Characterisation and mitigation of self-phase modulation in optical fibres

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Self-phase modulation (SPM), one of those very fascinating effects discovered in the early days of nonlinear optics, refers to the phenomenon by which an intense optical pulse propagating in a Kerr medium (e.g., an optical fibre) induces through the nonlinearity of the medium a modulation of its phase that is proportional to its own intensity profile. This time-dependent phase change is associated with a modification of the optical spectrum, which depends on the initial frequency modulation (chirp) of the pulse electric field. If the pulse is initially Fourier-transform-limited or up-chirped, SPM leads to spectral broadening, whereas an initially down-chirped pulse is spectrally compressed by the effects of SPM. For strong SPM, the optical spectrum can exhibit strong oscillations.

In this work, firstly we present a simple theoretical approach to predict the main features of optical spectra affected by SPM, which is based on regarding the optical spectrum modification as an interference effect [1]. The typical oscillatory character of the spectrum indeed originates from strong excursions of the instantaneous frequency, so that in general there are contributions from different times to the Fourier integral for a given frequency component. Depending on the exact frequency, these contributions may constructively add up or cancel each other. A two-wave interference model is found sufficient to describe the SPM-broadened spectra of initially transform-limited or up-chirped pulses, whereas a third wave should be included in the model for initially down-chirped pulses. Simple analytical formulae are derived which accurately predict the positions of the extrema of the spectrum.

Secondly, we discuss a simple technique to suppress undesirable SPM of optical pulses in fibre-optic systems, which is based on using an electro-optic phase modulator to impart the opposite phase to the pulses and, thus, emulates the use of a material with a negative nonlinear index of refraction. We present a proof-of-principle experiment demonstrating that for input pulses with standard intensity profiles, such as Gaussian or hyperbolic secant pulses, the use of a simple sinusoidal drive signal for the phase modulator with appropriate amplitude and frequency is sufficient to reduce the nonlinear spectrum broadening to a large degree, and to significantly enhance the spectral quality of the pulses while their temporal duration remains unaffected [2]. Further, we present an in-depth characterisation of the SPM mitigation by a sinusoidally time varying phase based on analytic results and numerical simulation of the governing equation [3]. We assess the effects of the initial pulse shape and duration on the effectiveness of the technique, and we highlight the differences between pre- and post-propagation compensation schemes.

References

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