Ultra-low phase noise optical pulses generated by coupled opto-electronic oscillator

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Abstract: EDFA-based coupled opto-electronic oscillator (COEO) can generate picosecond optical pulses and microwave signals. The phase noise of COEO is better than -135 dBc/Hz at 10 kHz away from the carrier.
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Coupled opto-electronic oscillator [1] is an integrated optical and microwave oscillator [3-5] capable of generating low time jitter optical pulses and ultra-low phase noise microwave signals, which finds applications in optical communications, optical analog-to-digital conversion, and radar systems.

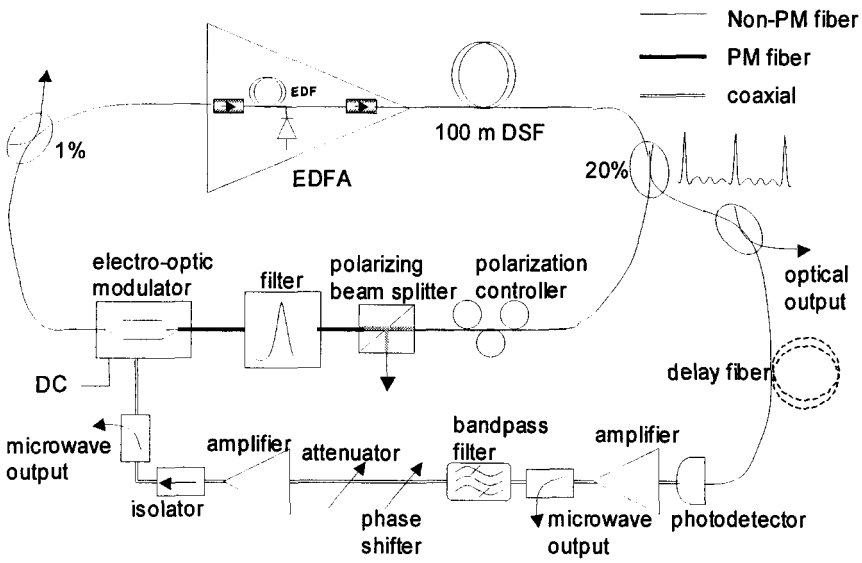

Fig. 1. Schematic of coupled opto-electronic oscillator (COEO). COEO is combination of mode-locked laser and opto-electronic oscillator.

The COEO setup here is similar to the experiments reported previously [6]. EDFA can provide 20 dBm max output. 100 m of dispersion-shifted optical fiber was used for soliton effect. Here we have a non-polarization-maintaining loop. The optical filter has 3 nm bandwidth at 1550.6 nm. The bandwidth of the microwave bandpass filter is 2 MHz at 8.4 GHz. For the experiment reported here we do not have any additional delay fiber in the optoelectronic feedback loop, which makes our system very similar to regenerative mode-locking [2]. In order to have oscillation in the COEO, one of the laser mode beat frequencies should coincide with one of the optoelectronic oscillator modes[1].

With this scheme we obtained optical pulses of 4.1 ps (FWHM) duration. The bandwidth of the pulse was 80 GHz, and the time-bandwidth product was 0.33 indicating that we have a nearly transform-limited $sech^2$ pulse. EDFA output power was about 14 dBm (25 mW) for 180 mA of current running the pump laser. The input power of EDFA was about 3 dBm, which implies that the total loop loss was

around 11 dB. The total dispersion for the optical loop was 0.19 ps/nm. This system operates stably for hours at a time, even without an active feedback loop.

We have measured the phase noise for the coupled opto-electronic oscillator using the frequency discriminator method [8]. Phase noise of the COEO in the 10 Hz-100 KHz range is shown in Fig. 2. For comparison, the phase noise measurement for an off the shelf synthesizer (HP 8761A) is included. At 10 kHz offset frequency phase noise is -135 dBc/Hz, among lowest for similar actively modelocked laser systems, where extremely low phase noise external source has to be used. The spurious peaks seen at 20-80 kHz may be due to relaxation oscillation of EDFA.

The phase noise measurement with no delay line sets our noise floor for the measurement system. To check whether we are limited by instrument noise, we used cross-correlation scheme [9], which removes uncorrelated noise added by components. We measured the same, which means that we are not limited by any of the instruments in our phase noise measurement system. The phase noise measurement shown in Fig. 2 was done using 4.46 km-long fiber with 4.5 ps/nm/km dispersion at 1550 nm. We used the same length of SMF-28 fiber with dispersion of 17 ps/nm/km at 1550 nm. We measured about 10 dB higher noise with SMF-28 than with low-dispersion fiber. Therefore, we are essentially measuring the noise floor with or without the fiber. We also measured the amplitude noise, and found that it is about 10 dB higher than the phase noise with no delay. We conclude that we are currently limited by the AM noise of the oscillator, and COEO phase noise is better than shown in Fig. 2.

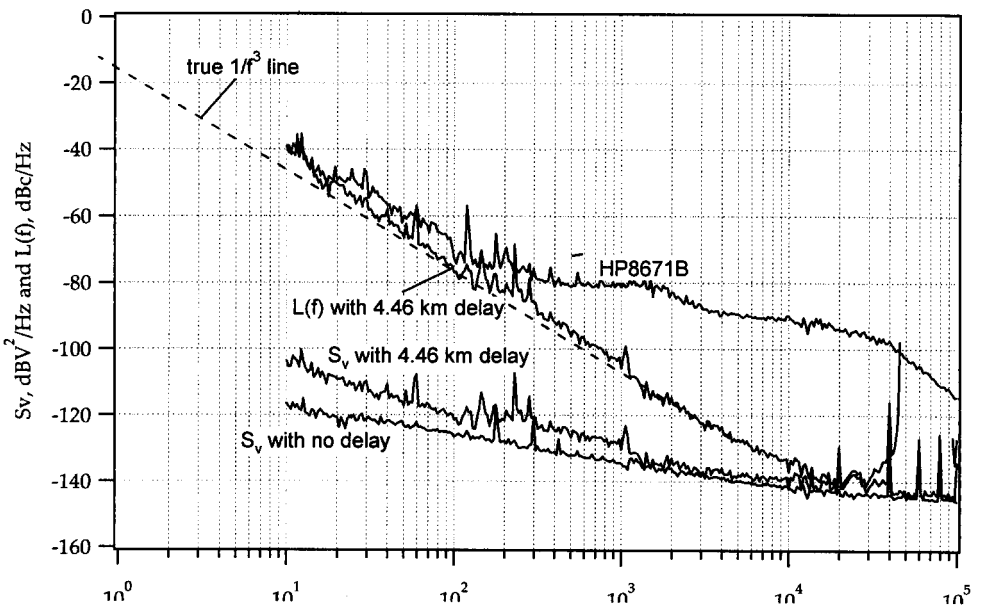

Fig. 2. Phase noise of COEO measured by frequency discriminator method using 4.46 km of fiber with 4.5 ps/nm/km dispersion. The inset shows the comparison of the phase noise measurement using the same length with higher dispersion fiber. This demonstrates that the fiber adds noise.

We have demonstrated exceptionally stable coupled opto-electronic oscillator with phase noise better than –135 dBc/Hz at 10 kHz offset frequency, which is our phase noise measurement limit set by the amplitude noise of the COEO. Currently we are studying different methods to improve the amplitude noise of the COEO.

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