The Laser Linewidth

It is commonly assumed that the linewidth of a continuous-wave (cw) laser is given by the Schawlow-Townes equation which results from a phase change introduced to the coherent state of photons by spontaneous emission. It is believed [O. Svelto, “Principles of Lasers”, 4th ed., Springer, New York, 1998, p. 292] that “since these fluctuations can be treated correctly only by a full quantum electrodynamics approach, derivation of the expression for this limit is beyond the scope of our present treatment” (means: a full book!). In this talk, I will show that the linewidth of any three-level or four-level, transient or cw laser below or above its threshold, for its gain being smaller (cw laser) or larger (transient, e.g. Q-switched laser) compared to its losses, can be derived from three revealingly simple equations. The laser eigenvalue, defined as the ratio of photons coupled out of the resonator divided by those photons not replaced by stimulated emission, emerges as the fundamental parameter describing the coherence of a laser. It relates the coherence time, Q-factor, and linewidth of a lasing resonator to the corresponding parameters of the underlying passive resonator, thereby unifying resonator and laser theory. Applying to the laser linewidth the approximations made by Gordon, Zeiger, and Townes [Phys. Rev. 99, 1264 (1955)] and Schawlow and Townes [Phys. Rev. 112, 1940 (1958)], the Schawlow-Townes equation easily derives in a single line as a three-fold approximation of the cw-laser linewidth. Unlike often assumed, the Schawlow-Townes approximation does not represent a fundamental limit to the laser linewidth. Coupling of the atomic system to the laser field, resulting in the formation of a Mollow triplet, can reduce the laser linewidth by a factor of two. These results were obtained in collaboration with Dr. Marc Eichhorn (ISL, St. Louis, France). I will briefly present an ultranarrow-linewidth laser on a silicon chip.