PHOTON NOISE REDUCTION AND COHERENCE PROPERTIES OF SQUEEZED FIELDS

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We derive a quantitative expression of photon noise reduction in interferometric experiments which is not based on a few field modes analysis. We show that the reduction factor is quite sensitive to the coherence properties of the squeezed field.

1. Introduction

New methods have been recently proposed in order to reduce photon noise in interferometric measurements [1,2]. They use special types of fields, the so called "squeezed fields" [3]. The purpose of this paper is to emphasize the importance of the coherence properties of such squeezed fields for the quantitative evaluation of photon noise reduction.

Consider, for example, a Michelson interferometer (fig. 1). A laser beam, entering in channel A, is divided by a beam splitter into two parts which are reflected by two mirrors M_1 and M_2, and then recombined to form two emerging beams in channels C and D. Any phase shift between the two interfering paths is transformed into an intensity change of these two emerging beams. In order to optimize the sensitivity of such a device, one usually measures the difference $\overline{N} = \overline{N}_C - \overline{N}_D$ between the mean number of photons in channels C and D, in conditions where the fringe contrast is equal to 1, and the phase difference ϕ between the two arms is adjusted to a value such that $\overline{N} = 0$. A small variation $d\phi$ of ϕ is then found to produce the optimum response

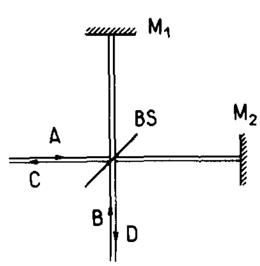

Fig. 1. The Michelson interferometer: we have sketched the beam splitter BS, the two mirrors M_1 and M_2, the two input ports A and B and the two output ones C and D. Usually, only one input port (A) is used.

$$d\overline{N} = \overline{N}_A \, d\phi. \tag{1.1}$$

We will suppose that the usual noise sources have been eliminated and that the only limitation to the sensitivity is quantum noise. Furthermore, we will consider that quantum noise is dominated by photon noise or shot noise and not by fluctuations of radiation pressure [4–6]. In this case, the fluctuations of $N = N_C - N_D$ are characterized by a variance [4–6]

$$\Delta N^2 = \Delta N_C^2 + \Delta N_D^2 = \overline{N}_C + \overline{N}_D = \overline{N}_A. \tag{1.2}$$

It has been recently realized that the photon noise (1.2) could be reduced by entering squeezed fields in the second input channel B of the interferometer [1]. A first analysis of this effect considers only four field modes, two input (A,B) and two output ones (C,D) with annihilation operators a, b, c, d. One thus shows that, if the input field is in a coherent state $|\alpha\rangle$ [7], eq. (1.2) has to be replaced by:

$$\Delta N^2 = \overline{N}_A \Delta b_2^2 + \overline{N}_B, \tag{1.3}$$

where

$$b_2 = i(b^+ - b) \tag{1.4}$$

is the component of b in quadrature with α (which is supposed real). Note that eq. (1.2) is a particular case of (1.3) corresponding to the situation where only vacuum fluctuations enter in B ($\overline{N}_B = 0$; $\Delta b_2^2 = 1$). It clearly appears in (1.3) that photon noise is reduced when the fluctuations of b_2 are squeezed, i.e. when

$$\Delta b_2^2 < 1 \tag{1.5}$$

(the number $\overline{N}_B$ of photons in the squeezed field is supposed much smaller than $\overline{N}_A$). It will be useful to rewrite (1.3) (using $[b,b^+] = 1$) as

$$\Delta N^2 = \overline{N}_A(1+q) + \overline{N}_B, \tag{1.6}$$

where

$$q = \langle : \delta b_2\, \delta b_2 : \rangle \tag{1.7}$$

is the normally ordered variance of b_2 ($\delta b_2 = b_2 - \langle b_2 \rangle$). Note that q is necessarily positive for any classical field and that squeezing is therefore a non classical feature [3].

Since the previous analysis considers the fields in the four channels as single mode fields, it does not include any description of the space–time coherence properties of these fields. It is however well known that photodetection signals are directly related to correlation functions of the field impinging on the photocathodes [7], so that such signals are generally quite sensitive to the coherence properties of the fields [8]. The main motivation of this paper is to derive a new expression for photon noise in a Michelson interferometer in terms of space–time integrals of correlation functions of the squeezed field entering B (for the sake of simplicity, we will suppose that the field entering A remains perfectly coherent).

We first consider (sect. 2) the problem of photon noise in a single counter experiment and discuss, in this simpler case, the dependence of photon noise versus the detection time T and the detection area S as compared to the coherence time τ_c and coherence area σ_c of the field. After a generalization to experiments using two photodetectors, we consider the problem of photon noise in a Michelson interferometer (sect.3) and derive a theoretical expression for ΔN^2 which generalizes (1.6). We finally discuss the physical content of such an expression (sect. 4).

2. Photon noise in photon counting experiments

The mean number $\overline{N}$ of photons detected by a single counter

$$\overline{N} = \iint \mathrm{d}t\, \mathrm{d}^2 r\, \langle I(\boldsymbol{r},t) \rangle \tag{2.1}$$

is the integral over the measurement time T and over the photocathode area S of the mean value of the intensity operator

$$I(\boldsymbol{r},t) = \mathcal{C} E^-(\boldsymbol{r},t) E^+(\boldsymbol{r},t), \tag{2.2}$$

$E^+(E^-)$ being the positive (negative) frequency component of the electric field operator, and $\mathcal{C}$ a multiplicative constant

$$\mathcal{C} = 2\epsilon_0 c/\hbar\omega \tag{2.3}$$

(we consider the field as quasi-monochromatic with mean frequency ω; we suppose that the photodetector is a perfect one with a quantum efficiency equal to 1). The theory of photodetection [7] gives also the expression of the factorial moment of order 2 of N

$$\overline{N(N-1)} = \iiiint \mathrm{d}t\, \mathrm{d}t'\, \mathrm{d}^2 r\, \mathrm{d}^2 r' \langle : I(\boldsymbol{r},t)\, I(\boldsymbol{r}',t') : \rangle, \tag{2.4}$$

where the colons mean that the operators are taken in the normal order

$$\langle : I(\boldsymbol{r},t)\, I(\boldsymbol{r}',t') : \rangle = \mathcal{C}^2 \langle E^-(\boldsymbol{r},t)\, E^-(\boldsymbol{r}',t')\, E^+(\boldsymbol{r}',t')\, E^+(\boldsymbol{r},t) \rangle; \tag{2.5}$$

from (2.1) and (2.4) one gets the photon noise

$$\Delta N^2 = \overline{N^2} - \overline{N}^2 = \overline{N} + C, \tag{2.6}$$

with

$$C = \iiiint \mathrm{d}t\, \mathrm{d}t'\, \mathrm{d}^2 r\, \mathrm{d}^2 r' \langle : \delta I(\boldsymbol{r},t)\, \delta I(\boldsymbol{r}',t') : \rangle, \tag{2.7}$$

where $\delta I = I - \langle I \rangle$. We can rewrite (2.6) as

$$\Delta N^2 = \overline{N}(1+Q) \tag{2.8}$$

with

$$Q = C/\overline{N}. \tag{2.9}$$

The factor C in (2.6), or equivalently the factor Q in (2.8), describes the deviation from Poisson statistics due to intensity correlations. In order to reduce photon noise, we need $Q < 0$ and also Q not too small compared to 1. For this reason, we now discuss qualitatively how to choose the detection time T and detection area S in order to maximise the absolute value of Q. The correlation function appearing in (2.7) vanishes when $|t - t'|$ is larger than the coherence time τ_c of the field or when $\boldsymbol{r}$ and $\boldsymbol{r}'$ are not in the same coherence area σ_c. If the detection time T and detection area S are respectively larger than τ_c and σ_c, C is proportional to $ST \times \sigma_c\tau_c$ whereas $\overline{N}$ is proportional to ST, so that Q varies as $\sigma_c\tau_c$. On the other hand, if $S < \sigma_c$ and $T < \tau_c$, $C \sim (ST)^2$ so that Q varies as ST. It follows that Q increases when the "observation volume" $V = ST$ is increased from very low values and saturates to the coherence volume $v_0 = \sigma_c\tau_c$ when $T > \tau_c, S > \sigma_c$. It may happen that larger values for $|Q|$ are reached in the intermediate region $T \sim \tau_c$, $S \sim \sigma$ (see for example [9]). But, if the correlation functions vary "smoothly" (for example, exponential decay versus $|t - t'|$ and gaussian variation versus $|\boldsymbol{r} - \boldsymbol{r}'|$, as it is often the case), the largest possible value for $|Q|$ corresponds to $T > \tau_c, S > \sigma_c$.

We consider now experiments using two photodetectors 1 and 2. For each detector i ($i = 1,2$), we have

$$\overline{N}_i = \iint \mathrm{d}t_i\, \mathrm{d}^2r_i\, \langle I_i(\boldsymbol{r}_i,t_i)\rangle, \tag{2.10}$$

$$\overline{N_i(N_i - 1)} = \iiiint \mathrm{d}t_i\, \mathrm{d}t_i'\, \mathrm{d}^2r_i\, \mathrm{d}^2r_i'\, \langle : I_i(\boldsymbol{r}_i,t_i)\, I_i(\boldsymbol{r}_i',t_i') : \rangle. \tag{2.11}$$

We can also calculate the "crossed" terms

$$\overline{N_1N_2 + N_2N_1} = \iiiint \mathrm{d}t_1\, \mathrm{d}t_2\, \mathrm{d}^2r_1\, \mathrm{d}^2r_2\, \langle : I_1(\boldsymbol{r}_1,t_1) I_2(\boldsymbol{r}_2,t_2) + I_2(\boldsymbol{r}_2,t_2) I_1(\boldsymbol{r}_1,t_1) : \rangle. \tag{2.12}$$

We will suppose that the two photocathodes are mirror images of each other through a beam splitter which divides the incident beam into two parts and sends them towards the two detectors. The two detectors explore the same surface in the incident field so that $I_1(\boldsymbol{r}_1,t_1)$ and $I_2(\boldsymbol{r}_2,t_2)$ can be strongly correlated if the mirror image of $\boldsymbol{r}_2$ is close enough to $\boldsymbol{r}_1$. From (2.10) and (2.12), one gets the variance of $N = N_1 - N_2$

$$\Delta N^2 = \overline{N}_1 + \overline{N}_2 + C, \tag{2.13}$$

with

$$C = \iiiint \mathrm{d}t\, \mathrm{d}t'\, \mathrm{d}^2r\, \mathrm{d}^2r'\, \langle : \delta I(\boldsymbol{r},t)\, \delta I(\boldsymbol{r}',t') : \rangle \tag{2.14}$$

where

$$I = I_1 - I_2, \quad \delta I = I - \langle I\rangle, \tag{2.15}$$

and where $\boldsymbol{r}, t, \boldsymbol{r}', t'$ mean $\boldsymbol{r}_1, t_1, \boldsymbol{r}_1', t_1'$ when appearing in I_1, and $\boldsymbol{r}_2, t_2, \boldsymbol{r}_2', t_2'$ when appearing in I_2. Here also the term C in (2.13) describes deviation from Poisson statistics due to intensity correlations. The same argument as above shows that the surface S of the photocathode and the measurement time T have to be chosen large compared to σ_c and τ_c (at least, of the same order) in order to maximise the effect on ΔN^2 of this correlation term C.

Note that such a condition is opposite to the condition of observation of photon correlations. If one wants the effect of correlations (bunching effect [10, 11] as well as antibunching effect [12,13]) not to be washed out in the integration over S and T, one has indeed to choose $S < \sigma_c, T < \tau_c$.

3. Photon noise in a Michelson interferometer

The previous section clearly shows the importance of the coherence properties of the field for a quantitative evaluation of photon noise. We now extend this treatment to the Michelson interferometer considered in section 1.

In the optimal conditions, leading to the optimal response (1.1), the two output fields in channels C and D are related to the two input fields in channels A and B by ‡

‡ When writing (3.1), we implicitly suppose that the frequency dispersion and angular spread of the fields entering the interferometer are much narrower than respectively the spectral and angular acceptance of this interferometer

$$E^{\pm}_{\mathrm{C}}(\boldsymbol{r}_{\mathrm{C}},t) = [E^{\pm}_{\mathrm{A}}(\boldsymbol{r}_{\mathrm{A}},t) \mp \mathrm{i}E^{\pm}_{\mathrm{B}}(\boldsymbol{r}_{\mathrm{B}},t)]/\sqrt{2},$$

$$E^{\pm}_{\mathrm{D}}(\boldsymbol{r}_{\mathrm{D}},t) = [E^{\pm}_{\mathrm{B}}(\boldsymbol{r}_{\mathrm{B}},t) \mp \mathrm{i}E^{\pm}_{\mathrm{A}}(\boldsymbol{r}_{\mathrm{A}},t)]/\sqrt{2}. \tag{3.1}$$

In these expressions, the four points $\boldsymbol{r}_{\mathrm{A}}, \boldsymbol{r}_{\mathrm{B}}, \boldsymbol{r}_{\mathrm{C}}, \boldsymbol{r}_{\mathrm{D}}$ are "conjugated" two by two in the interferometer, which means (fig. 2) that $\boldsymbol{r}_{\mathrm{C}}$ and $\boldsymbol{r}_{\mathrm{D}}$ are the images in channels C and D of the same point $\boldsymbol{r}_{\mathrm{A}}$ in the input channel A, and also of the same point $\boldsymbol{r}_{\mathrm{B}}$ in channel B (after reflection or transmission due to the beam splitter and to the two mirrors M_1 and M_2). From now on, we will use the simpler notation $\boldsymbol{r}$ for the four conjugated points $\boldsymbol{r}_{\mathrm{A}}, \boldsymbol{r}_{\mathrm{B}}, \boldsymbol{r}_{\mathrm{C}}, \boldsymbol{r}_{\mathrm{D}}$ (or $\boldsymbol{r}'$ for $\boldsymbol{r}'_{\mathrm{A}}, \boldsymbol{r}'_{\mathrm{B}}, \boldsymbol{r}'_{\mathrm{C}}, \boldsymbol{r}'_{\mathrm{D}}$), being understood that $E^{\mp}_{i}(\boldsymbol{r})$ actually represents $E^{\mp}_{i}(\boldsymbol{r}_i)$ with i = A, B, C, D. We will also suppose that the two photocathodes in the two output channels are conjugated in the interferometer. This optimizes crossed correlation terms appearing in the following calculations.

The mean value $\overline{N}$ of $N = N_{\mathrm{C}} - N_{\mathrm{D}}$ can be written

$$\overline{N} = \iint \mathrm{d}t\ \mathrm{d}^2r\ \langle I(\boldsymbol{r},t)\rangle \tag{3.2}$$

where

$$I(\boldsymbol{r},t) = I_{\mathrm{C}}(\boldsymbol{r},t) - I_{\mathrm{D}}(\boldsymbol{r},t)$$
$$= \mathrm{i}\mathcal{C}[E^{-}_{\mathrm{B}}(\boldsymbol{r},t)\,E^{+}_{\mathrm{A}}(\boldsymbol{r},t) - E^{-}_{\mathrm{A}}(\boldsymbol{r},t)\,E^{+}_{\mathrm{B}}(\boldsymbol{r},t)]. \tag{3.3}$$

For the particular value of the dephasing ϕ here chosen, the signal $\overline{N}$ appears as an homodyning signal between the two input fields E_{A} and E_{B}. It must be noted that the variation of $\overline{N}$ with the phase difference ϕ remains given by (1.1) provided that the energy entering B is much weaker than the energy entering A. It appears also from (3.1) that

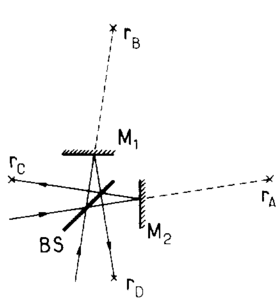

Fig. 2. Output fields E_{C} and E_{D} are taken at two "conjugated" points r_{C} and r_{D}, images of the same point r_{A} (resp. r_{B}) in input channel A (resp. B).

$$\overline{N}_{\mathrm{C}} + \overline{N}_{\mathrm{D}} = \overline{N}_{\mathrm{A}} + \overline{N}_{\mathrm{B}} \tag{3.4}$$

which expresses energy conservation.

We come now to the problem of photon noise. One gets from (2.13)

$$\Delta N^2 = \overline{N}_{\mathrm{C}} + \overline{N}_{\mathrm{D}} + C = \overline{N}_{\mathrm{A}} + \overline{N}_{\mathrm{B}} + C, \tag{3.5}$$

where we have used (3.4). The correlation factor C describing the deviation from Poisson statistics has the same expression as in (2.14) with $I(r,t)$ given by (3.3)

$$C = -\mathcal{C}^2 \iiiint \mathrm{d}t\ \mathrm{d}t'\ \mathrm{d}^2r\ \mathrm{d}^2r'$$
$$\times \langle :\delta(E^{-}_{\mathrm{B}}E^{+}_{\mathrm{A}} - E^{-}_{\mathrm{A}}E^{+}_{\mathrm{B}})\,\delta(E^{-}_{\mathrm{B}}E^{+}_{\mathrm{A}} - E^{-}_{\mathrm{A}}E^{+}_{\mathrm{B}})' :\rangle \tag{3.6}$$

where the two parentheses are taken respectively at points $(\boldsymbol{r},t)$ and $(\boldsymbol{r}',t')$.

4. Physical discussion

4.1. Structure of the correlation factor

As mentioned in the introduction, we suppose that the field entering A is in a coherent state. Since the operators are normally ordered in (3.6), we can therefore replace the operators $E^{\pm}_{\mathrm{A}}$ by the corresponding classical fields $\mathcal{E}^{\pm}_{\mathrm{A}}$. Expression (3.6) thus appears to give the correlation factor C in terms of space–time integrals of the second order correlation functions of the field entering B

$$F^{-+}_{\mathrm{B}}(\boldsymbol{r},t;\boldsymbol{r}',t') = \mathcal{C}\langle\delta E^{-}_{\mathrm{B}}(\boldsymbol{r},t)\,\delta E^{+}_{\mathrm{B}}(\boldsymbol{r}',t')\rangle \tag{4.1}$$

$$F^{++}_{\mathrm{B}}(\boldsymbol{r},t;\boldsymbol{r}',t') = \mathcal{C}\langle\delta E^{+}_{\mathrm{B}}(\boldsymbol{r},t)\,\delta E^{+}_{\mathrm{B}}(\boldsymbol{r}',t')\rangle \tag{4.2}$$

(and the complex conjugate expressions). The first correlation function, F^{-+}_{B}, is very usual in quantum optics. It can be measured for example as an intensity signal in a two beam interference experiment [8]. The second one is less familiar. Actually, it cannot be easily measured on the field E_{B} alone. It appears here because of the homodyning between the two fields entering A and B.

More precisely, the correlation factor C may be written

$$C = C_0 - C_2 \cos\psi, \tag{4.3}$$

where

$$C_0 = 2\mathcal{C}\iiiint dt\, dt'\, d^2r\, d^2r'$$

$$\times\ \mathcal{E}_A^-(r',t')\ \mathcal{E}_A^+(r,t)\, F_B^{-+}(r,t;r',t'), \qquad (4.4)$$

$$C_2 e^{i\psi} = 2\mathcal{C}\iiiint dt\, dt'\, d^2r\, d^2r'$$

$$\times\ \mathcal{E}_A^-(r',t')\ \mathcal{E}_A^-(r,t)\, F_B^{++}(r,t;r',t'). \qquad (4.5)$$

The factor 2 in the expression (4.4) of C_0 is due to the fact that there are two contributions in (3.6) related to F_B^{-+} and that these contributions are equal. There is also a contribution proportional to F_B^{--} which is actually complex conjugate to the contribution proportional to F_B^{++}, which explains how cos ψ appears in (4.3).

The first term C_0 of (4.3) is positive since it can be considered as the norm of the state

$$|\bar{\varphi}\rangle = \iint dt\, d^2r\ \mathcal{E}_A^-(r,t)\, \delta E_B^+(r,t)|\varphi\rangle, \qquad (4.6)$$

where $|\varphi\rangle$ is the state of the field entering B. Such a positive term can only increase photon noise. On the other hand, the sign of the second term depends on the value of cos ψ (we can suppose $C_2 > 0$ in eq. (4.5)). By varying the phase of the field $\mathcal{E}_A$, we can actually achieve cos $\psi = 1$ and thus $C = C_0 - C_2$. Photon noise is thus reduced when $C_2 > C_0$. The present treatment taking into account coherence effects confirms that photon noise can be reduced by homodyning a squeezed field by a coherent one [14–17].

4.2. Matching of the two input fields

We now discuss how the time and space dependence of the A and B fields have to be matched in order to increase the factor C_2 (see (4.5)) which is responsible for photon noise reduction. We will consider first the simple case where the A field is a plane monochromatic wave with frequency ω_A.

Consider the double time integration appearing in (4.5) and let us introduce the new variables

$$\theta = (t + t')/2; \quad \tau = t - t'. \qquad (4.7)$$

The factor $\mathcal{E}_A^-(r,t)\ \mathcal{E}_A^-(r',t')$ varies as $\exp(2i\omega_A\theta)$ and is independent of τ. The correlation function F_B^{++} varies as $\exp(-2i\omega_B\theta)$, where ω_B is the mean frequency of the B field, and also depends on τ. When $\omega_A \neq \omega_B$, the integral over θ therefore vanishes. If we want to reduce photon noise, we must take $\omega_B = \omega_A$. In other words, we must achieve a "time matching" of the two input fields. The integral over θ gives in this case a factor T (measurement time). Note that the integrand in (4.4) does not depend on θ so that the C_0 term is proportional to T even if $\omega_A \neq \omega_B$.

Consider now the space integration in (4.5). Since the A field is a plane wave, $\mathcal{E}_A^-(r,t)$ and $\mathcal{E}_A^-(r',t')$ do not depend on the position of r and r' on the photocathodes. Suppose then that F_B^{++} only depends on a reduced space variable ρ. The double space integration in (4.5) thus gives a factor S (detection area) on one hand and an integral over ρ on the other hand. This corresponds to a "space matching" of the two fields.

In such a case, expressions (4.4) and (4.5) can be simplified. Noting that

$$\bar{N}_A = \mathcal{C}|\,\mathcal{E}_A|^2 ST \qquad (4.8)$$

($|\mathcal{E}_A|^2$ is constant for a plane wave), we can write (supposing $S \gg \sigma_c$, $T \gg \tau_c$):

$$Q = C/\bar{N}_A = Q_0 - Q_2 \cos\psi, \qquad (4.9)$$

with

$$Q_0 = 2\iint d\tau\, d^2\rho\, F_B^{-+}(\rho,\tau), \qquad (4.10)$$

$$Q_2 = |2\iint d\tau\, d^2\rho\, F_B^{++}(\rho,\tau)| \qquad (4.11)$$

(ρ is the reduced space variable; it is equal to $r - r'$ in (4.10) but not necessarily in (4.11)). The expression (3.5) of the photon noise becomes

$$\Delta N^2 = \bar{N}_A(1 + Q) + \bar{N}_B. \qquad (4.12)$$

This generalizes (1.6) but the correlation factor Q now appears as a space–time integral over the coherence volume $\sigma_c\tau_c$ of some correlation functions of the B field.

Suppose for example that the correlation functions of the B field vary as $\exp(-|t - t'|/\tau_c)\exp(-\rho^2/2\sigma_c)$. One thus gets

$$Q_0 = 2(2\tau_c)(2\pi\sigma_c) F_B^{-+}(0,0), \qquad (4.13)$$

$$Q_2 = 2(2\tau_c)(2\pi\sigma_c)|F_B^{++}(0,0)|. \qquad (4.14)$$

Coming back to the definition (4.1) of the correlation functions (see also (2.3)), one notes that Q_0 and Q_1 have the meaning of a number of photons in the coherence volume $\sigma_c c\tau_c$.

The case of plane waves studied above is very crude. The A and B fields have generally a curvature which cannot be neglected. The principle of space matching remains however valid. One must adjust the curvatures of the two fields so that the product appearing in (4.5) does not depend on two variables but only one. With such a space matching, the double space integral of (4.4) and (4.5) reduces to the product of the detection surface S by a single space integral where the coherence area σ_c of the B field appears.

4.3. Generalization to a bichromatic field

Suppose now that the A field is a bichromatic field with two frequencies $\omega_A + \nu$ and $\omega_A - \nu$.

The factor $\mathcal{E}_A^-(r,t)\,\mathcal{E}_A^-(r',t')$ thus contains two types of terms. The "squared" terms where the two $\mathcal{E}_A$ evolve at the same frequency will give non zero contribution when this frequency, $\omega_A + \nu$ or $\omega_A - \nu$, is equal to the mean frequency ω_B of the B field (see the previous section for the discussion of such terms). The "crossed" term varies versus θ and τ (see (4.7)) as $\exp(2i\omega_A\theta)\exp(\pm i\nu\tau)$. The time matching (non vanishing θ integral) thus requires $\omega_A = \omega_B$: the two frequencies of the A field have to be symmetric with respect to the mean frequency of the B field. The new feature of these crossed terms is the appearance of oscillating factors $\exp(\pm i\nu\tau)$ in the integrals (4.10) and (4.11). In other words, we now take the Fourier transform of the correlation function of the B field at frequencies $+\nu$ and $-\nu$ rather than at frequency 0 as in (4.10) and (4.11). This extra degree of freedom (choice of ν) can be interesting for two reasons. First, it is well known that other noise sources can be important at very low frequency but much reduced at higher frequency. Second, it allows to use for photon noise reduction, squeezed fields such that the spectrum of the correlation functions appearing in C_2 is important at non zero frequency.

5. Conclusion

We have presented in this paper a quantitative evaluation of photon noise in an interferometric experiment. In the interesting case where the two input fields in A and B are respectively a coherent field (A) and a squeezed field (B), photon noise can be reduced. We have expressed the corresponding reduction factor in terms of space–time integrals of well defined correlation functions of the B field and shown that the reduction of photon noise is quite sensitive to the coherence properties of the B field.

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