Compact 2.4 GHz Microwave Generation System Based on an Ultralow Noise Femtosecond Laser

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***Summary*—Communication systems with high timing precision require microwave signals with ultra-low phase noise. In this work, we establish a compact and convenient 2.4 GHz microwave generation system based on the transfer oscillator technique for optical frequency division via a low-SWaP 1-GHz solid-state fiber laser and a 657 nm narrow linewidth laser. High SNR (> 30 dB) of carrier envelop offset frequency and beat note between two lasers are obtained via the octave spectrum without amplification.**

Keywords—Photonically generated microwave; ultra-low noise; high repetition rate; low-SWaP; fiber laser; non-amplification

I. INTRODUCTION

2.4 GHz microwave signal plays an irreplaceable role in wireless communications for its farther coverage range and penetration of solid objects. The phase noise of commercially available microwave sources, which based on the crystal oscillators in room temperature, is less likely to satisfy the requirements of the next-generation communication systems with higher SNR, higher resolution, and higher density [1, 2]. Higher spectral purity would enable phase-encoded signals with lower error rates [3]. The transfer oscillator technique for optical frequency-divided (TO-OFD) permits extraction of frequency divided signals with high stability and ultra-low noise [4]. Here, we demonstrate a 2.4 GHz microwave signal system based on TO-OFD via an ultra-low noise high repetition rate mode-locked fiber laser and a 657 nm narrow linewidth laser.

II. METHODS/RESULTS

The setup of 2.4 GHz microwave signal generation system is shown in Fig. 1. A home-made 1 μm, 1 GHz repetition rate, solid-state Yb: fiber laser is used as the optical frequency comb source [5]. With ~ 150 fs pulse width and > 600 mW output power, the laser can obtain an octave-spanning supercontinuum by pumping a tapered photonic crystal fiber (PCF) without amplification. The carrier envelope offset (CEO) frequency is detected by Michelson-type f-to-2f interferometer, in which light around 1064 nm is doubled in a periodically poled lithium niobate (PPLN) crystal and overlapped with the spectral components at 532 nm in time and space. Thus, the unutilized

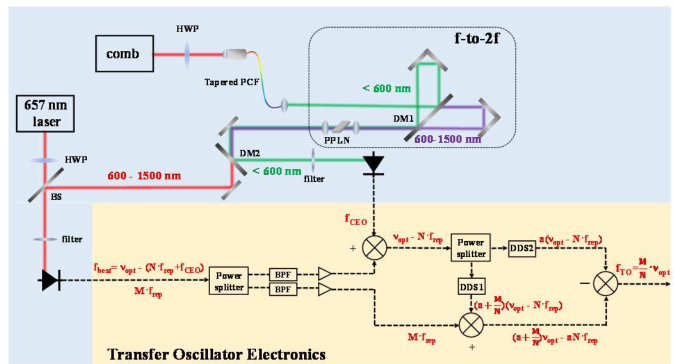

Fig. 1. Setup of 2.4 GHz microwave signal generation system. HWP, half wavelength plate; PCF, photonic crystal fiber; DM, dichroic mirror; PPLN, periodically poled lithium niobate; BS, beam splitter; BPF, band-pass filter; DDS, direct digital synthesis; TO, transfer oscillator.

light can be effectively used to derive optical beat signal against the 657 nm ultra-stable optical reference by inserting a dichroic mirror. As the fundamental repetition rate of our laser is as high as ~ 1 GHz, the pulse interleaver is unnecessary [4], which is used to increase the strength of recovered microwave signal and improve the measured noise floor induced by thermal effect of photodetector.

The Mth harmonic of repetition rate (Mfrep) and the beat signal (f_{beat}) between the comb and the optical reference are detected by a Balanced-Optical-Microwave Phase-Detector (BOM-PD) [6]. The CEO frequency (f_{ceo}) is measured by an avalanche photodiode (APD). By mixing the three signals in electronics, f_{TO} would be obtained as

$$f_{TO} = M \cdot f_{rep} + \frac{M}{N}(f_{beat} + f_{ceo}) = \frac{M}{N}\nu_{opt}, \qquad (1)$$

where the resulting microwave signal is only related to the optical frequency reference and the integer value of M and N. In this scheme, the 2.4 GHz microwave signal was generated from this optical frequency comb (OFC), while canceling the noise contributions from the OFC.

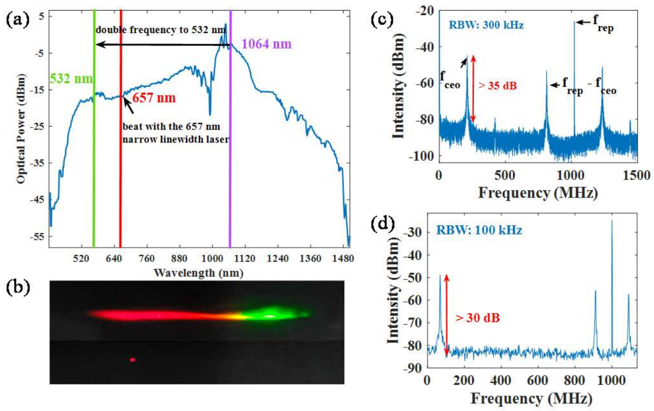

Fig. 2. Experimental results. (a) The octave-spanning supercontinuum generated by pumping the tapered PCF; (b) The output visible light of supercontinuum (top) and the 657 nm laser (bottom) dispersed by the diffraction grating; (c) The f_{ceo} beat note of the OFC based on Yb: fiber mode-locked laser at 300 kHz RBW; (d) The beat signal between the OFC and the 657 nm laser at 100 kHz RBW.

III. DISCUSSION/INTERPRETATION

Fig. 2 shows the results of our experiment. A smoothly octave-spanning spectrum contains the two key wavelength components of 532 nm and 657 nm is obtained by seeding ~ 400 pJ, ~ 150 fs pulse train into a dispersion-managed tapered PCF as shown in Fig. 2 (a). Fig. 2 (b) demonstrates the visible diffraction spectra of the OFC (top) and the 657 nm laser (bottom). Fig. 2 (c) shows the SNR of the f_{ceo}, which is larger than 35 dB in 300 kHz resolution bandwidth. Meanwhile, the beat note between OFC and the narrow linewidth laser also has sufficient SNR (> 30 dB) for signal processing in electronics (Fig. 2 (d)).

IV. CONCLUSIONS

In conclusion, we build a 2.4 GHz microwave signal generation system based on a low noise and high repetition rate fiber mode-locked laser by using TO-OFD technique. High SNR (> 30 dB) of f_{ceo} and f_{beat} are simultaneously obtained without locking operation. Benefiting from the high repetition rate, high average output power and ultrashort pulse width, the system could remove the optical amplification system and the interlever system, which demonstrates the potential for out of lab use with our low SWaP laser.

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