Supercontinuum in telecom applications

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Abstract: We provide a general overview of spectral broadening and SC generation applications in fiber-optic telecommunications from a historical perspective, with a particular focus on the most recent developments.

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Supercontinuum (SC) generation, first observed in 1970 by R. R. Alfano and S. L. Shapiro in bulk borosilicate glass [1], is an non-linear phenomenon arising from synergic combination of several fundamental processes, most important of which are self-phase modulation (SPM), four-wave mixing (FWM) and stimulated Raman scattering (SRS). The interplay between these effects has a substantial impact on important SC properties such as homogeneity and coherence. These interactions are determined by the pumps' spectral locations and powers and the non-linear and dispersive characteristics of the medium. Highly nonlinear fibers (HNLFs) and particularly photonic crystal fibers (PCFs) [2] offer interesting opportunities to control SC generation, being specially tailored waveguides with the desirable dispersive and non-linear properties [3, 4], and thus SC generation and spectral broadening of coherent or partially coherent light in optical fibres have captured much attention over the past couple of decades. Fiber-optic based supercontinuum presents multiple practical applications both within and outside the field of optical communications, and the interest in this phenomenon has led to an improved knowledge of the interplay between the different non-linear processes affecting high-power radiation evolution in optical fibre waveguides. By applying techniques such as frequency-resolved optical gating (FROG) or its variant GRENOUILLE [5-8], and spectral-phase interferometry for direct electric-field reconstruction (SPIDER) [9], researchers have been able to painstakingly analyse nonlinearly-broadened radiation, improve on the models used to describe the broadening process and increase our understanding of the phenomenon. From a practical point of view progress has also been impressive, allowing for example, for the generation of high-power supercontinuum radiation with spectra extending thousands of nm [10-14]. Large spectral broadening and SC in optical fibre at telecom wavelengths was first demonstrated in [15, 16], while the use of PCF for SC generation was demonstrated in 1999 in [17]. Despite important recent advances in SC studies, and in spite of a good knowledge of the main mechanisms of SC generation [18], some fundamental problems are yet to be explored, and the complex interplay of intervening factors can be elusive. Important topics for basic research have included the study of noise and coherence properties [19] of SC, the effect of polarisation [20] in the non-linear broadening process, the observation of extreme events such as rogue waves [21], or the formulation of a general theory based on wave turbulence [22], to name a few.

Application-wise, a healthy fraction of the current research is focused on exploitation of fiber-optic spectrally broadened radiation, whether in bio-medical optics, where it allows for the improvement of longitudinal resolution in optical coherence tomography by more than an order of magnitude; in optical frequency metrology, where extraordinary breakthroughs have been achieved [23, 24]; or in other areas from material science to telecommunications. Note that in telecoms the ultra-large broadening associated with SC generation is often not a desirable feature at all, and many useful applications require moderate or even minimal spectral broadening of the signal or pumping wave [25]. Research conducted over the past 20 or so years has convincingly demonstrated the possibility of efficient telecom applications relying on SC techniques, mostly in WDM and DWDM technologies using large numbers of channels with different wavelengths. However, despite their promise, these technologies have yet to be widely adopted in the industry. Most probably, considerations about poor resilience to master oscillator or amplifier failure, or difficulties in the generation of uniform radiation parameters over a broad spectral range have played a role in delaying their adoption. Still, improvements to the reliability of the components used in SC generators and the development of methods to better equalise SC radiation parameters within a broad spectral range might yet allow SC technologies to fully realize their potential and bring them into into mainstream telecommunication applications. The aim of our presentation will be to provide the reader with a general overview of the recent development of spectral broadening applications and SC generation in the particular area of optical communications. We will talk about applications in areas such as pulse compression and short pulse generation [26, 27], pulse train generation at high repetition rates [28, 29], multi-wavelength optical source, including those for superchannel and coherent communications [30, 31], all-optical analogue-to-digital conversion, TDM-WDM-TDM [32] conversion and fibre characterization and metrology [33], to name a few.

2. References

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