A hybrid 10 GHz photonic-microwave oscillator with sub-femtosecond absolute timing jitter

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***Abstract*— We demonstrate a 10 GHz hybrid oscillator comprised of a phase stabilized optical frequency comb divider and a room temperature dielectric sapphire oscillator. Characterization of the 10 GHz microwave signal via comparison of two independent hybrid oscillators yields a combined phase noise, L(f) = -100 dBc/Hz at a 1 Hz offset and L(f) < -185 dBc/Hz for frequencies > 1 MHz. The associated absolute timing jitter is 0.6 fs (1 Hz to 5 GHz).**

I. Introduction

High spectral purity X-band microwave oscillators have emerging applications in radar [1] and imaging systems [2], timing synchronization in free electron laser facilities [3] and very long baseline interferometry [4], and as the master oscillator in Cs fountain atomic clocks [5]. Recently, a photonic approach to microwave generation based on a cavity stabilized laser and an optical frequency comb divider (OFCD) demonstrated a 10 GHz signal with a close to carrier phase noise [6] comparable with that achieved in cryogenic sapphire microwave oscillators [7]. Although this photonic approach to microwave generation has achieved outstanding phase noise performance at low offset frequencies, lower signal strength due to photodiode saturation currently limits it performance at high offset frequencies to -160 dBc/Hz (> 100 kHz) [6]. In comparison, room temperature dielectric sapphire loaded cavity oscillators (SLCO) with higher signal strengths exhibit superior performance far from the carrier near -190 dBc/Hz [8], but at the expense of the phase noise close to carrier. Here we describe an experiment that combines the performance of a SLCO and a OFCD-based photonic generator in a hybrid approach to produce 10 GHz microwaves with sub-femtosecond absolute timing jitter.

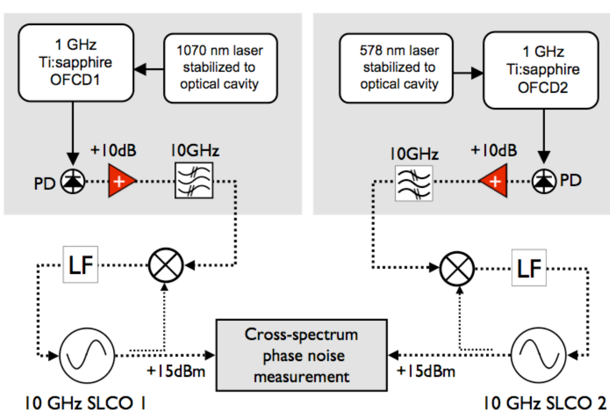

Figure 1. Experimental setup for generation and cross-spectrum phase noise measurement of two 10 GHz hybrid microwave sources. LF denotes loop filter and PD denotes photodiode.

II. Experimental Setup and Results

The experimental setup used for generation and characterization of two independent hybrid microwave sources is depicted in Figure 1. Each hybrid oscillator employs a commercial 10 GHz SLCO that is phase locked, with a 5 kHz bandwidth, to the microwave signal generated from an OFCD. The OFCDs are based on 1 GHz repetition rate modelocked Ti:sapphire lasers that produce an optical spectrum comprised of ~10^5 equally spaced longitudinal modes. This optical comb spectrum is stabilized to a continuous wave laser that is reference to high quality factor (Q ~ 10^{11}) optical reference cavity [9,10]. Stabilization transfers the stability and accuracy of the optical reference to the OFCD laser pulse train, which when photodetected then produces a stable electronic pulse train. This microwave signal is filtered at 10 GHz, amplified to 0 dBm, and is then used as a reference for the SLCOs (more details pertaining to the photonic oscillator can be found in Ref. [5].) Characterization of the phase noise of two fully independent hybrid oscillators is obtained via a cross-spectrum phase noise measurement [11], which allows for a reduction in the uncorrelated noise in the phase noise measurement system by the square root of the number of averages.

The results are shown in Figure 2. Our hybrid approach achieves a combined 10 GHz phase noise, L(f) = -100 dBc/Hz at a 1 Hz offset that drops to -190 dBc/Hz for frequencies > 1 MHz. This results in an unprecedented combined absolute timing jitter for the two hybrid 10 GHz oscillators of 0.3 fs (1 Hz to 1 MHz), which increases to only

0.6 fs when the integration is extended to 5 GHz at the present noise floor of -190 dBc/Hz [12]. Assuming that both oscillators contribute equally, the single oscillator timing jitter would be 0.42 fs.

Although the presented measurements employ Ti:sapphire based OFCDs, the use of Er:fiber OFCDs that have demonstrated comparable phase noise close to carrier [12] would provide a more robust, compact and less expensive alternative.

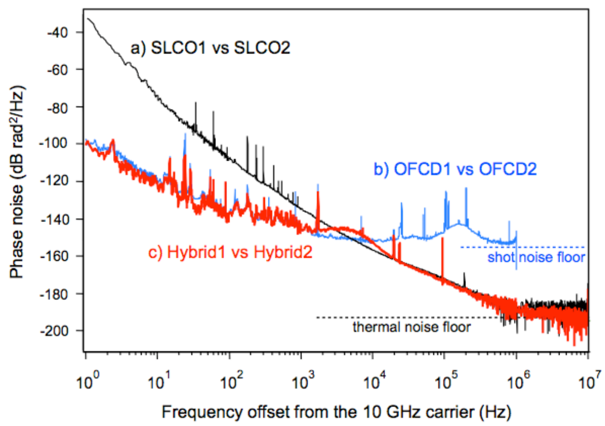

Figure 2. Single sided, single sideband phase noise, L(f), for the two oscillator comparison of a) a room temperature SLCOs b) photonic microwave generators, and c) hybrid photonic-microwave generators.

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