Full Stabilization and Control of an Integrated Photonics Optical Frequency Synthesizer

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Abstract: We demonstrate a frequency-stabilized, dual-Kerr microcomb that guides an integrated Vernier-laser optical frequency synthesizer, all derived from an RF clock. The synthesizer's stability is $<10^{-12}/\tau$ with Hz-level tuning resolution across a 32 nm tuning range.

1. Optical frequency synthesis using integrated photonics

Optical frequency combs enable a coherent phase link between microwave and optical domains, and allow for the transfer of relative frequency stability to achieve high spectral purity signals. Applications in optical metrology, microwave photonics, coherent LIDAR, and molecular spectroscopy benefit greatly from disciplining an optical source to a stable RF clock [1]. Integrated photonic elements yield additional benefits in these applications and others through portability, low-cost, and low power consumption. Here we present our work on a self-referenced and frequency-stabilized microcomb system using Si_3N_4 and SiO_2 microresonators for low-noise Kerr soliton generation. Subsequent phase locking of an integrated tunable laser to the stabilized microcomb system accurately synthesizes the frequency of light relative to an RF clock, while being widely tunable across most of the C band. All comb and laser components are consistent with an integrated system consuming less than 1 W of electrical power.

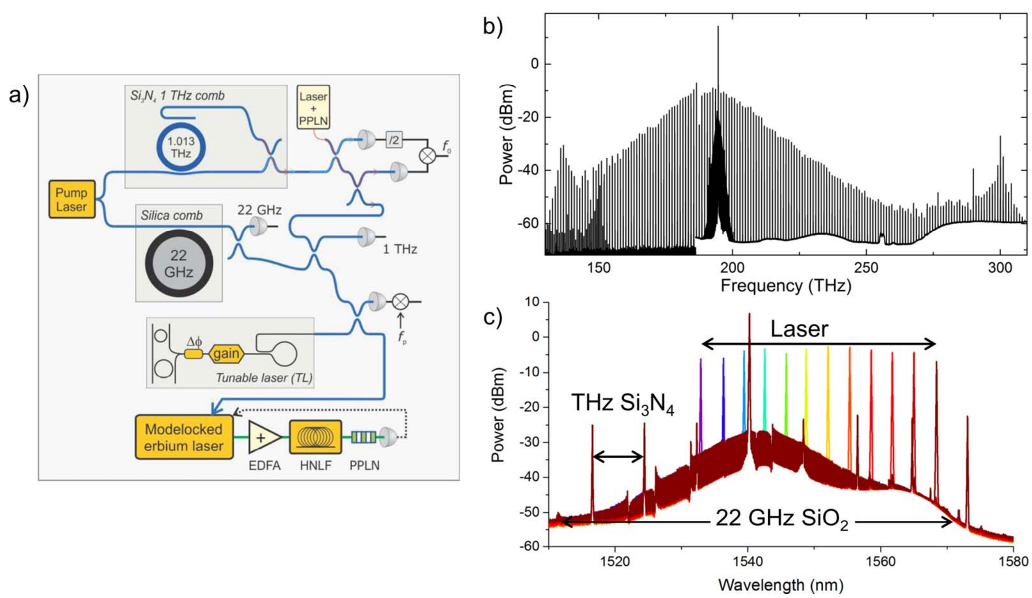

Figure 1: (a) The frequency stabilized dual-Kerr microcomb and integrated Vernier tunable laser optical synthesizer, including reference mode-locked laser supercontinuum. (b) The octave spanning 1.013 THz Si_3N_4 and tightly spaced 22 GHz silica microcombs provide full stabilization to an RF clock, while (c) the III/V-Si based integrated tunable laser allows for ultra-stable synthesis at arbitrary optical frequencies across the laser tuning range.

The full optical synthesizer system is shown in Figure 1a, including the comparison to a fully stabilized reference mode-locked fiber laser system on a shared 10 MHz clock. To achieve precisely known comb teeth that the tunable laser can reference to, we utilize two microcombs of different repetition rates (f_{rep}).The first is a waveguide coupled Si_3N_4 THz microcomb with a radius of 23 μm and height of 600 nm, which is dispersion engineered to generate over an octave of bandwidth efficiently to enable f-2f interferometry and carrier-envelope offset frequency (f_{ceo}) detection [2]. An external cavity laser at 1999 nm is amplified in Thulium-doped fiber, doubled through a periodically poled $LiNbO_3$ waveguide device developed by Srico, Inc., and heterodyned against the THz microcomb at 1999 nm and 998 nm to generate the requisite electrical signals for stabilizing f_{ceo} via input power to the comb. The second device is a chip-compatible silica wedge resonator with a 22 GHz f_{rep} [3], which enables measurement and control of the 1.013 THz f_{rep} and provides reference comb lines for tunable laser heterodyne signals within the bandwidth of a microwave photodetector. Both microcombs are pumped with a shared external cavity laser at 1540 nm, which is split, amplified, and rapidly swept in separate single sideband modulators for efficient comb generation and eventual f_{rep} stabilization [4]. Spectra of the shared pump dual microcombs are shown in Figure 1b. The final piece of the synthesizer is a heterogeneous Si/III-V laser developed by Aurrion Inc. The laser includes III/V gain material, monolithically integrated Si loop mirrors, 2 intracavity add-drop filters for linewidth narrowing, and thermal phase tuners to adjust the round trip phase and each filter's resonance wavelength [5]. Figure 1c highlights the laser's tuning range of >35 nm across the silica comb lines.

2. Stabilized optical synthesizer results

Once the tunable laser is phase locked to the self-referenced THz microcomb, we verify that the relative stability of the RF clock used to stabilize the system is accurately reproduced on the laser's CW output. We take a tap of the synthesizer output and heterodyne against an independent mode-locked Er:laser comb that is also fully self-referenced to the same RF source. By using a gap-free pi counter, we verify robust phase locking with an overlapping Allan deviation of $<10^{-12}/\tau$ of stability and clean histograms for 2 adjacent silica modes near 1545.2 nm, shown in Figure 2a. We verify the output frequency of dual comb synthesizer is arbitrarily tunable to any frequency from 191.6-195.6 THz and accurate at the level of 0.8 Hz when averaged for 200 s Finally, arbitrary frequency control is demonstrated by applying 32 levels of frequency shift keying to the synthesizer offset phase lock. Figure 2b highlights the counter trace for a 100 ms gate, 2 second pause at each frequency, along with the expected frequency offset levels in gray showing excellent agreement.

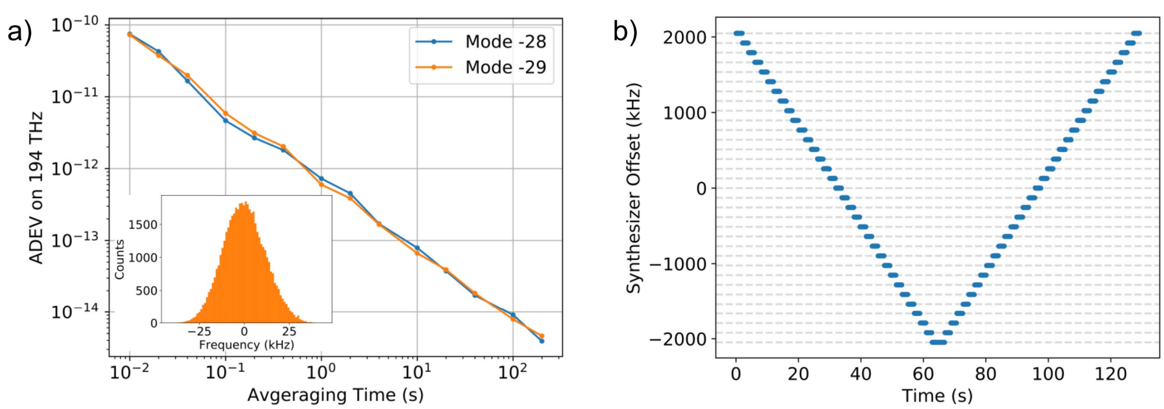

Figure 2: (a) Overlapping Allan deviation and histogram counts of the synthesized frequency at 2 adjacent silica comb lines (mode number referenced from the pump laser). (b) Arbitrary laser frequency control across 32 levels by digitally tuning the offset phase lock. Counter trace for 100 ms gate/2 s pause per level is in blue, expected synthesizer frequency levels are in dotted gray.

4. References

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