cm and TEM_{00} emission). The experimental results are shown in fig. 1 and agree

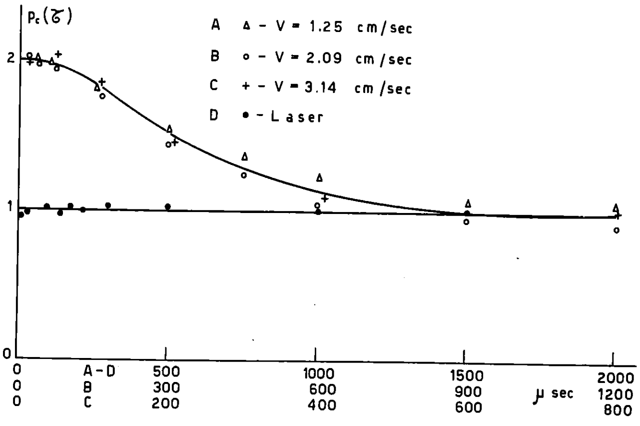

Fig. 1. Conditional probability $p_c(\tau)$ of a second count occurring at a time τ after a first has occurred at time $\tau = 0$.

with the theoretical results of Mandel [1]. In fig. 1a two time scales are superimposed, the scaling factor being the relative linear velocity of the spot on the disc in the three experiments made in order to test the behaviour of the system with different coherence times.

Next we discuss experiment b). The time intervals distribution between two successive pulses can be derived from the above conditional probability as follows:

$$p_{01}(\tau) = \alpha I \exp\left[-\int_0^\tau p_c(x)\, dx\right] \qquad (2)$$

where p_{01} is the probability density of the second event occurring at τ while the first one has occurred at $\tau = 0$. A start-stop system was used to perform the measurement and the experimental results are reported in fig. 2a and b on a semi-logarithmic plot.

While the laser light gives a single exponential, the thermal light has a short-time dependence which tends to an exponential with an initial time constant twice as large as that of the long-time asymptotic exponential, in accordance with (1) and (2).

For the Gaussian field comparison with the spectral amplitude distribution $I(\omega)$ of $I(t)$ measured with a wave analyzer gives the correct correspondence between $I(\omega)$ and $|\gamma_{11}(\tau)|^2$ that is

$$|\gamma_{11}(\tau)|^2 = \int_0^\infty I^2(\omega) \cos \omega\tau \, d\omega ,$$

within the experimental errors.

The same experiment has been previously performed with a two meter laser going on two

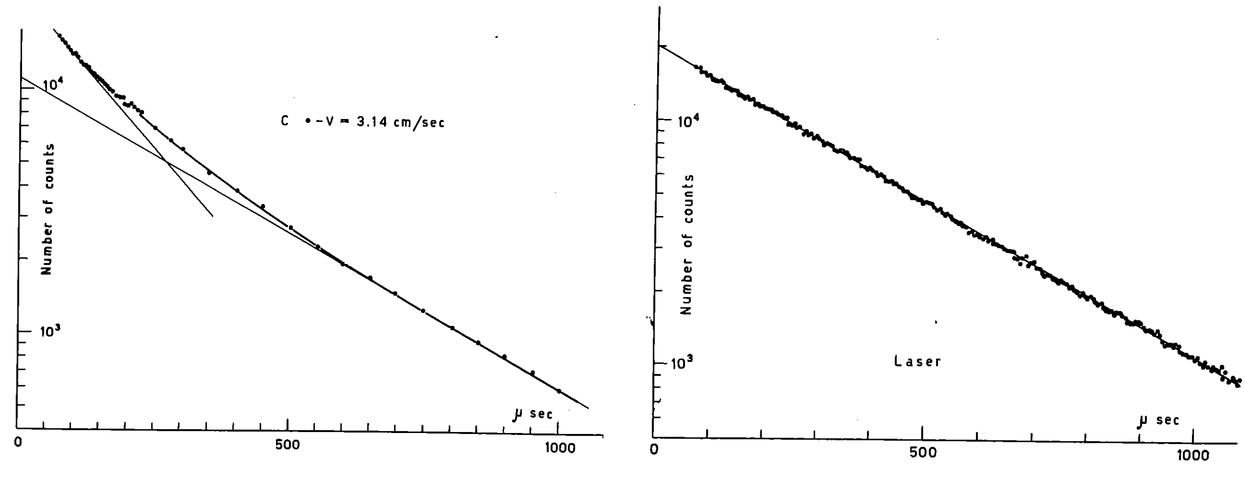

Fig. 2. Time delay distribution $p_{10}(\tau)$ between two successive pulses coming from a single photon counter illuminated by: a) a thermal source in a coherence area; b) a single mode laser.

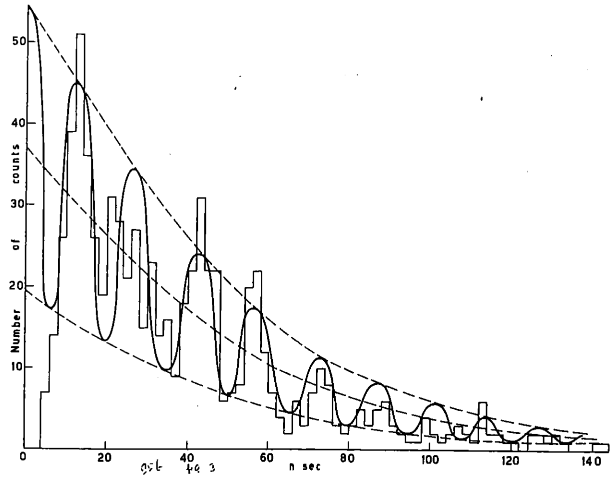

Fig. 3. Time delay distribution $p_{10}(\tau)$ between two successive pulses coming from a single photon counter illuminated by a two mode gas laser with a 2 m cavity length (75 Mc/sec beat frequency).

axial modes, and the time intervals distribution was derived recording on a photographic film a series of oscilloscope sweeps and then measuring on an enlarged projection the time intervals between successive pulses. Due to the value of the beat frequency (75 Mcs) corresponding to a 13.5 ns period, a resolving power of 2ns at least was required to evidence the time dependence of this distribution without smearing off the maxima and minima. The method has the resolution required, however, it has a dead time due to the impossibility of distinguishing two pulses closer than 4 ns. The results obtained are shown in fig. 3. The continuous curve corresponds to the expression

$$p_{10}(\tau) = \alpha\bar{I}\exp(-\alpha\bar{I}\tau)(1 + \tfrac{1}{2}\cos\omega\tau)$$

derived assuming a time dependence of $I(t)$ of the type $I(t) = \bar{I}(1 + \sin\omega t)$, where ω is the beat frequency of the two modes.

The experimental method here described presently yields information only on the second order correlation function, and therefore is equivalent to an Hanbury Brown and Twiss (either double coincidence or intensity correlation) experiment. However, it can be easily generalized to derive higher order correlation functions by measuring the joint probabilities of the kind $p_c(\tau_1 | \tau_2)$.

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References

1. L. Mandel, in: Progress in optics, ed. E. Wolf (North-Holland Publishing Co., Amsterdam, 1963) vol. II, p. 183.
2. L. Mandel and E. Wolf, Rev. Mod. Phys. 37 (1965) 231.
3. F. T. Arecchi, Phys. Rev. Letters 15 (1965) 912.

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