Noiseless signal amplification with phase sensitive multimode parametric down conversion

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Noiseless amplification of signals is important for high-resolution measurements and imaging processes when it is needed to detect low signals [1] or low difference of signals [2]. However, amplifiers can add additional noise and therefore the sensitivity of these measurements is limited by noise factor of the amplifier [3]. It is well known that in ideal case one-mode degenerate parametric amplifier does not induce additional noise, so that signal to noise ratio (SNR) is not changed, while non-degenerate parametric amplifier does. In the case of quantum imaging high spatial resolution is needed and so a multi-mode amplifier should be used.

In this work we consider parametric down conversion process (PDC) in a nonlinear crystal and investigate the possibility to amplify the signal with maximal possible SNR. For non-degenerate regime we seed the crystal only in one channel (signal for example), although the output signal is non-zero in both channels (signal and idler) it will not depend on the phase between the seed and the pump (phase insensitive regime). However, in degenerate regime phase sensitivity is expected. To characterize it we introduce visibility, or the ratio of difference between signal minimum and maximum to the maximum. The visibility of the signal is strongly connected with noise factor (the relation of SNR at the input to SNR at the output). If visibility is 1 the noise factor will be 1, which is the best regime that can be achieved with parametric amplifiers.

Firstly, we develop methods of getting the highest visibility by changing spatial properties of the seed. A Gaussian spatial seed is taken. Its width and the central angle are varied. At very small spatial width it is similar to a spherical wave and at high spatial width it is a plane wave. In far field photons with opposite transverse wave-vectors are correlated. Consequently, by plane-wave we seed only one channel and so the amplification is phase insensitive. For a spherical wave we seed correlated channels and the regime is phase sensitive. However, good visibility can be achieved in the high-gain regime only. One of the goals is to determine the optimal width providing high visibility of the phase sensitivity. It is found that this value is determined by PDC spatial spectra width. Finally, similar analysis is performed in the frequency domain. A pulsed seed is considered and its parameters optimal for the noiseless phase-sensitive amplification are found.

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References

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