Simple model of self-phase modulation spectral patterns in optical fibres

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Self-phase modulation (SPM) has been extensively studied for several decades in optical fibers. This phenomenon manifests itself by a change of the frequency spectrum of a pulse, owing to the nonlinear index variation that follows the temporal evolution of the pulse. In the general case, the spectrum of the transmitted pulse cannot be calculated analytically and only approximate or rms expressions giving the bandwidth of the transmitted spectrum are used.

In this paper, we present a novel theoretical treatment of SPM based on a spectral interference model. We show that a two-wave interference process is sufficient to describe the main features of the SPM-broadened spectra of initially Fourier-transform limited pulses or pulses with an initial positive linear chirp, and to accurately predict the extreme values of the spectra. The latter provide a more plausible measure of the spectrum extent than the rms width. Simplified but fully tractable closed formulae are derived for the positions of the outermost peaks of the spectra, which are particularly relevant to several recent applications of SPM. In the case of negatively chirped input pulses, the description of the SPM spectral patterns requires the inclusion of a third wave in the interference model.

Our spectral interference approach can also help better understand qualitatively the genesis of peculiar spectrum shapes of laser pulses, such as the batman ear spectra observed in all-normal dispersion lasers or Mamyshev oscillators. While the present discussion focuses on SPM, the concept can also be applied to other nonlinear modulations of the phase of a pulse, such as the modulation generated by cross-phase modulation or an external modulator.