Spatial Confinement Picture Of Excess Quantum Noise

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Abstract

Excess quantum noise in unstable resonators can be interpreted as the spatial confinement of vacuum noise fluctuations. A wide range of computer simulations demonstrating this process in both 1D and 2D cavities will be presented.

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The phenomenon of excess quantum noise admits a variety of different definitions and interpretations. On the one hand, the excess noise (Petermann) factor for a laser mode $u_n(\underline{r})$ can be defined as

$$K_n = \frac{1}{|\int u_n(\underline{r}) v_n(\underline{r}) \underline{dr}|^2}$$

where $v_n(\underline{r})$ is the adjoint of $u_n(\underline{r})$. In an unstable resonator, strong cancellation can occur in the overlap integral leading to large values of K_n. On the other hand, K_n can be shown to be mathematically identical to the Injected Wave Excitation (IWE) factor which quantifies the power advantage gained by time-reversed excitation of a mode, as opposed to traditional mode matching [1-2]. New [1] presented a numerical demonstration of the equivalence of the IWE and K_n-factors, while van Eijkelenborg et al [2] have developed a simple formula for the IWE factor (and hence K_n) based on a geometrical argument.

Both [1] and [2] suggest an interpretation of excess noise in which vacuum noise fluctuations become confined within a laser resonator, and gain a power advantage over the self-reproducing mode during the period that they remain trapped. If one envisions an unstable resonator laser with single-sided output coupling (wavevector $+\underline{k_i}$), vacuum fluctuations with the same wavevector will give rise to standard laser noise properties. However, vacuum fluctuations with wavevector $-\underline{k_i}$ have to perform many passes through the resonator before they are finally coupled out with wavevector $+\underline{k_i}$. The differential multipass gain felt by these vacuum fluctuations corresponds to the excess noise factor.

We will present a wide range of numerical demonstrations of the IWE process that corroborate the picture outlined above. While previous simulations of IWE have all been for the lowest-order even mode in unstable 1D strip resonators, we will report on recently-developed techniques for computing accurate higher-order mode profiles that enable this restriction to be lifted. Ways of calculating the associated IWE factors will also be discussed while excess noise computations in novel 2D resonators will be presented for the first time.

Other recent excess noise results will be summarised. In particular, we have explored the extension of the numerical and semi-analytical results of [1] to cover the low Fresnel number regime, in which most of the recent experimental work has been performed.

[1] G.H.C. New, J. Mod. Opt. **42** (1995) 799.

[2] M.A. van Eijkelenborg, A.M. Lindberg, M.S. Thijssen and J.P. Woerdman, Phys. Rev. A **55** (1997) 4556.