Higher Order Spectral Line Distribution of the Laser

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The photon statistical distribution for the stead-state laser well above threshold can be considered as Poissonian. However, for example, a typical Helium-Neon laser is substantially different from a Poissonian distribution. The quantum noises which are responsible for the fluctuations in the number of photons in the laser field are also responsible for the phase fluctuations which lead to the finite linewidth of the laser. The noise of the instantaneous frequency gives a Lorentzian shape of the emission spectrum, which is well known as the Schawlow–Townes linewidth [1]. The determination of the mean value of the laser field \( \langle E^-(t) \rangle \) would yield the laser linewidth, which is related to the off-diagonal element of the laser density matrix [2]

\[
\langle E^-(t) \rangle \sim \sum_{n=0}^{\infty} \sqrt{n+1} p_n^{(1)}(0) e^{-Dt},
\]

Here we report an experimental study of the higher-order spectral line distribution of the laser field, which related to the higher-order off-diagonal elements of the laser density matrix. Off-diagonal elements of the density matrix vanish at steady state, regressing to zero as

\[
\rho_n^{(k)}(t) = \rho_n^{(k)}(0) e^{k^2 Dt}
\]

Figure 1 Experimental results of the ¹st order, ²nd order, and ³rd order Lorentzian spectral profiles. The estimated bandwidths are 107.9 kHz, 420.6kHz, and 963.3kHz, respectively. The black dots are experimental data and the red curves are theoretical fittings.