

# 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.

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 have low phase noise characteristics, especially in 100 Hz-100 kHz range.

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 feedback loop that has long length of optical 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 fiber is increased.

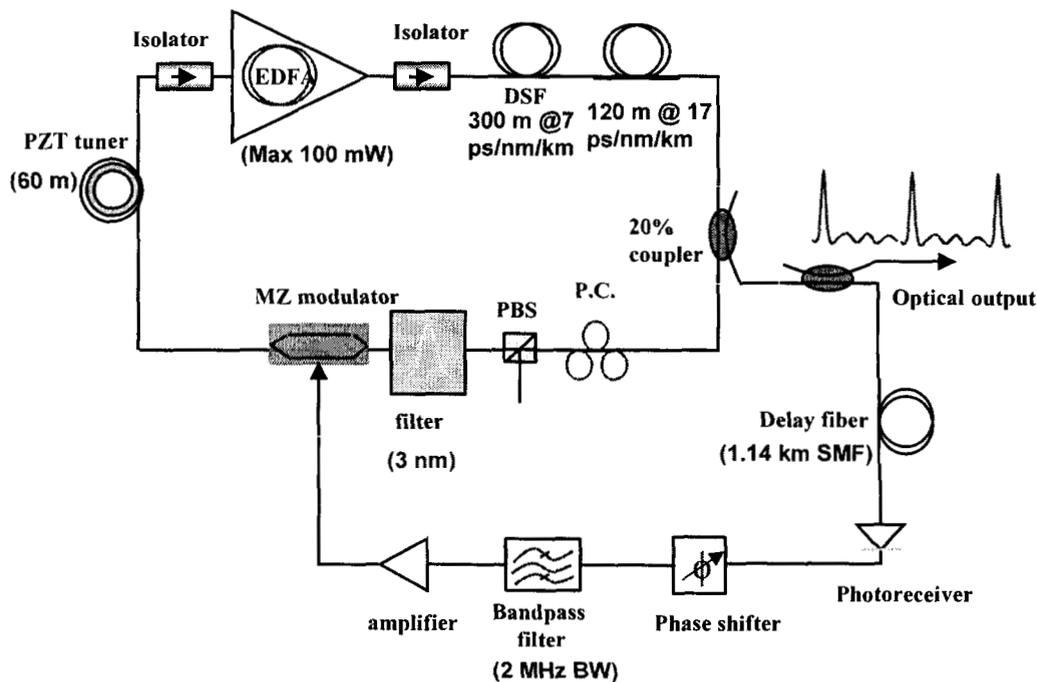


Fig. 1. Schematic of coupled opto-electronic oscillator (COEO). COEO is combination of mode-locked laser and opto-electronic oscillator.

In our current implementation, in the mode-locked laser part we have used an erbium-doped fiber amplifier (EDFA) with 23 dBm max output, dispersion-shifted optical fiber with 7 ps/nm-km dispersion at 1550 nm to have soliton effect, 120 m SMF-28 fiber, a 20% coupler, polarization controller since we did not have polarization-maintaining loop, a polarizing beam splitter, an optical filter with 3 nm bandwidth at 1550.6 nm, an LiNbO3 electro-optical modulator. In the opto-electronic feedback part we had fiber delay, a photodetector, microwave phase shifter, microwave bandpass filter with 2 MHz bandwidth, and a microwave amplifier. Previously a similar COEO was reported in LEOS 2002 [6]. With this scheme we obtained optical pulses of 3.3 ps FWHM duration, and 100 GHz bandwidth, so time-bandwidth product is 0.33 indicating that we have a nearly transform-limited pulse. The microwave frequency out of the laser was about 9.4 GHz, so harmonic mode-locking was used.

In order to have oscillation in the COEO, one of the laser mode beat frequencies should match with one of the optoelectronic loop modes. Our mode-locked laser loop was about 500 m in length, so the spectral distance between successive laser mode beat frequencies was about 400 kHz. If we have no additional delay fiber in the optoelectronic feedback, the total length of fiber pigtailed in the optoelectronic feedback loop is about 3 m, so the opto-electronic feedback loop modes will be spaced about 67 MHz. Since the microwave filter we use has 2 MHz bandwidth, we need to tune the microwave filter for oscillation. However, when we have 1 km fiber in the optoelectronic feedback loop, then the modes will be spaced only 200 kHz apart, and about 10 modes will be within the filter bandwidth, and some adjustment of phase will be enough to match a laser beat node and an optoelectronic loop mode within the filter bandwidth.

We have measured the phase noise for the coupled opto-electronic oscillator using 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.

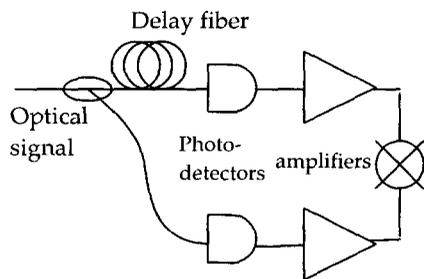


Fig. 2. Phase noise measurement setup.

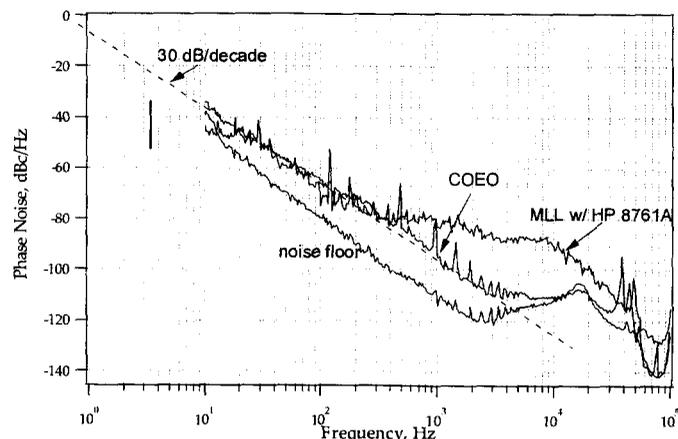


Fig. 3. The phase noise of COEO.

Phase noise of the COEO for 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 synthesizer-driven MLL for

1-100 kHz range. 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 delay fiber in the optoelectronic loop is also an important issue, as the pulses generated can be broadened as they propagate. 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 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.

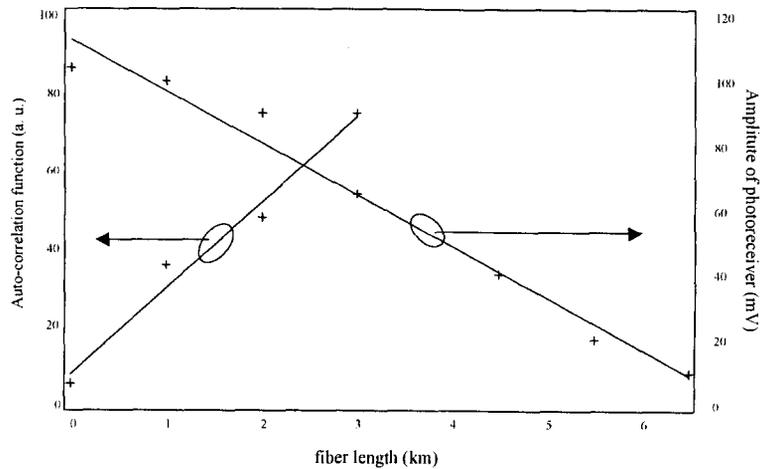


Fig. 4. Pulse-width and microwave amplitude at the output of the photodetector.

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