Double Frequency Combs and Coherent Parametric Mechanism of Self-Mode Locking in the Superradiant Lasers

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We report on finding an intriguing regime of formation of double frequency combs due to simultaneous generation of two trains of superradiance pulses and soliton-like pulses in a CW multi-mode class C laser. We consider a 2-level 1D laser model with a low-Q combined Fabry-Perot – distributed-feedback cavity supporting two broadband superradiant modes and many quasi-monochromatic self-locked modes under a condition of double resonance: (i) the latter modes have an intermode spacing two times less than a frequency spacing between the superradiant modes (a parametric resonance), (ii) a pulse-repetition interval for each superradiant mode is multiple of a pulse-repetition cycle of the self-mode-locked solitons (a timing resonance).

Numerical modeling of Maxwell-Bloch equations reveals (a) a novel parametric coherent self-mode-locking and (b) a timing resonance of a superradiant-pulse and soliton-pulse trains formed under CW pumping of an active medium with a strong inhomogeneous broadening of its spectral line and active-center polarization lifetime of the order of the photon lifetime in the cavity [1,2].

The predicted parametric coherent self-locking of some of the quasi-equidistant modes takes place in the general case of a broadened continuous spectrum of superradiant modes, even if a superradiant-pulse train is not strictly periodic. The only important condition is the presence of significant superradiant spectral components, with the intermode spacing being double of that for the quasi-monochromatic modes. According to this mechanism, the intracavity soliton formation and, hence, a periodic lasing occurs without using any additional mode-locking techniques [2,3].

If the superradiant pulse train is almost periodic, then the self-mode-locking becomes more robust and results in a more stable soliton pulse under the condition of timing resonance when a ratio of periods in the superradiant-pulse and the soliton-pulse trains is an integer. In this case, the CW superradiant laser generates two frequency combs with the integer-fold spacings [3,4]. The most effective mode-locking and phasing of two combs related to the two aforementioned pulse trains with integer-fold periods occur in the presence of the main parametric resonance when the frequency difference of some discrete spectral components of two superradiant modes is exactly twice the intermode spacing of the quasi-monochromatic modes.

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