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# All-fiber triple frequency comb light source

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**Abstract:** We present a triple-comb, frequency agile, all-fiber light source. We show that mutual coherence is preserved by using a triple-core fiber and that 1ps transform-limited pulses can be obtained. © 2023 The Author(s)

An Optical Frequency Comb is a multimode coherent light source, emitting a broad spectrum of evenly spaced narrow frequency lines. Tri-Comb Spectroscopy set-up (TCS) includes two frequency combs exciting a non-linear medium. The corresponding Four Wave Mixing (FWM) signal is converted in the Radio-Frequency domain by the use of a third frequency comb, of slightly different repetition rate, as local oscillator. That enables the fast acquisition of 3D interferograms with high spectral and temporal resolution [1].

The main requirement for TCS is a high degree of coherence between the three different frequency combs. To obtain such a coherence, several architectures are possible, including the phase-locking of three Mode Locked Lasers) [1,2], or the generation of three different modes in a non-linear resonator [3]. Cavity based techniques made with active or passive cavities, have their own advantages but the repetition rates of the combs are fixed by the cavity parameters and they must be phase locked through complex electronic devices. At variance to all fiber cavity less solutions for which, the pulses counter-propagate to preserve the coherence [4]. However, this limits the system to dual-combs architectures only.

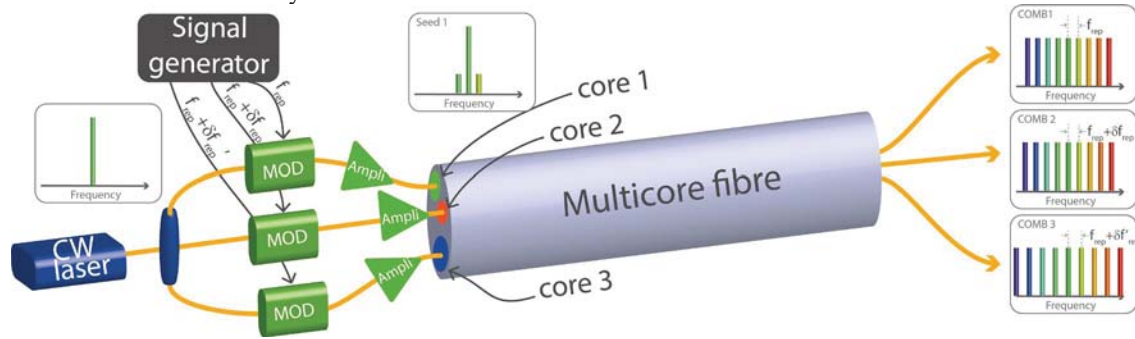


Figure 1: Simplified sketch of the set-up.

Here, we experimentally demonstrate a novel approach to generate three frequency combs of 1 THz-wide spectra, with a high mutual coherence between them by exploiting the spatial multiplexing concept in optical fibers. A simplified sketch of the setup is shown in Fig. 1. It is composed of a continuous wave laser at 1550 nm, divided into three arms of electro-optic modulation (EOM). The three electro-optic frequency combs are thus self-phase locked and it is pretty easy to tune their carrier and repetition rate frequencies. Each input comb are then broadened during the propagation in a three core fiber. They propagate in their own core, independently from the others but close enough to minimize the difference of phase noise accumulated through the propagation.

We fabricated a tri-core fiber with a normal dispersion at the pump wavelength (Fig. 2 (a)). The three input electro-optic combs are connected to the fiber's core by means of a fan (Fig. 2(b)) with 1 dB insertion loss. The output spectra demultiplexed by a fan are shown in Fig. 2 (c). The output spectra are almost flat and the spectral width is about 1 THz for each comb. In order to check the mutual coherence between the core is preserved, we measured the interferograms for each core duo. As an example the interferogram between cores 1 & 2 is depicted in inset in Fig. 2 (d). The periodic structure of the interferogram can clearly be observed. In the radio frequency domain, the interferogram spectrum has a similar shape compared to the optical spectrum with a magnification factor corresponding to  $\Delta f_{\text{rep}}/f_{\text{rep}} = 10^{-5}$ . It is centered at 200 MHz, the frequency shift induced by an acousto-optic modulator inserted in one of the input arms to shift the carrier frequency. A zoom on the upper side of the RF spectrum is depicted in Fig. 2 (e). A clear comb teeth structure is revealed with about 15 dB signal to noise ratio and

a teeth-to-teeth spacing equals to the repetition rate difference between the combs (5 kHz). This confirms the mutual coherence between the combs is good enough to observe clear interference between the combs. For the sake of clarity, we do not show the interferograms corresponding to other core-core combinations, but we obtained very similar results. Finally, during the SPM induced spectral broadening, the pulses acquire a nonlinear chirp. We show it is possible to compress the output pulses by passing through a *Waveshaper*. The autocorrelation (AC) trace is shown in Fig. 2 (f) (green curve). The AC width at full width at half maximum (FWHM) is 2 ps. It is almost similar to the trace calculated from the experimental spectrum (Fig. 2 (b)) with 1.3 ps duration at FWHM corresponding to 700 fs pulse duration at FWHM. We can thus extrapolate from this value that the pulse duration after recompression in experiments is 1 ps. Almost Fourier transform limited pulses can be generated at the output of the fiber which is of interest for nonlinear spectroscopy experiments.

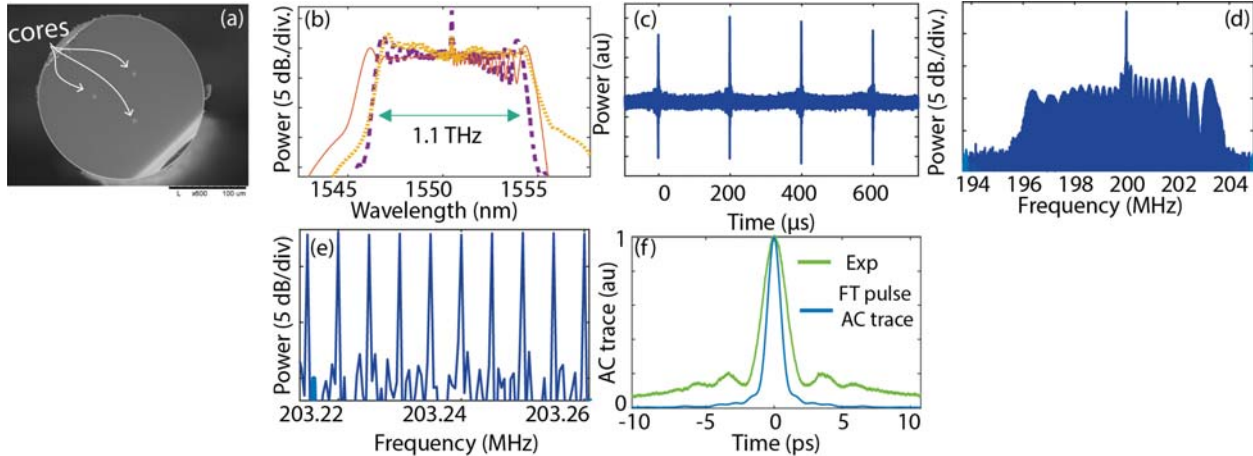


Figure 2: (a) Tri-core fiber input face, (b) output spectra in each arm, (c) interferogram example between cores 1 & 2, (d) RF spectrum of the interferogram and (e) zoom on the upper side of the spectrum. (f) Autocorrelation traces of the compressed pulse after compression (green trace) and calculated trace from the experimental spectrum. Parameters : fiber length 1 km, 1 THz width, 0.5 nJ,  $f_{rep}=0.5$  GHz,  $\Delta f_{rep}=5$  kHz between each arms, 2000 teeth, recompression about 1ps duration.

In conclusion, we report for the first time an all-fiber, frequency agile, triple frequency comb light source. We show that the use of a tree-core fiber preserves a fairly high mutual coherence between the three initial EOM combs. These results have been reported in the telecommunications field with a pulse duration of ps at a repetition rate of 0.5 GHz, but we believe that pulse durations of hundreds of fs at a repetition rate of several GHz at 1  $\mu$ m could be achieved to meet the requirements of coherent anti-Stokes spectroscopy experiments, for example.

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