EDFA-based coupled opto-electronic oscillator and its phase noise

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Abstract: EDFA-based coupled opto-electronic oscillator (COEO), an integrated optical and microwave oscillator that can generate picosecond optical pulses, is presented. The phase noise measurements of COEO show better performance than synthesizer-driven mode-locked laser.

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Coupled opto-electronic oscillator [1] is an integrated optical and microwave oscillator capable of generating picosecond optical pulses. Such oscillators have potential applications in optical communications, optical analog-to-digital conversion, and radar systems. For all these applications, the oscillator is required to operate in the 10-40 GHz range and have low phase noise characteristics.

A detailed schematic of COEO is shown in Fig. 1. COEO is a combination of a mode-locked fiber laser [2-4] and opto-electronic oscillator loop that has long length of optical delay fiber to increase the quality factor of the oscillator. As shown for opto-electronic oscillator (OEO) [5], the phase noise of the oscillator is expected to decrease as the length of the delay fiber is increased.

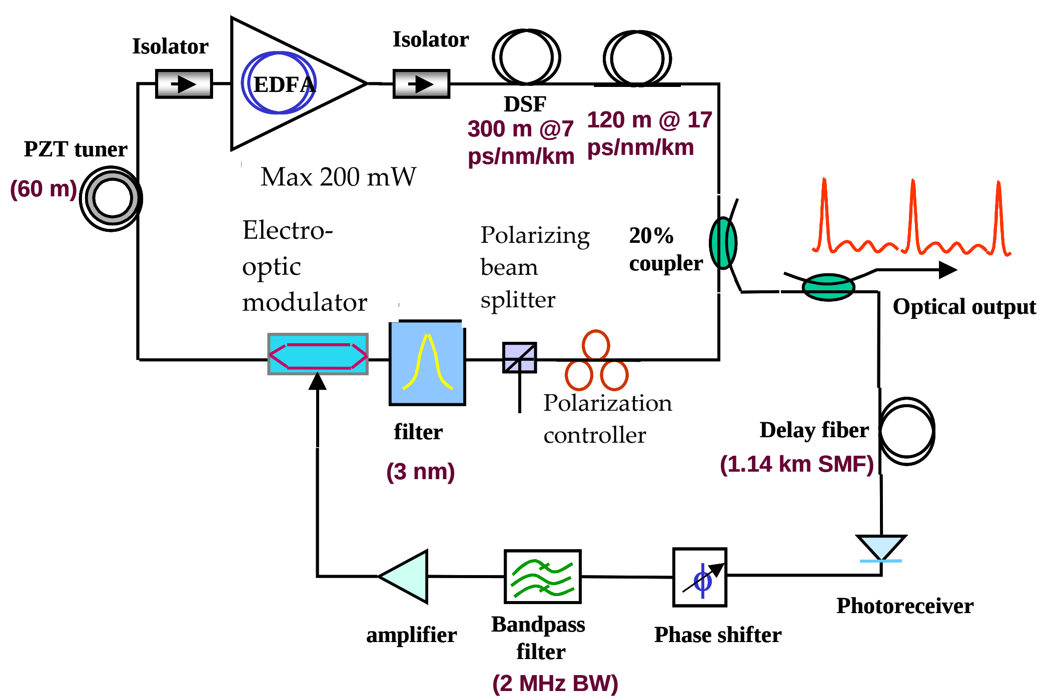
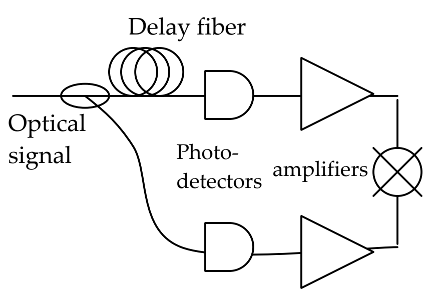


Fig. 1. Schematic of coupled opto-electronic oscillator (COEO). COEO is combination of mode-locked laser and opto-electronic oscillator.

The COEO setup is similar to the experiments reported previously [6]. In the mode-locked laser part we have used an erbium-doped fiber amplifier (EDFA) with 23 dBm max output. The dispersion-shifted optical fiber used for soliton effect has 7 ps/nm-km dispersion at 1550 nm. 120 m SMF-28 fiber, and a 20% coupler follow. We used a polarization controller and a polarizing beam splitter since we did not have polarization-maintaining loop. The optical filter with 3 nm bandwidth at 1550.6 nm was placed before the LiNbO3 electro-optical modulator. In the opto-electronic oscillator part we had a delay fiber of 1.14 km in length, a photodetector, microwave phase shifter, microwave bandpass filter with 2 MHz bandwidth at 9.4 GHz, and a microwave amplifier. With this scheme we obtained optical pulses of 3.3 ps FWHM duration through harmonic mode-locking. The bandwidth of the pulse was 100 GHz, and the time-bandwidth product was 0.33 indicating that we have a nearly transform-limited $sech^2$ pulse.

In order to have oscillation in the COEO, one of the laser mode beat frequencies should coincide with one of the optoelectronic oscillator modes. Our mode-locked laser loop was about 500 m in length, the spectral distance between successive laser mode beat frequencies was about 400 kHz. If we have no additional delay fiber in the optoelectronic oscillator, the total length of fiber pigtails is about 3 m, and the opto-electronic feedback loop modes are spaced about 67 MHz. Because of its 2 MHz bandwidth, we need to tune the microwave filter for oscillation. This is similar to regenerative mode-locking operation [2]. However, when we have 1.14 km delay fiber in the optoelectronic oscillator, then the modes are spaced only 200 kHz apart, and about 10 modes will be within the filter bandwidth, and some adjustment of phase will be enough to make a laser beat node coincide with a mode of the optoelectronic oscillator loop, within the filter bandwidth. High quality microwave oscillator can thus be generated.

We have measured the phase noise for the coupled opto-electronic oscillator using the frequency discriminator method. The setup for phase noise measurement and the instrument phase noise are shown in Fig. 2. Both RF and LO ports of the mixer were saturated for phase detection. Note that, we are measuring the absolute phase noise of the optical pulse output, rather than the residual noise often reported in the literature [7].



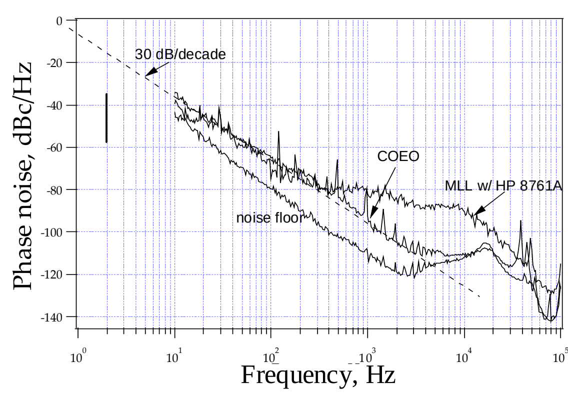


Fig. 2. Phase noise measurement setup.   Fig. 3. The phase noise of COEO.

Phase noise of the COEO in the 10 Hz-100 KHz range is shown in Fig. 3. For comparison the phase noise measurement for a mode-locked laser (MLL) driven by an off the shelf synthesizer (HP 8761A) is included. Clearly COEO performance is much better than the synthesizer-driven MLL above 500 Hz from the carrier. This particular COEO used 1.14 km SMF-28 fiber as delay fiber to increase the cavity quality factor. The bump seen at 5-80 kHz may be due to relaxation oscillation at EDFA. We are in the process of measuring the amplitude noise to understand whether this bump is a result of phase noise or amplitude noise.

The selection of the fiber delay in the optoelectronic oscillator loop is also an important issue, as the pulses generated can be broadened as they propagate due to fiber dispersion. To understand the effect of fiber dispersion on such pulses, we have measured the photodetector microwave output vs fiber length for the same average optical power into the photodetector. The result is displayed in Fig. 4. As expected, the pulsewidth increased with fiber length, and the amplitude of the microwave signal at the output of the photodetector decreased. If indeed the longer lengths of delay fiber improve the phase noise performance, the effect of pulse broadening in the fiber might be a limitation. The results for COEO with longer fiber lengths and its phase noise characteristics will be presented at the conference.

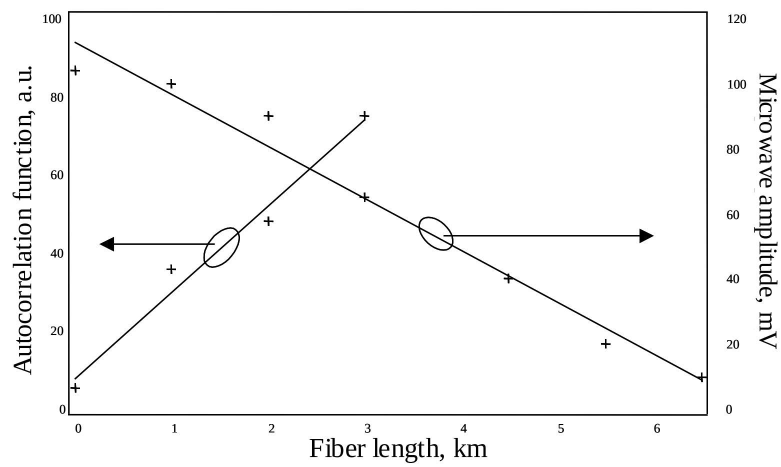


Fig. 4. Pulse-width and microwave amplitude at the output of the photodetector after propagating through the fiber.

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