Distributed measurement of supercontinuum in an optical fiber using a reflectometry technique

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The supercontinuum generation is the spectral broadening of an intense light arising from the interplay between several nonlinear optical effects. Although it is easy to measure the spectrum at the end of the fiber, the only way to get an insight of what is happening along the fiber is to apply the cut-back method, which leads to the destruction of the fiber. In this paper, we propose an non-destructive optical time domain reflectometry set-up to perform a distributed measurement of the light spectrum. As a preliminary step, we applied the proposed set-up to the characterization the modulation instability evolution along a telecom optical fiber.

Introduction

Supercontinuum generation (SGC) consists in the development of a broad continuous spectrum when high power pulses propagate through a nonlinear medium. It was first observed in 1970 by Alfano and Shapiro [1]. During the past decade, SGC has been extensively studied in optical fibers since the light confinement in the core provides a high nonlinear efficiency [2]. The complexity of the nonlinear phenomena interplay underlying the spectral broadening is the main research topic on the subject. Its metrology has not yet been fully explored. Although it is easy to measure the spectrum at the end of the fiber, the only way up-to-now to have an overview of what is happening along the fiber, is the cut-back method, which leads to the destruction of the fiber. In this paper, we first propose an experimental tool based on an optical reflectometry approach for a nondestructive measurement of the SC spectral evolution. We then present the first experimental results related to the characterization on the modulation instability (MI) gain spectrum evolution. Distributed measurements of MI have already been presented in [3]. However, in this paper, the measurement is performed for the first time in a long DSF optical fiber.

Experimental Set-up

The proposed generic experimental step-up is described in Figure 1. The principle relies on replacing the low power broadband source of the OTDR (optical time domain reflectometer) by a high power monochromatic tunable source. The source included in the OTDR emits optical pulses that are sent to a detector that provides at its output an electrical pulse train used for synchronizing an electrical pulse generator. The latter generates a pulse train having a repetition rate identical to that of the OTDR. The pulse duration determines the spatial resolution of the measurement. The electrical signal generator is used to modulate a continuous laser source. The optical pulses are then amplified by an EDFA (Erbium Doped Fiber Amplifier) to obtain the peak power level needed for the SCG.

TBF1 (Tunable Bandpass Filter) centered on the wavelength of the laser aims to filter out the majority of the EDFA noise. A coupler then directs the amplified pulses into the fiber under test. At the fiber input, we obtained a pulse signal having the same repetition rate as the signal transmitted by the OTDR and having the desired characteristics for the supercontinuum generation (wavelength pump, peak power and pulse duration). When the high peak power pulses propagate in the fiber, a supercontinuum spectrum is growing all along its length. Let us consider that a new component at a wavelength λ is generated. As it propagates through the fiber, it undergoes at each point the Rayleigh backscattering phenomenon. The generated backscattered signal propagates toward the fiber input and reaches the internal detector of OTDR after passing through the coupler and the filter TBF2. The OTDR detector measures the power of the backscattered signal as a function of the pulse position. Centering the TBF2 on the wavelength λ, the OTDR will display the spatial evolution of the λ component along the fiber. This reasoning can be extended to all wavelengths generated in the supercontinuum. By changing the center wavelength of the TBF2, we can obtain the spatial evolution of the different spectral components of the SC along the fiber.

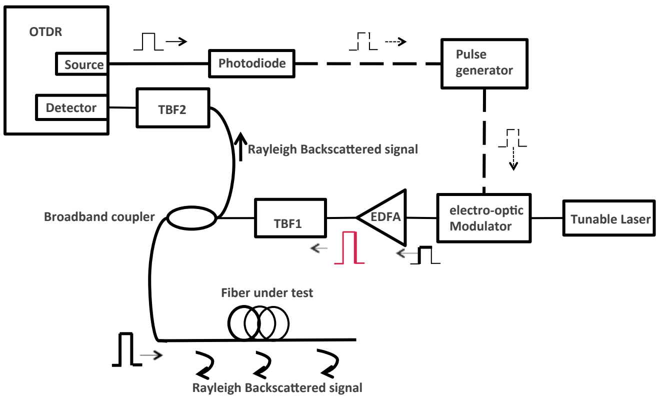

Figure 1: experimental set up

Development of the tunable OTDR

The first experimental work consisted in the realization of a tunable wavelength OTDR. It corresponds to the set-up presented in figure 1 but without using the TBF2 . In this first step, the EDFA gain was set to a low value in order to avoid the spectral broadening. In this case, the only component of the Rayleigh backscattering signal is at the pump wavelength (wavelength of the tunable laser source). This work is an important step for the realization of the final experimental device since it allows checking the good synchronization between the various devices (modulator, OTDR pulse generator) before generating non-linear effects.

In figure 2, we present typical traces obtained with the developed tunable OTDR for different average powers at the EDFA output. These measurements were obtained on a standard single mode fiber (SMF) of 2.8 km and for an interrogating wavelength of 1550 nm. The pulse width was set to 100 ns, giving a spatial resolution of 10m. The recorded traces are typical OTDR traces since one can easily distinguish the reflection peaks that indicates the beginning and end of fiber and the Rayleigh backscattering in between.

Let us also note that the higher the average output power of the amplifier, the higher the level of the backscattered signal.The results indicate that the reflectometer configuration provides a sufficient signal to noise ratio (about 20 dB). Note that the fluctuations recorded within the backscattered signal is due to the coherent (or fading) noise caused by the use of a narrowband source. This will be fixed in the near future by sweeping the wavelength of the source on a range of 1 nm during the measurement.

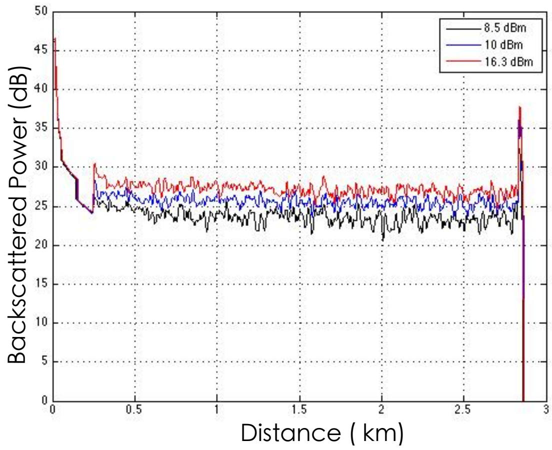

Figure 2: Evolution of the backscattered signal for different average power,

Distributed measurement of the modulation instability

The second experimental work aimed to perform a first distributed measurement of the spectral broadening along a 25 km telecom fiber in the case where only the modulation instability plays a role. It should be noted that a pre-amplified laser source was required in order to get enough power to generate the MI. A second EDFA has therefore been used between the laser source and the modulator. The experimental apparatus is depicted in figure 3. The measurement principle is the same as described above: the tunable filter allows scanning the MI gain spectrum.

The pulse width was set to 250 ns, giving a 25 m spatial resolution. The fiber under test was a 24 km dispersion shifted fiber (DSF) characterized by an attenuation of 0,22 dB/km and a zero dispersion wavelength at 1550 nm. The pump wavelength used in the experiments was 1564,710 nm, in the anomalous dispersion regime of the fiber. The average power at the fiber input was measured to be 14.4 dBm. The width of the tunable filter was 50 pm.

In figure 4, we present the results of the distributed measurements performed at the pump wavelength and at the maximum of the two MI lobes. Along the fiber, we note a global accumulated loss of 13 dB at the pump wavelength. We should expect a total loss of 5.3 dB according to the lineic attenuation of 0,217 dB/km. The extra loss of power is due to the generation of nonlinear effects (MI in this case). All a long the fiber we note a fairly good symmetry between the two lobes of instability modulation. This is due to the use of a pump wavelength sufficiently distant (14 nm) from the zero dispersion wavelength, which minimizes the effet of the third order dispersion.

Conclusion

In this paper, we proposed a generic measurement set-up for the distributed measurement of supercontinuum generation along an optical fiber.The first

experimental results concerned the distributed measurement of the spectral broadening generated by the modulation instability phenomenon.
We showed that it was possible to perform a spatially-resolved measurement of the MI on a 24 km DSF fiber. The next step is to modulate the laser source at 10 Gbit/s in order to generate a complete supercontinuum. A photon-counting OTDR will also replace the conventional OTDR in order to get a centimetric spatial resolution.

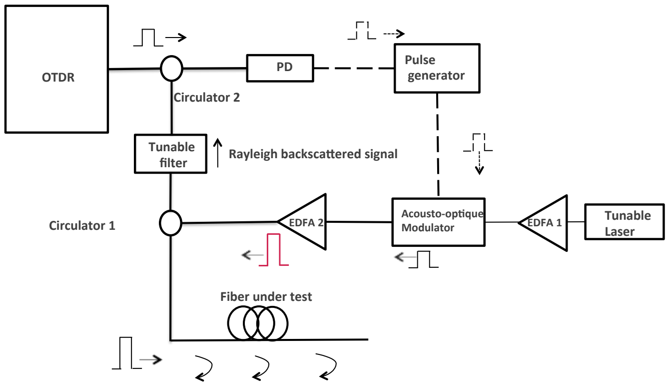

Figure 3: Experimental set up for the distributed measurement of MI

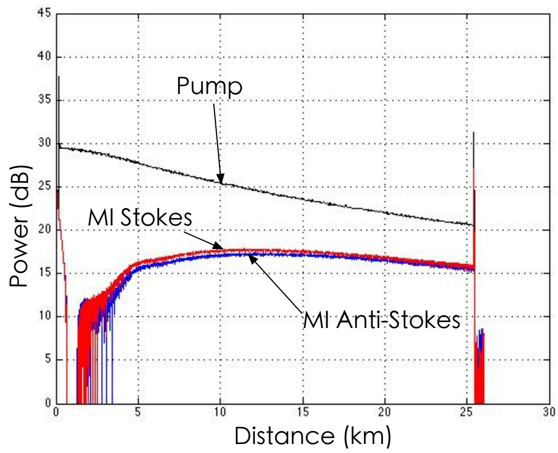

Figure 4: Distributed measurement at the pump, stokes and anti-stoked wavelengths.

Acknowledgements

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