ELSEVIER

6 March 1995

PHYSICS LETTERS A

Physics Letters A 198 (1995) 286–294

Optimized phase detection

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Received 20 October 1994; revised manuscript received 8 December 1994; accepted for publication 3 January 1995
Communicated by P.R. Holland

Abstract

We analyze the detection of the phase of a single mode of the field with respect to a local oscillator, with the aim of optimizing the sensitivity as a function of the radiation intensity. We found that ideal scaling of sensitivity versus input energy is achieved for the open double homodyne detector in the limit of unit quantum efficiency.

1. Introduction

Despite the problem of phase detection having a long history, only recently it has been applied to actually feasible phase-detectors (see for example Refs. [1,2], and references therein). The relevance of the topic lies in the possibility of interferometric detection of minute variations of environmental parameters through the induced phase shift on the incident light beam. The optimization of such measurements versus the radiation intensity is of interest, because back-action effects due to radiation pressure pose severe limits to the energy carried by the input field.

The most appropriate approach to describe phase detection in the quantum domain is the quantum estimation theory of Helstrom [3]. The detection apparatus is described by means of a probability operator measure (POM) $\mathrm{d}\mu(\phi)$, which provides the probability distribution of the phase outcomes for the field in the state ρ according to the formula

$$\mathrm{d}P(\phi) = \mathrm{Tr}[\rho\,\mathrm{d}\mu(\phi)]\ . \tag{1}$$

Actually, every POM corresponds to a conventional observable which acts on a larger Hilbert space describing also the apparatus degrees of freedom. At a purely abstract level the quantum estimation theory provides the following POM for an ideal apparatus,

$$\mathrm{d}\mu(\phi) = \frac{\mathrm{d}\phi}{2\pi}\sum_{n,m=0}^{\infty}\exp[\mathrm{i}(n-m)\phi]\,|n\rangle\langle m|\ . \tag{2}$$

The best r.m.s. sensitivity $\delta\phi$ in this case is achieved by weakly squeezed states [2], giving the ultimate quantum limit

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SSDI 0375-9601(95)00009-7