Microresonator Frequency Comb Stabilization with the Vescent Photonics D2-125 Reconfigurable Servo

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We generate an optical frequency comb by pumping a Kerr-active microresonator with a narrow linewidth cw laser. The microresonator is designed to exhibit a free spectral range of 17.9 GHz around the pump wavelength of 1600 nm. The comb's two degrees of freedom, the comb spacing and the carrier-envelope offset frequency, are phase locked independently to two microwave synthesizers. As the heat volume of the microresonator is only 2×10^{-15} m^3, the comb spacing is highly susceptible to technical noise such as pump power fluctuation, temperature variation, and optical alignment drift. A feedback loop with a bandwidth well above 500 kHz is thus critical for stabilizing the comb spacing of the microresonator frequency comb. In this application note, we will describe the detail of our comb spacing feedback loop with the Vescent Photonics D2-125 reconfigurable servo (Figure 1).

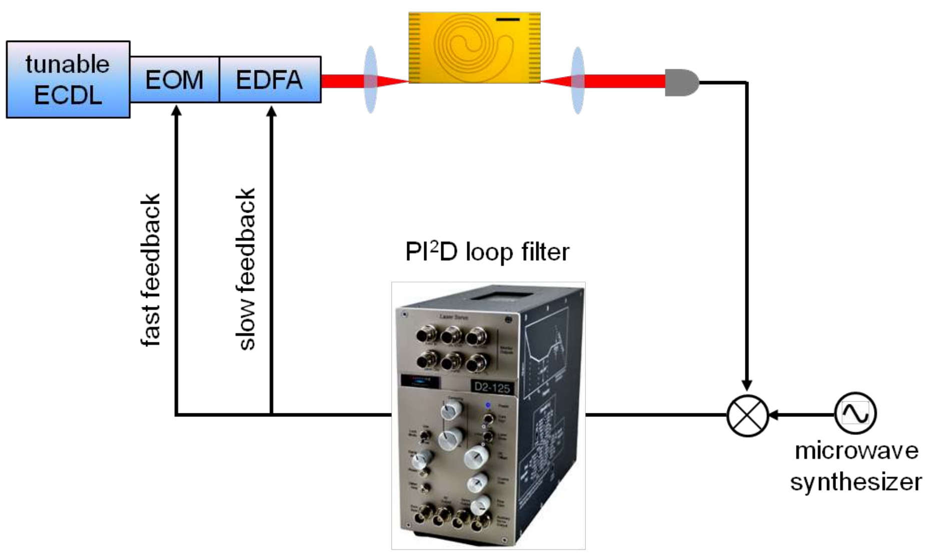

Figure 1. Schematic diagram of the experimental setup. ECDL: external cavity diode laser; EOM: electro-optic modulator; and EDFA: erbium-doped fiber amplifier.

The comb spacing of 17.9 GHz is directly measurable by sending the microresonator frequency comb to a high speed photodetector (Electro-Optics Technology ET-3500), followed by a low noise electrical preamplifier (RFbay GNA-157F). Figure 2 plots the demodulated beat note, showing a signal-to-noise-ratio (SNR) larger than 60 dB with a resolution bandwidth (RBW) of 100 kHz. The electrical signal is mixed with a microwave synthesizer (Gigatronics 905) in a double balanced mixer (Pasternack PE8653), and the downmixed signal after a 2.5 MHz low-pass filter (Minicircuits BLP-1.9+) serves as the error signal fed to the PI^{2}D loop filter (Vescent Photonics D2-125).

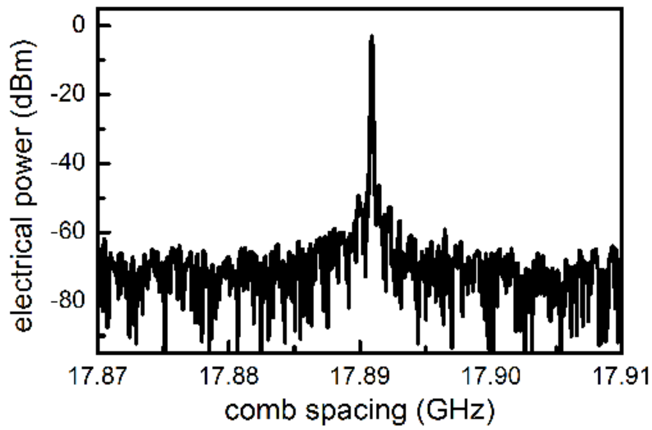

Figure 2. Comb spacing beat note, showing a SNR larger than 60 dB with a RBW of 100 kHz.

The frequencies of the first and the second integrators are set at 1 kHz and 200 kHz, respectively, for the best noise suppression performance. The derivative control with the corner frequency set as 500 kHz and the differential gain set at 10 dB was used to make the feedback loop more stable. Then the servo output was sent to a fiber electro-optic modulator (EOM) to control the input power of the erbium-doped fiber amplifier (EDFA) pumping the microresonator. The EDFA was running in a current-control mode such that the input regulation is translated to the output power more directly. Pump power is an effective way to control the comb spacing through thermal expansion, thermo-optic effects and nonlinear phase accumulation. Figure 3 depicts the AC error monitor of the free-running (red line) and stabilized (black line) microresonator optical frequency comb. The stabilized comb spacing tracks faithfully the microwave synthesizer to within a standard deviation of 50 mrad.

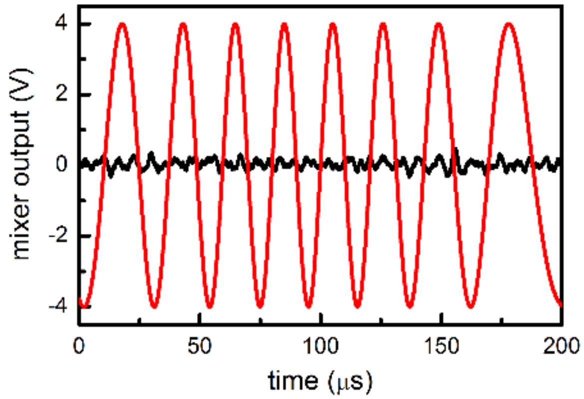

Figure 3. AC error monitor of the free-running (red line) and stabilized (black line) microresonator optical frequency comb. The stabilized comb spacing tracks faithfully the microwave synthesizer to within a standard deviation of 50 mrad.

Due to the optics alignment drift, the mean level of the servo output keeps increasing until the lock is lost in 10 minutes. For this reason, we also include a slow feedback utilizing the auxiliary servo output of the D2-125 laser servo. The gain is set as 1 second, and the gain sign is properly selected using the DIP switch. The auxiliary servo output is connected to modulate the drive current of the EDFA. It allows us to extend the stable lock for hours of operation.

Figure 4 plots the Allan deviations of the free-running and the stabilized comb spacing. Free running, the Allan deviation increases as $\tau^{1/3}$ as the result of technical noises (black open squares). The active feedback on the comb spacing improves the stability by more than five orders of magnitude, reaching $3.6mHz/\sqrt{\tau}$ (blue closed squares). The residual comb instability is limited by the microwave synthesizer and close to the counter limit at 1 second gate time.

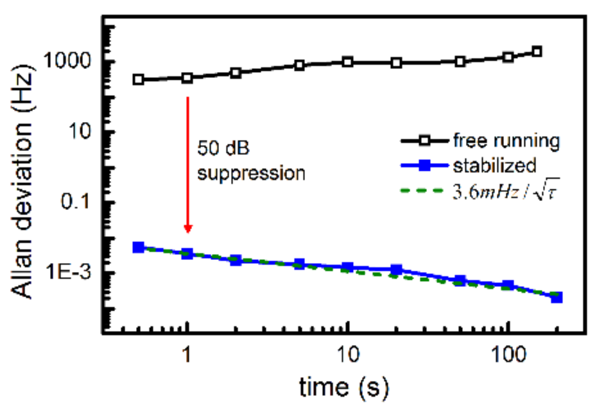

Figure 4. Allan deviation of the free-running (black open squares) and stabilized (blue closed squares) comb spacing. The feedback loop improves the Allan deviation by more than 50 dB and the stabilized comb spacing shows a consistent trend of $3.6\mathrm{mHz}/\sqrt{\tau}$ (green dashed line) when the gate time is in the range from 0.5 s to 200 s.