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J. Chou, C. V. Bennett, O. Boyraz, B. Jalali

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Triggerable Continuum Source for Single-shot Ultra-fast Applications

Jason Chou\textsuperscript{1}, Corey V. Bennett\textsuperscript{2}, Member, IEEE, Ozdal Boyraz\textsuperscript{3}, and Bahram Jalali\textsuperscript{1}, Fellow, IEEE
\textsuperscript{1}Department of Electrical Engineering, University of California, Los Angeles, California 90025 USA
\textsuperscript{2}University of California, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94551 USA
\textsuperscript{3}Department of Electrical Engineering and Computer Science, University of California, Irvine, California 92697 USA

Abstract—We demonstrate a triggerable continuum source based on a modulated DFB laser. Such a source eliminates the need to synchronize a mode-locked-laser with an incoming signal in applications such as spectroscopy and wideband signal processing.

Continuum sources have wide uses in applications ranging from chirped pulse WDM [1], wavelength division sampling [2], time-stretched ADC [3,4], temporal imaging of optical signals [5,6], femtosecond Raman spectroscopy [7], and all-electronic absorption spectroscopy [8]. In these applications, proper synchronization of the continuum pulse with the signal of interest is critical. Continuum generation using a mode-locked laser has limited use because the repetition rate is fixed by the cavity length. The ultimate solution, from the point of view of synchronization, is a source where the arrival time of the continuum pulse is entirely triggerable.

Continuum generation has been well studied across various lasers, nonlinear materials, and pulse compression techniques. It typically utilizes an ultra-short high peak power optical pulse generated by a repetitive mode-locked laser. Recently, continuum generation has also been demonstrated using a gain-switched DFB laser, Q-switching, two mode-beating, direct modulation using an electroabsorption modulator [9] and using modulation instability to generate the seed pulse [10]. In applications where the continuum interacts with an incoming signal, such as ultrafast spectroscopy and other applications mentioned above, these repetitive sources will require synchronization with the signal. In this paper, we demonstrate a truly single shot continuum source that is created by combining a triggerable picosecond RF pulse generator with a Mach-Zehnder modulator to directly create a high-extinction optical seed pulse. The single-shot triggerability offers complete control of the arrival time of the continuum pulse.

Our triggerable continuum generation approach is illustrated in Fig. 1. At the pulse carving stage, a picosecond RF pulse is formed by a triggerable wideband pulse generator. A DFB laser is then intensity modulated in order to create a picosecond optical pulse at the output of a Mach-Zehnder Modulator (MZM). Proper control of the bias and input laser polarization ensures minimum light transmission in the absence of an electrical input. Next, in the continuum generation stage, the peak power of the optical pulse is increased using Soliton Effect Compression (SEC). Here, a high-order soliton is formed through judicious amounts of optical amplification and anomalous dispersive fiber. Narrow optical bandpass filters are inserted to suppress the out-of-band amplified spontaneous emission (ASE) noise. Finally, the pulse enters a nonlinear optical medium which will generate a continuum through self- and cross-phase modulation, four-wave mixing and Raman processes. The dispersion parameters of the nonlinear medium and characteristics of the optical pulse affect the shape and stability of the generated spectrum.

In the experimental setup, the seed laser is 40 mW DFB with a center wavelength of 1557 nm. A 40 Gbps MZM is driven by a 20 ps RF pulse, generated from a Picosecond Pulse Lab pulsor (model 4015c) and an impulse forming network (model 5208). Single-shot pulses may be triggered using a low voltage trigger signal. Precise polarization and DC bias control is used to maintain a 30 dB MZM on/off extinction ratio. The 20 ps output pulse exhibits a peak power of 6 mW due to the MZM loss and a peak input voltage below $V_{\pi}$. A low-noise preamp-power-amp system increases the pulse peak power to 1 W and generates an $N = 3$ soliton. The ASE noise is suppressed using a 0.8 nm band pass filter at the output of each EDFA. The pulse is undergoes SEC in a single mode fiber ($D = 16.3$ ps/nm/km $D' = 0.069$ ps/nm$^2$/km at 1550 nm) and reaches a minimum width after 2.3 km. Finally, a
As the peak power of the optical pulse is increased beyond 1 W, the spectrum observed in our experiment becomes progressively noisy. The usable bandwidth of the continuum is limited by EDFA introduced ASE which is introduced from the amplifiers. The primary source of the instability can be attributed to the ASE which is injected into the spectral band of the seed laser. During the nonlinear pulse propagation in the anomalous dispersion region, noise spikes are rapidly enhanced by the modulation instability (MI) effect. The growth rate of noise spikes associated with MI can be shown to be faster than the spectral broadening rate of the main pulse [11]. As a result, the spectral shape and stability will be degraded. Methods to mitigate ASE induced distortion, and thus, increase the continuum bandwidth are: (1) operate purely in the normal dispersion region where MI does not occur, (2) use narrower band pass filters to reduce ASE injected noise, and (3) use a higher power laser and increase signal voltage into the MZM to intensify the carved output pulse before amplification. Further study is required to improve the performance of the continuum generation.

In summary, we have demonstrated a triggerable continuum source for single-shot ultra-fast applications. The trigger can enable complete control of the arrival time of the continuum pulse. The approach is different from previous work on DFB-based continuum generation since it does not use a repetitive RF source. As proof of concept, a triggerable chirped optical pulse is generated without the use of a mode-locked laser.

**REFERENCES**