Generation of a 150 fs pulse train at 12.5 GHz repetition rate via cavity filtering of a self-referenced frequency comb

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***Abstract*— We report on the generation of >50 nm of a 12.5 GHz-spaced frequency comb in the 1550 nm band, achieved by optically filtering a 250 MHz self-referenced frequency comb. Pulse compression yields 150 fs pulses.**

I. Introduction

Multi-gigahertz repetition rate low noise mode-locked lasers operating in the 1550 nm band have a number of signal processing, coherent communication and scientific applications, such as analog-to-digital conversion [1], optical arbitrary waveform generation, optical code division multiple access communication, wavelength division multiplexing [2], and astronomical spectrograph calibration [3]. The appropriate laser source must meet stringent requirements on the pulse-to-pulse timing and amplitude fluctuations for time domain applications and must possess a high level of frequency stability and broad bandwidth for optical frequency domain applications. Self-referenced optical frequency comb sources are capable of producing the high level of stability and bandwidth required, but multi-gigahertz repetition rates for these lasers at 1550 nm has thus far been elusive. In order to exploit the bandwidth and stability of self-referenced comb sources while generating >10 GHz repetition rate, an etalon filter cavity to selectively pass every N^{th} mode of a sub-gigahertz-spaced stabilized optical frequency comb source can be used [4-7]. The resulting repetition rate is N times that of the input comb. Here we report on selecting one mode of every 50 from a 250 MHz-spaced self-referenced frequency comb, thereby generating a 12.5 GHz-spaced frequency comb spanning >50 nm. The corresponding 80 ps separated low-noise pulses were amplified to 60 mW average power and compressed to 150 fs. This represents a broader bandwidth at a higher repetition rate than previous reports at 1550 nm wavelength [6-7].

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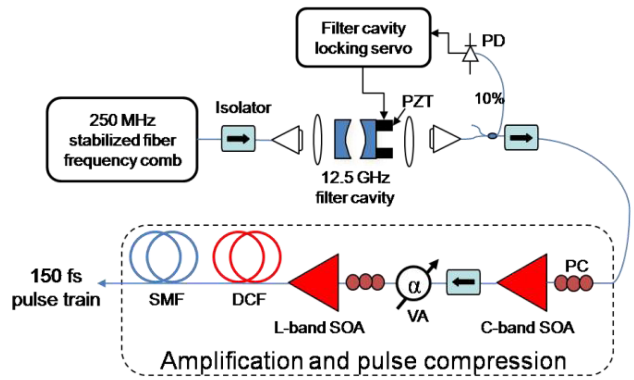

Fig. 1. Experimental setup. The filter cavity is composed of two 50 cm ROC mirrors of high reflectivity (~99.85%). The filter cavity is in free space; all other components are fiberized. The current to the SOAs and the variable attenuator were optimized to give the broadest bandwidth with the highest power. DCF and SMF follow amplification to compress the pulse. PZT, piezoelectric transducer; PD, photodetector; PC, polarization controller; SOA, semiconductor optical amplifier; VA, variable attenuator; DCF, dispersion compensating fiber; SMF, single mode fiber.

II. Experimental Setup and Results

The experimental setup is shown in Fig. 1. A 250 MHz repetition rate pulse train is generated by an Erbium-based passively mode-locked fiber laser. Part of the laser output is amplified and broadened to an octave in nonlinear fiber. The carrier envelope offset frequency is detected with a standard f-2f interferometer. Both the carrier-envelope offset frequency and the repetition rate are locked to low noise oscillators. A portion of the stabilized 250 MHz pulse train with 30 mW average power is transmitted through a high finesse (F~2000 at 1550 nm) air-gap etalon with a free spectral range of 12.5 GHz. The high finesse cavity passes modes separated by 12.5 GHz with low loss, while other modes are greatly suppressed. The 12.5 GHz etalon is locked to the frequency comb by imparting a dither (~50 kHz) on the etalon cavity length and locking to a peak in the transmitted power. This lock has shown to be robust for several days of continuous operation.

Whereas the modes of the mode-locked laser are equally spaced, dispersion in the cavity mirrors results in unequal

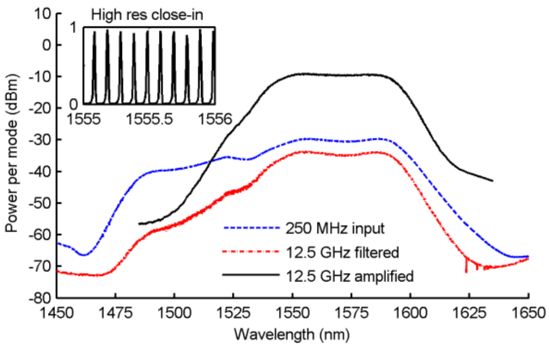

Fig. 2. Power per optical mode at different stages of comb filtering and amplification. The inset shows a high resolution spectrum of the amplified 12.5 GHz output.

spacing of the etalon filter cavity modes. The cavity dispersion causes a walk-off between the laser modes and the etalon transmission peaks resulting in the wings of the spectrum having both a reduced throughput and a lower suppression ratio of spurious modes. The reduced throughput in the wings of the spectrum can be seen in Fig. 2 by comparing the 250 MHz-spaced input spectrum with the 12.5 GHz filtered spectrum. Despite the reduction in the wings of the spectrum, a 50 nm full width at half maximum (FWHM) has been preserved after the filter cavity. This represents ~500 12.5 GHz-spaced modes.

Measurements on the level of suppression of unwanted modes were also performed. Suppression of the modes nearest to the selected 12.5 GHz-spaced modes was measured across the spectral range of 1525 nm to 1580 nm. This measurement was performed by optical heterodyning the filtered comb with a tunable CW laser. From 1540 nm to 1580 nm, the modes closest to the 12.5 GHz-spaced selected modes are suppressed >38 dB. This level of suppression is consistent with an etalon finesse of 2000. A small reduction in the etalon reflectivity at 1530 nm and 1525 nm yields a suppression of 34 dB and 30 dB for the respective wavelengths.

While care has been taken to preserve the power of the selected 12.5 GHz-spaced modes, a significant reduction in the total power of the output pulse train is unavoidable. The 12.5 GHz spacing at the output of the filter cavity represents one out of every fifty modes of the input, and therefore, at best, only 1/50 of the input power is transmitted. Unfortunately, amplifying the 12.5 GHz comb with a conventional Erbium-doped fiber amplifier does not conserve the broad optical bandwidth. To overcome this, cascaded semiconductor optical amplifiers with gain peaks separated by ~40nm were used. This configuration yielded 60 mW average output power while preserving the 50 nm FWHM bandwidth of the 12.5 GHz-spaced frequency comb. (The average power after the filter cavity was 200 μW.) The amplified optical spectrum is shown in Fig. 2. A high resolution spectrum that resolves the 12.5 GHz-spaced modes is shown in the inset.

The time domain characteristics of the amplified 12.5 GHz pulse train were also investigated. After amplification, the pulses were ~20 ps as a result of the chirp on the pulses originating from the laser and the amount of optical fiber in the setup. Chirp compensation was achieved via an overlong on-hand piece of dispersion compensating fiber and standard single mode fiber. This resulted in compressed pulses with an autocorrelation FWHM of 210 fs, or a pulse width of 150 fs (assuming Gaussian pulses), shown in Fig. 3. This represents ~1.5 times the transform limit. The sampling-scope trace and the intensity spectrum of the photodetected pulse train are also shown in Fig. 3. The large suppression of the 250 MHz-spaced spurs in the intensity spectrum indicate small residual amplitude and timing fluctuations on the pulse train. The 250 MHz-spaced spurs can be further suppressed with a double pass configuration that is currently under investigation.

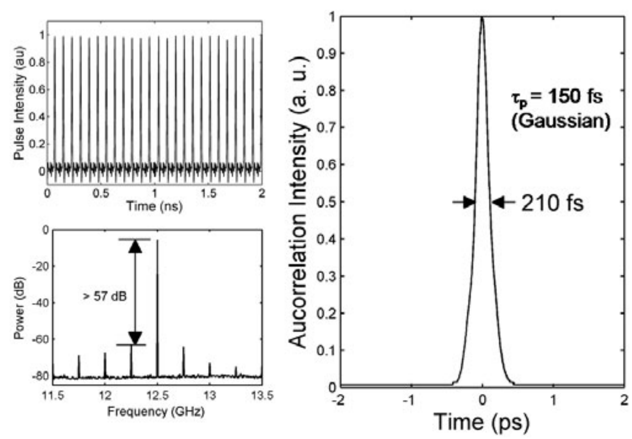

Fig. 3. Time domain characteristics of the amplified 12.5 GHz pulse train. The left upper plot shows high uniformity in the photodetected sampling scope trace. The lower left plot shows the microwave spectrum of the photodetected pulse train with >57 dB suppression of 250 MHz-spaced spurs. Pulse intensity autocorrelation showing 150 fs pulse width (assuming Gaussian pulse shape). The transform limited pulse width is 100 fs.

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