Design of Dispersive Interferometers for the Self-Stabilization of Optical Frequency Combs

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***Abstract*—A promising approach for photonic-chip-based ultra-low-phase-noise microwave generation is to stabilize an optical frequency comb (OFC) using active feedback from a short-delay asymmetric interferometer. Previously, indirect evidence indicated that the microwave phase noise was limited by dispersion in the interferometer that reduced the interferometer's sensitivity, ηrep, to the OFC's repetition rate. No direct evidence was shown. Here, we compare direct measurements of ηrep in interferometers using single-mode and dispersion-shifted fibers (SMF and DSF). With SMF, ηrep was approximately 30% of the value that we measured with DSF, corresponding to a change in microwave phase noise of up to 10 dB.**

Keywords—Optical frequency combs, low phase noise microwave generation, active feedback

I. Summary

A promising approach for generating ultra-low-phase-noise microwaves on a photonic integrated chip (PIC) is to use an optical frequency comb (OFC) to generate a microwave that is coherent with its repetition rate (f_{rep}), and then to use a short-delay-line asymmetric interferometer to measure the f_{rep} noise and provide active feedback to the OFC to stabilize it. Recent experiments have used interferometers with delays as short as 40-ns (i.e., 8-m of standard single-mode fiber) to generate low-phase microwaves [1]. It was reported that filtering the OFC light with a bandpass filter at the input of the interferometer reduced the stabilized microwave phase noise; that finding was interpreted to mean that dispersion reduced the maximum sensitivity, η_{rep}, of the interferometer to the OFC's f_{rep} [2]. Notably, dispersion was not a limiting factor in most previous demonstrations of optical frequency stabilization using fiber-optic interferometers, since the interferometer is usually probed with a single-frequency laser [3], rather than the OFC used in the architecture described above [1]. In the present work, we directly measured a dispersion-induced increase in η_{rep} by comparing two otherwise identical interferometers using standard single-mode and dispersion-shifted optical fibers (SMF and DSF, respectively), probed with the ~50-nm bandwidth pulsed output of a commercially available OFC (Menlo Systems). We found that in the SMF, η_{rep} was approximately 12 dB less than the value that we measured with the DSF and 18 dB less than the value expected for a zero-dispersion interferometer. The dispersion-related sensitivity loss measured in the SMF may correspond to an increase in microwave phase noise of up to 18 dB. Moreover, integrated photonic waveguides may have dispersion parameters that are up to 50 times higher than that of SMF [4]. Hence, in order to realize this stabilization technique on a PIC, the waveguide dispersion must be compensated or reduced.

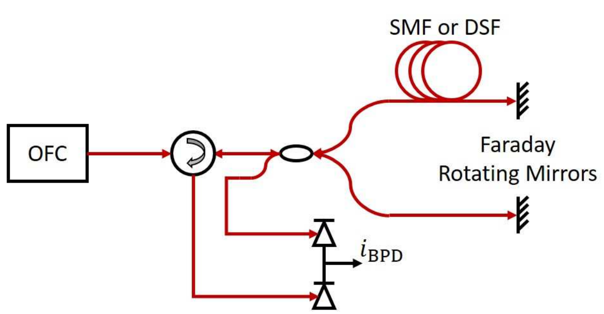

Fig. 1: Architecture of the Michelson interferometer.

II. Results

The purpose of this work was to verify via direct measurements whether the sensitivity, η_{rep}, of a short-delay interferometer increased when the amount of dispersion in the delay line decreased. We evaluated the Michelson interferometer (MI) shown in Fig. 1 and compared the results using two different delay lines: (1) a 4-m length of Corning SMF-28 ($D_\lambda \approx 17.5$ ps/nm·km at the OFC's center wavelength of 1550 nm) and (2) a 4-m length of DSF ($D_\lambda \approx 0$ ps/nm·km at 1550 nm). Because of the reflected path in the MI, the relative delay in both cases was approximately 40 ns. The sensitivity measurement apparatus is shown in Fig. 2. We modulated the OFC's f_{rep} by applying a 20 Hz sinusoidal voltage signal to an

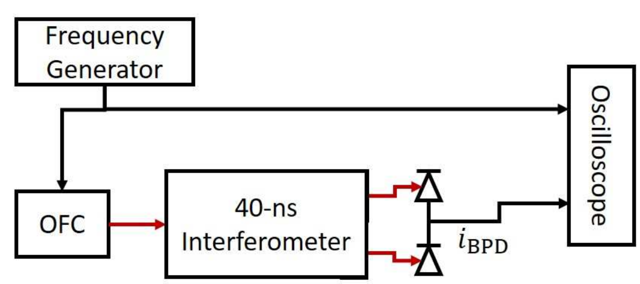

Fig. 2: Sensitivity measurement.

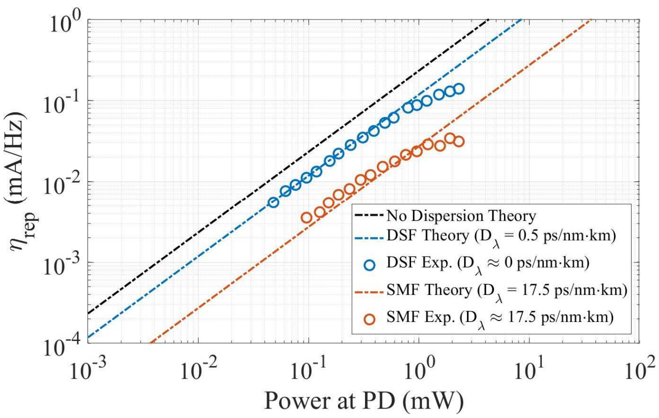

Fig. 3: Maximum sensitivity, η_{rep}, versus optical power at the input of the photodetector (PD).

intra-cavity piezo-mounted mirror. We simultaneously recorded the f_{rep} modulation and balanced photodiode (BPD) photocurrent (i_{BPD}) using an oscilloscope. We found the maximum sensitivity according to the equation, $\eta_{rep} = \max[|di_{BPD}/df_{rep}|]$. The results are shown in Fig. 3; the η_{rep} measured with the DSF is shown by the blue circles, and the η_{rep} measured with the SMF is shown by the red circles. We also plot the results of a model [5] demonstrating good agreement for dispersion parameters of 0.5 and 17.5 ps/nm·km for DSF and SMF, respectively. In the interferometer with SMF, η_{rep} was measured to be approximately 18 dB less than the η_{rep} expected in a zero-dispersion interferometer. So even with a short delay line, the amount of dispersion in the SMF was sufficient to significantly reduce the interferometer's sensitivity.

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