Microwave Extraction Based on Synchronization of Ti:sapphire Optical Frequency Comb and Optoelectronic Oscillator

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***Summary*—We demonstrate a highly stable microwave extraction method based on the synchronization of an optical frequency comb generated by Ti:sapphire mode-locked laser and microwave generated by an optoelectronic oscillator. The absolute phase noise of locked OEO at a carrier frequency of 2 GHz, reaching -92 dBc/Hz at 20 Hz and -141 dBc/Hz at 100 kHz.**

Keywords—optical frequency comb; mode-locked laser; microwave extraction; optoelectronic oscillator

I. Introduction

Optical frequency comb (OFC) is a sort of light whose spectrum is consisted of serval distinct and equally spaced combs. Due to the characterization of OFC's spectrum, OFC plays the role of bridge between optical frequency and radio frequency standards and has been widely used in a number of fields [1-3], such as frequency metrology, time-frequency transmission, and optical clocks. Therefore, optical frequency combs will become the fundamental components of the time and frequency standard system and network in the near future.

Additionally, the extraction of highly-stable and low-noise microwaves from OFC has raised a lot of interest. Many technical and scientific applications including radar systems [4], synchronization of large-scale scientific facilities [5], and very-long baseline interferometry detection [6], depend on Ultralow phase noise microwave signal sources.

Direct photodetection is the simplest way to extract microwave signals from an optical pulse train emitted by a mode-locked laser (MLL). However, when direct photodetection is used, excess phase noise is added in the optical-to-electronic (O/E) conversion process due to nonlinearity, saturation, temperature drift, and amplitude-to-phase conversion in photodiodes [7]. A solution based on a Ti:sapphire mode-locked laser, Sagnac loop, and voltage-controlled oscillators (VCO) was proposed to address this issue [8]. Nevertheless, as the carrier frequency of the VCO increases, the phase noise performance deteriorates [9]. Compared to a conventional VCO, an optoelectronic oscillator (OEO) with a long delay fiber link can generate a high-purity microwave with the same low phase noise at a very high carrier frequency [10].

Here we demonstrate the highly-stable microwave extraction based on optical frequency comb and microwave synchronization by using a sub-10-attosecond timing jitter Ti:sapphire mode-locked laser, OEO, and Sagnac loop.

II. Methods/Results

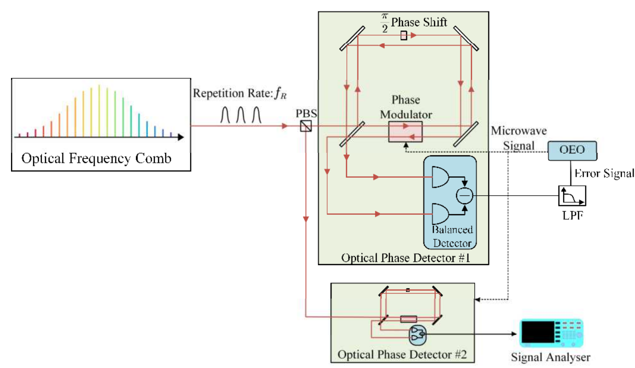

Fig. 1. Schematic for extraction of a highly-stable microwave based on synchronizing Ti:sapphire OFC and OEO utilizing an optical phase detector. PBS: Polarization Beam Splitter; OEO: optoelectronic oscillator; LPF: low pass filter.

Figure 1 shows the scheme of microwave extraction Based on Ti:sapphire optical frequency comb and microwave synchronization. A 100-MHz repetition-rate Ti:sapphire mode-locked laser, which has a state-of-art performance of 7as integrated timing jitter resolution by doing careful noise suppression [11], is responsible for generating optical frequency comb. The stable pulse train of the OFC is sent to the Sagnac loop which removes impacts of temperature fluctuations, air currents, and mirror vibrations [8]. The two pulses in the Sagnac loop experience opposite phase modulation and then output beams are detected by a balanced detector that generates an error signal. The microwave signal is generated in OEO under influence of the error signal. Meanwhile, the microwave signal is sent to the phase modulator to perform phase detection. Two identical optical phase detectors are used in the system, one for synchronizing OFC and microwave signal and the other for out-of-loop monitoring microwave signal and analyzing the phase error. The specifics of optical phase detectors are discussed in Jung and Kim [8].

III. DISCUSSION/INTERPRETATION

Recently, my research group has developed a state-of-art 7as timing jitter OFC and Xu [11] outlines how it works in detail. Low timing jitter OFC means that highly stable microwave extraction can be realized by a high-power Ti:sapphire mode-locked laser and a low noise optoelectronic oscillator. We measured the absolute phase noise of locked OEO at a carrier frequency of 2 GHz, reaching -92 dBc/Hz at 20 Hz and -141 dBc/Hz at 100 kHz.

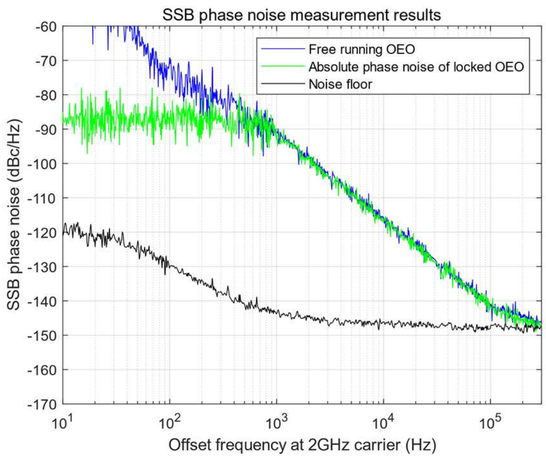

Fig. 2. SSB phase noise measurement results.

IV. CONCLUSIONS

We present a preliminary result of microwave extraction based on optical frequency comb and microwave synchronization. To achieve a lower-noise microwave, we will in the future optimize the optical path's structure and collimation.

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