

Homodyne detection

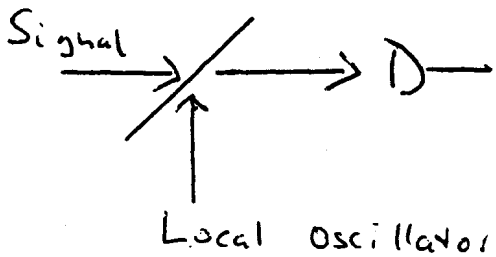
(B.L. Schumaker, Opt. Lett. 9, 183 (1984))

$$E = i \sqrt{\frac{\hbar \omega}{2\epsilon_0 V}} \hat{\epsilon} [a e^{i(\lambda r - \omega t)} - a^\dagger e^{-i(\lambda r - \omega t)}]$$

Heisenberg rep.

One-port homodyning

$$= -2 \sqrt{\frac{\hbar \omega}{2\epsilon_0 V}} \hat{\epsilon} [a_1 \sin(\lambda r - \omega t) + a_2 \cos(\lambda r - \omega t)]$$



Photodetector

quadrature operator

$$a_1 = \frac{1}{2}(a + a^\dagger)$$

$$a_2 = \frac{1}{2i}(a - a^\dagger)$$

Transmission
Reflection

$$T = t^2$$

$$1 - T = r^2$$

of beam splitter

Signal

$$a = \underbrace{A_1 + \Delta a_1}_{\cos \omega t} + i \underbrace{(A_2 + \Delta a_2)}_{\sin \omega t}$$

$a_1, a_2, \Delta a_1, \Delta a_2$
Operators

A_1, A_2 Numbers

$$A_1 = \langle a_1 \rangle$$

Local oscillator

$$b = B_1 + \Delta b_1 + i \Delta b_2$$

($\cos \omega t + \text{noise}$)

Photocurrent I is proportional to

$$I \propto (t a + r b)^2 = r^2 B_1^2 + 2 r t A_1 B_1 + 2 r B_1 (\tau \Delta b_1 + t \Delta a_1)$$

Strong LO limit $r^2 B_1^2 \gg t^2 A_1^2$

[phase sensitive detection of only the $\cos \omega t$ quadrature component]

Signal current:

$$2 r t A_1 B_1$$

noise

$$I^2 - \langle I \rangle^2 = [2 r B_1]^2 (\tau^2 \Delta b_1^2 + t^2 \Delta a_1^2)$$

$$SNR = \frac{t A_1}{[t^2 \langle \Delta a_1^2 \rangle + (1-t^2) \langle \Delta b_1^2 \rangle]^{1/2}}$$

Maximum (and independent of LO noise) if $t \approx 1$ (with $(1-t^2)B^2$ finite).

It seems that attenuated high power LO has less noise than low power LO.

Indeed, attenuation by a factor r attenuates both

B_1 and Δb_1 . For a minimum uncertainty state

(coherent state) $\langle \Delta b_1^2 \rangle = 1/4$ [in units which

$$\text{give } B_1^2 = \# \text{ of photons } N; \quad \langle (B_1 + \Delta b_1)^2 \rangle \approx N + 2B_1 \Delta b_1$$

$$\langle (B_1 + \Delta b_1)^4 \rangle \approx N^2 + \frac{4N \langle \Delta b_1^2 \rangle}{N} = N^2 + N \quad \text{Shot noise}$$

In a certain sense, attenuation even attenuates the minimum uncertainty Δb_1 !

However, For vanishing signal $A_1 \rightarrow 0$, the

photocurrent is $r^2 B_1^2$ with a noise of $2r B_1 (r^2 \langle \Delta b_1^2 \rangle + (1-r^2) \langle \Delta a_1^2 \rangle)^{1/2}$.

With $N_r = r^2 B_1^2$ (number of photons after attenuation):

$$\text{noise} = 2\sqrt{N_r} (r^2 \langle \Delta b_1^2 \rangle + (1-r^2) \langle \Delta a_1^2 \rangle)^{1/2}$$

With $\Delta b_1^2 = 1/4$ this would be below shot noise,

if one could have $\Delta a_1^2 = 0$. However, even the

Vacuum Fluctuations have $\Delta a_1^2 = 1/4$, thus

$$[r^2 \langle \Delta b_1^2 \rangle + (1-r^2) \langle \Delta a_1^2 \rangle]^{1/2} \geq 1/2 \text{ and noise} \geq \sqrt{N_r}$$

However, if the vacuum is squeezed in the quadrature component 1, the combined beam has reduced fluctuations in this quadrature component.

Thus it is correct to say that attenuation (\hat{A} beam splitter) attenuates the noise even below the minimum uncertainty; but the open port of the beam splitter couples in the vacuum fluctuations thus reestablishing the minimum uncertainty. A Squeezed vacuum generates therefore a Squeezed transmitted beam.

This was recently used to do spectroscopy with squeezed light (Kimble et al., Phys. Rev. Lett., 68, 3020 (1992)).

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8.422 Atomic and Optical Physics II
Spring 2013

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