Fourier Domain Mode-locked Optoelectronic Oscillator for Multi-band Chirped Microwave Waveform Generation

Tengfei Hao, *Student Member, IEEE,* Ming Li, *Member, IEEE*

***Abstract*—In this report a photonic approach to generating multi-band chirped microwave waveform is proposed and experimentally demonstrated based on a Fourier domain mode-locked optoelectronic oscillator (FDML OEO). In the proposed approach, a frequency scanning multi-passband microwave photonic filter (MPF) is incorporated into the FDML OEO cavity. Multi-band chirped microwave waveform is generated at the output of the FDML OEO by synchronizing the scanning period of the MPF to the cavity round-trip time to achieve Fourier domain mode-locking operation. The key significance of the approach is that it allows the generation of multi-band chirped microwave waveforms without using a high-speed baseband single-chirped microwave source. In addition, the central frequency and bandwidth of the generated waveforms can be easily reconfigured. The proposed approach has great potential in applications such as modern multi-band radar systems.**

***Index Terms*—Optoelectronic oscillator, Fourier domain mode locking, chirped microwave waveform, multiband radar.**

I. Introduction

In addition to ranging, radar systems are developing to have multiple functionalities, such as recognition, tracking, mapping, etc. In order to achieve these functionalities, reconfigurable chirped microwave waveforms over multiple bands are demanded. Generally, chirped microwave waveforms can be generated by using electrical methods, such as voltage-controlled oscillators (VCOs), direct digital synthesizers (DDSs) and analog-to-digital converters (ADCs). However, the generation of wideband and high-frequency chirped microwave waveforms with acceptable stability and precision are still a challenge in the pure electrical domain.

Recently, we have proposed and experimentally demonstrated photonics-assisted chirped microwave waveform generation methods based on a Fourier domain mode-locked optoelectronic oscillator (FDML OEO) [14]. An OEO is simple and cost-effective photonics-assisted microwave signal generation methods. Single frequency microwave signals with ultra-low phase noise have been generated using OEO, thanks to the use of a high Q-factor or low-loss optical delay line. However, continuous chirped microwave waveforms cannot be generated directly from a traditional OEO cavity, since new oscillation frequency has to build up repeatedly from noise when the OEO is tuned to achieve frequency chirping. Fortunately, by using a frequency scanning filter and synchronize the scanning period of the filter to the cavity round-trip time of the OEO cavity to achieve Fourier domain mode-locking operation, all the frequency components of an entire frequency sweep can be active simultaneously in the FDML OEO cavity. The generation of continuous single-band chirped microwave waveforms has been successfully demonstrated based on an FDML OEO.

Here we propose and experimentally demonstrate a multi-band chirped microwave waveform generation method based on an FDML OEO. The based idea is to incorporate a frequency scanning multi-passband microwave photonic filter (MPF) into an OEO cavity, and synchronize the tuning period of the MPF to the cavity round-trip time to achieve Fourier domain mode-locking operation. As a result, multi-band chirped microwave waveform can be generated directly from the FDML OEO cavity. The key significance of the approach is that it allows the generation of multi-band chirped microwave waveforms without using a high-speed baseband single-chirped microwave source. In addition, the central frequency and bandwidth of the generated multi-band chirped microwave waveforms can be easily reconfigured. The proposed approach has great potential in modern multiband radar systems.

II. Proposed Scheme and Results

The schematic diagram of the proposed multi-band chirped microwave waveform generation system is shown in Fig. 1(a). The system is based on a FDML OEO, which consists of a frequency scanning multi-wavelength light source, a phase modulator (PM), an optical notch filter, an erbium-doped fiber amplifier (EDFA), an optical fiber, a photodetector (PD), an electrical high-pass filter (HPF), an electrical power divider and an electrical low-noise amplifier (LNA). The key of the FDML OEO is a frequency scanning multi-passband MPF, based on phase-modulation to intensity-modulation (PM-IM) conversion by using the frequency scanning multi-wavelength light source, the PM, the optical notch filter and the PD. The operation principle of the frequency scanning multi-passband MPF is as follows. Lights from the multi-wavelength light source are

T. Hao, and M. Li are with State Key Laboratory on Integrated Optoelectronics, Institute of Semiconductors, Chinese Academy of Sciences, P. O. Box 912, Beijing 100083, China and School of Electronic, Electrical and Communication Engineering, University of Chinese Academy of Sciences, Beijing 100049, China (email: tfhao@semi.ac.cn; ml@semi.ac.cn).

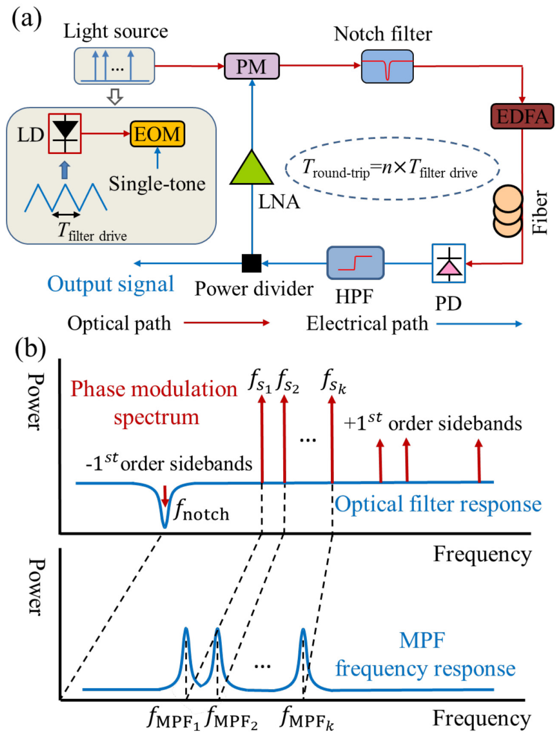

Fig. 1. (a) Schematic of the proposed multi-band chirped microwave waveform generation method based on a Fourier domain mode-locked optoelectronic oscillator (FDML OEO). A frequency scanning multi-passband microwave photonic filter (MPF) is incorporated into the FDML OEO cavity, and the tuning period of the MPF is synchronized with the cavity round-trip time to achieve Fourier domain mode-locking operation. (b) Operation principle of the multi-passband MPF when it is static. LD, laser diode; EOM, Electro-optic modulator; PM, phase modulator; EDFA, Erbium-doped fiber amplifier; PD, photodetector; HPF, high-pass filter; LNA, low-noise amplifier.

modulated by the microwave signals at the PM. With the help of the optical notch filter to remove one of the 1st order sidebands of the phase modulated light waves, a microwave signal can be detected at the PD. So an equivalent MPF based on PM-IM conversion is achieved. As shown in Fig. 1(b), assuming the -1st order sides are removed by the optical notch filter, the center frequency of the passbands of the MPF is equal to the frequency difference of the multi-wavelength light source and the optical notch filter. Clearly, a frequency scanning multi-passband MPF can be achieved by sweeping the frequency of the multi-wavelength light source. The frequency scanning multi-wavelength light source can be implemented by different methods. For example, as shown in Fig. 1(a), it can be implemented by using a laser diode (LD) and an electro-optic modulator (EOM). Multi-wavelength operation is achieved by applying a single-frequency microwave signal to the EOM, and frequency scanning operation is achieved by sweeping the frequency of the LD, which is driven by a triangular driven current. In the FDML OEO, the scanning period of the MPF is synchronized with the round-trip time of the OEO cavity to achieve Fourier domain mode-locking operation. If the OEO loop is closed, the frequency components in an entire frequency chirp would be returned to the MPF at the exact time when the MPF is scanned at the same spectral position. Every frequency components in the frequency chirp can be sustained in the

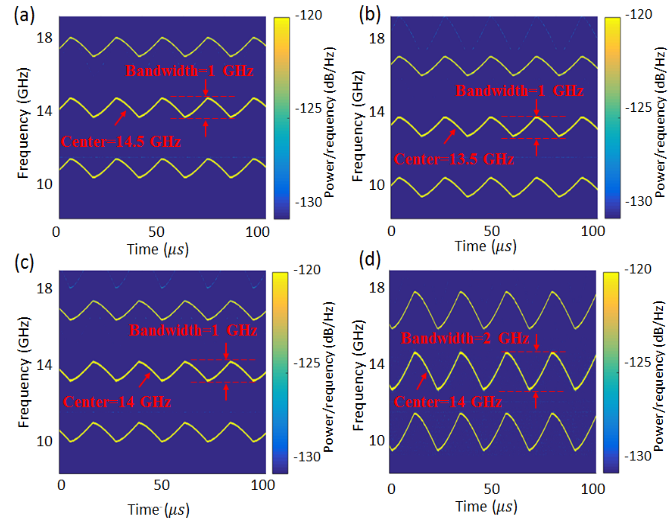

Fig. 2. Instantaneous frequency-time diagram of the generated multi-band chirped microwave waveforms with different center frequency and bandwidth. The frequency of the single-tone driving signal of the EOM is 3 GHz.

FDML OEO cavity simultaneously. Multi-band chirped microwave waveform can be generated by the FDML OEO with the help of the frequency scanning multi-passband MPF. The center frequency and frequency difference between adjacent bands can be tuned by tuning the frequency of the LD and single-tone RF signal at the EOM, respectively. Moreover, the proposed method allows the generation of multi-band chirped microwave waveforms by using only a very low frequency (tens of kHz) electrical driving source, which avoids the use of an expensive baseband chirped microwave source.

Experiments based on the scheme shown in Fig. 1(a) are carried out to verify the proposed multi-band chirped microwave waveform generation method. Figure 2 shows the instantaneous frequency-time diagram of the generated multi-band chirped microwave waveforms with different center frequency and bandwidth. The frequency-time diagram is obtained by calculating the short-time Fourier transform (STFT) of the generated temporal waveform. Three different bands can be observed from Fig. 2, which corresponds to the three optical carriers from the equivalent multi-wavelength light source.

III. Career Plan and Fellowship Impact

I am truly honored and grateful to the IEEE Microwave Theory and Techniques Society (MTT-S) for the recognition and support. The award is a great motivation to continue my research in microwave photonic signal generation, photonic-assisted microwave frequency measurement and integrated microwave photonics. I look forward to have more contribution to the advances in this field and to the IEEE MTT-S society. As for my career plan, I am open to both industry and academia to continue my research.

References

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