Single-Photon Quantum Non-Demolition Measurements*

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Introduction

1. QND devices measure observables and couple the back-action noise to the conjugate of the measured quantity.

2. Optical QND devices are usually considered in the context of photon-number measurements.

3. One can perform such a measurement with a so-called Kerr nonlinearity, which is extremely small.

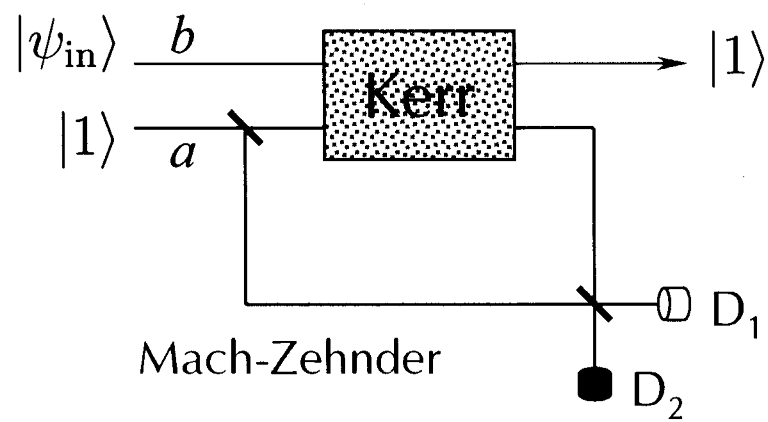
4. Here, we present a scheme to implement a single-photon quantum nondemolition device with only linear optics and projective measurements.

QND using Kerr nonlinearities

A photon-number quantum nondemolition device based on the Kerr effect.

A photon in mode b changes the phase of the photon in mode a. This phase shift can be measured with a Mach-Zehnder interferometer.

However, the Kerr effect is extremely small.



Quantum nondemolition measurement of the photon number via the optical Kerr effect, N. Imoto, H.A. Haus, and Y. Yamamoto, Phys. Rev. A **32**, 2287 (1985).

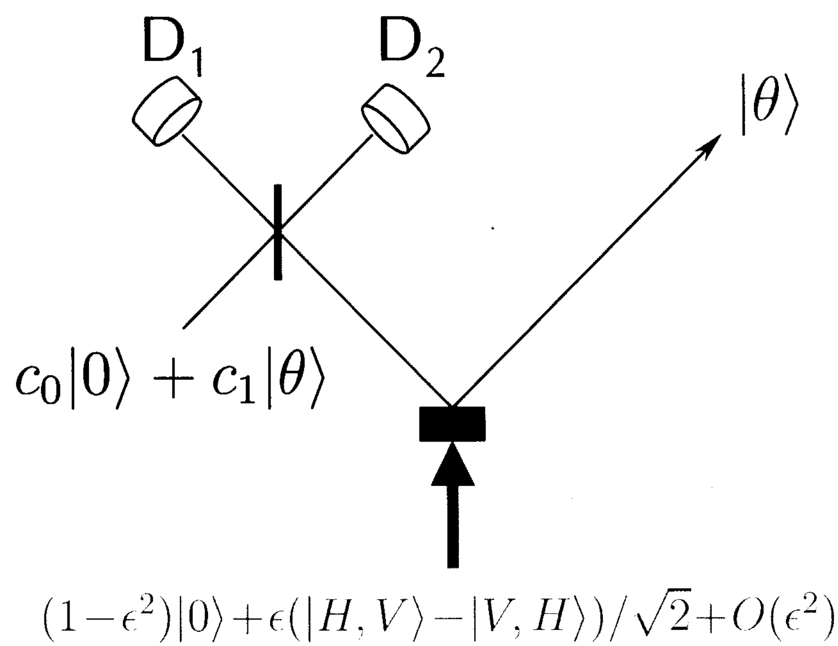
Figure I

Teleportation-based QND

Relaxing conditions:

1. We only wish to detect the presence of a single photon.
2. The detection does not need to be deterministic.

This scheme breaks down when there is more than one photon in the input mode.



In: *Single-photon quantum nondemolition detectors constructed with linear optical and projective measurements*, P. Kok, H. Lee, and J.P. Dowling, submitted to Physical Review A.

Figure II

Polarization-independent QND

The detection of a photon in D_1 and D_2, while nothing happens in D_3, signals the presence of a single photon in the input state. With the appropriate beam splitter transmission coefficients the probability of such an event is $4/27 \cong 15\%$.

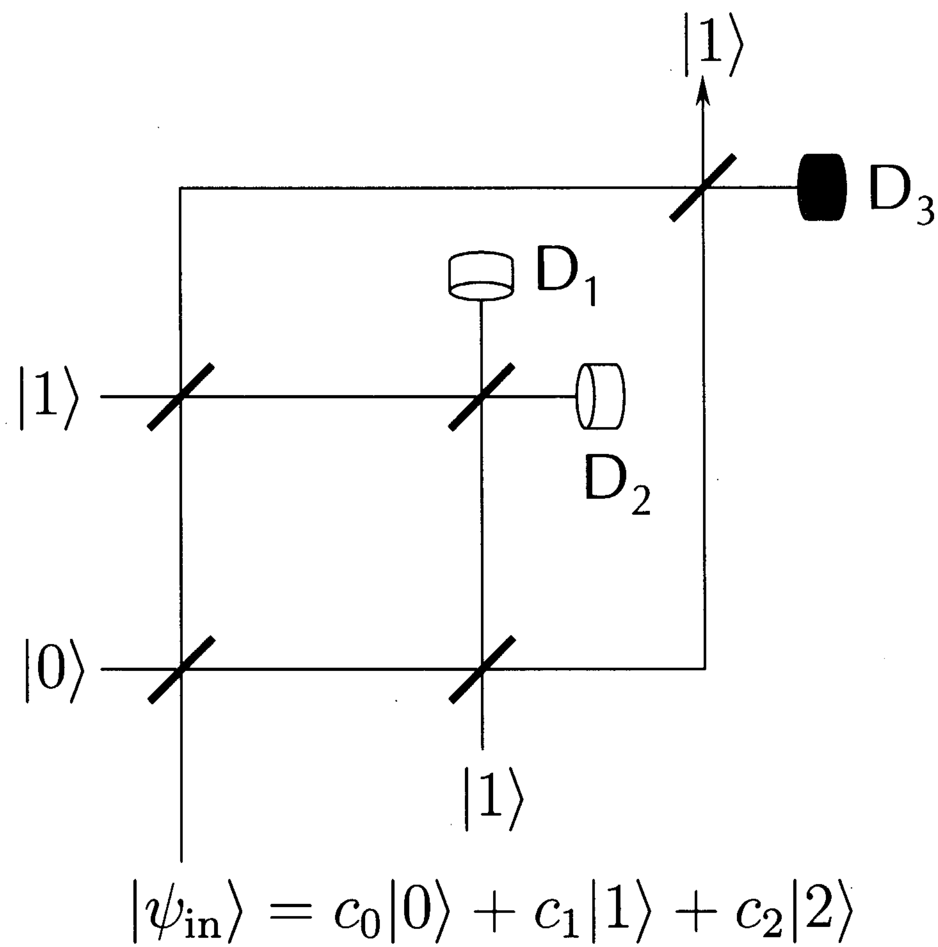


Figure III

Polarization-preserving QND

The detection of four photons in D_1, D_2, D_3, and D_4 signals the presence of a single photon with arbitrary (possibly unknown) polarization in the input state. The probability of such an event is $(4/27)^2 \cong 2\%$. R is a polarization rotation of $\pi/2$.

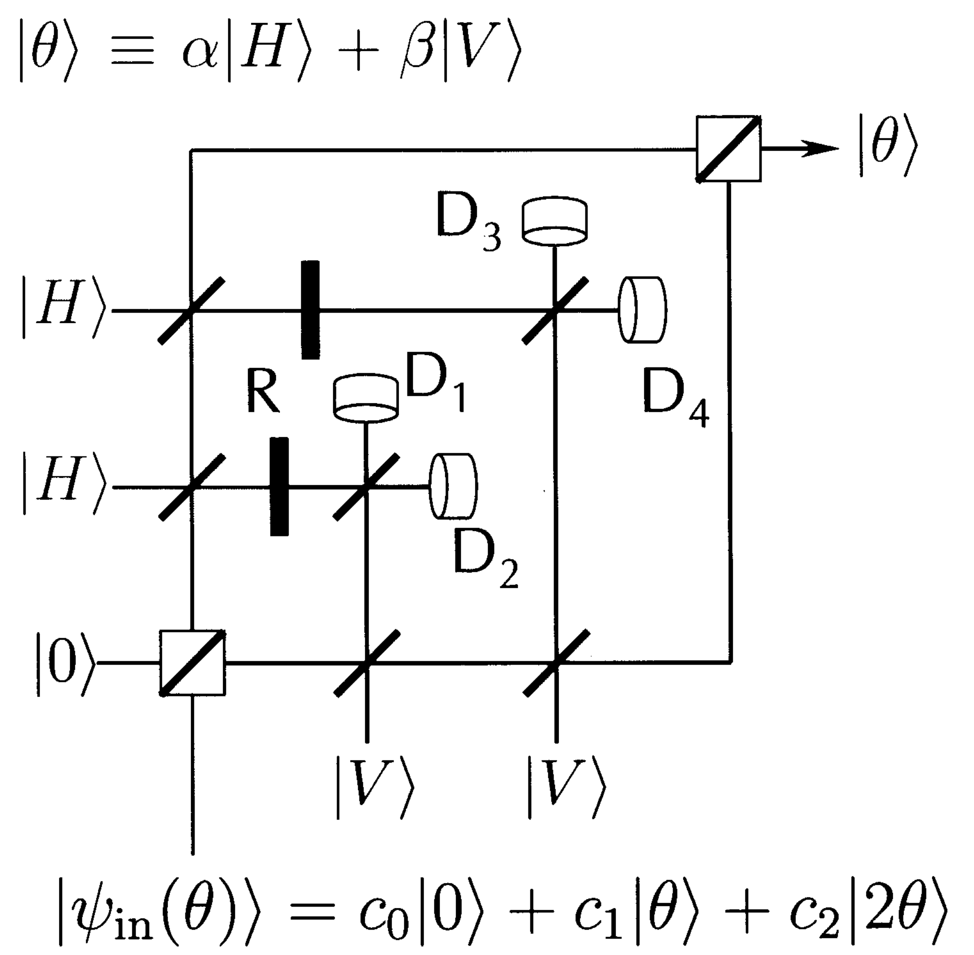


Figure IV

The effect of inefficient detectors

In general, we define the fidelity as:

$$F \equiv \mathrm{Tr}[\rho_{\mathrm{out}}|\psi\rangle\langle\psi|] \leq 1$$

The different curves correspond to different input states ($\gamma \equiv |c_2|^2/|c_1|^2$).

Surprisingly, the polarization-preserving QND device is significantly more robust against detector losses.

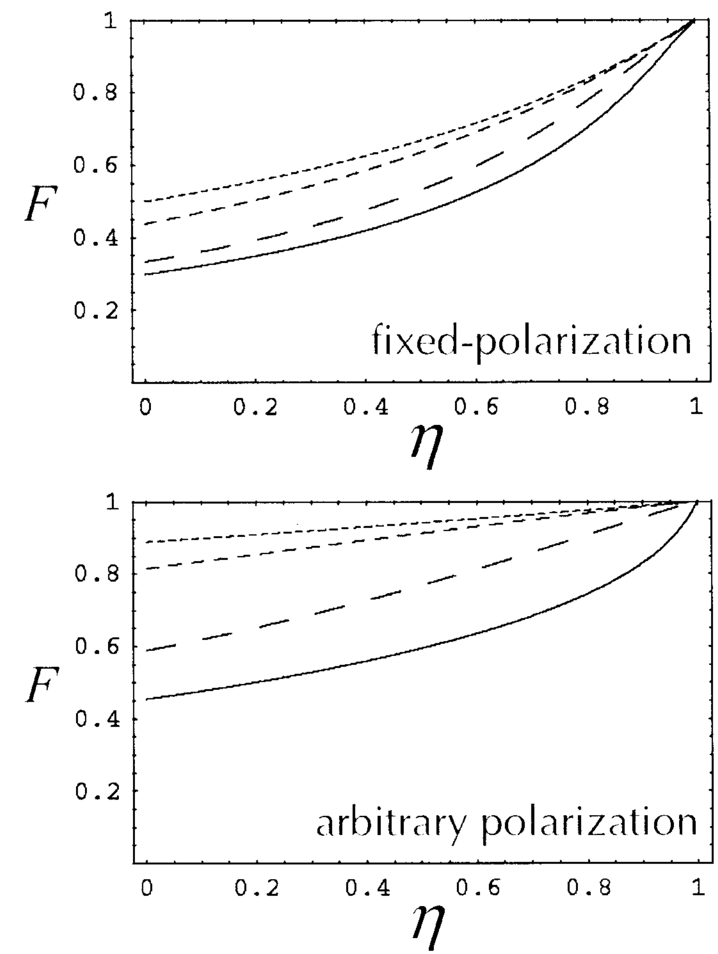


Figure V

Conclusions

We presented an optical interferometric quantum nondemolition device using only linear optics and projective measurements. The device can faithfully identify single photons from optical states containing up to two photons. The effective efficiency of the QND detector is 4/27 and lower.

Further research will have to determine to what extent projective measurements can replace Kerr nonlinearities.

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