High-resolution Comb-assisted Microwave Frequency Identification and Down-conversion System

1st Yihang Zhang
State Key Laboratory of Information Photonics and Optical Communications
Beijing University of Posts and Telecommunications
Beijing, China
zhangyihang@bupt.edu.cn

2nd Zhixue Li
State Key Laboratory of Information Photonics and Optical Communications
Beijing University of Posts and Telecommunications
Beijing, China
lizhixue@bupt.edu.cn

3rd Mingwen Zhu
State Key Laboratory of Information Photonics and Optical Communications
Beijing University of Posts and Telecommunications
Beijing, China
zhumingwen1998@bupt.edu.cn

4th Shangsu Ding
State Key Laboratory of Information Photonics and Optical Communications
Beijing University of Posts and Telecommunications
Beijing, China
dingshangsu@bupt.edu.cn

5th Song Yu
State Key Laboratory of Information Photonics and Optical Communications
Beijing University of Posts and Telecommunications
Beijing, China
yusong@bupt.edu.can

6th Jianming Shang
State Key Laboratory of Information Photonics and Optical Communications
Beijing University of Posts and Telecommunications
Beijing, China
shangjamin@bupt.edu.can

7th Bin Luo
State Key Laboratory of Information Photonics and Optical Communications
Beijing University of Posts and Telecommunications
Beijing, China
luobin@bupt.edu.cn

***Abstract*—A high-resolution system for spectrum detection and RF signal down-conversion is proposed, which utilizes an optical frequency comb and wavelength-tunable lasers for multi-frequency measurement and spectrum recovery. The frequency deviation of the spectrum is less than 1.3 MHz. Additionally, a laser synchronization system based on an optical frequency comb is used to achieve down-conversion of modulated signals, with the standard deviation in 1 hour smaller than 1.4 Hz.**

***Index Terms*—microwave, frequency identification, down-conversion**

I. Introduction

With the modern communication, radar, electronic warfare systems continue to develop in the direction of high speed rate, wide bandwidth, effective interception and identification of enemy electronic signals for electronic reconnaissance and intelligence support work is of great significance [1]. The electromagnetic environment contains a variety of formats, different strengths and weaknesses, spectral distribution of complex signals, the receiver's receiving bandwidth, spectral resolution and real-time processing speed has put forward higher requirements. In many antenna-related applications, such as remote antennas for radar [2]and distributed antenna systems for wireless communications [3], remote antennas receive RF signals miles away from the central station.When the frequency of the RF received by the antenna is unknown, it is crucial to first detecting signal frequency, then transmit high-frequency RF signals (tens of GHz) from the remote end to the local site and then convert them to low-frequency intermediate frequency (IF) signals (hundreds of MHz) for analog-to-digital conversion. However, existing electronics to process RF signals face an electronic choke point of bandwidth [4]. In conventional RF signal receiving systems, the signal can be obtained by directly using a large bandwidth photodetector (PD) and the large bandwidth spectrum analyzer after loading the signal into a large bandwidth modulator, but both large bandwidth PD and large bandwidth spectrum analyzer are difficult to obtain and the frequency of the RF signal may still be beyond the system bandwidth.The optical frequency comb (OFC) can accurately transfer phase and frequency information from a high stability reference to hundreds of thousands of tones in the optical domain, and is a bridge connecting RF and optical frequency [5], so the measurement and down-conversion of modulation frequency can be realized by using the tone characteristics of the OFC.

979-8-3503-5427-0/24/$31.00 ©2024 IEEE

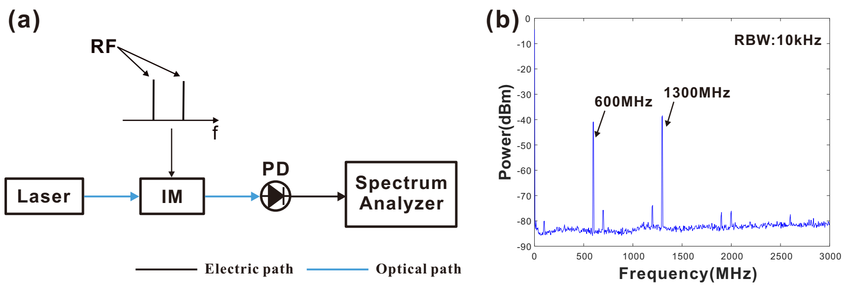


Fig. 1. (a) Modulated Signal Direct Detection System Diagram, IM:Intensity Modulator, (b) The Spectrum diagram of the signal to be measured

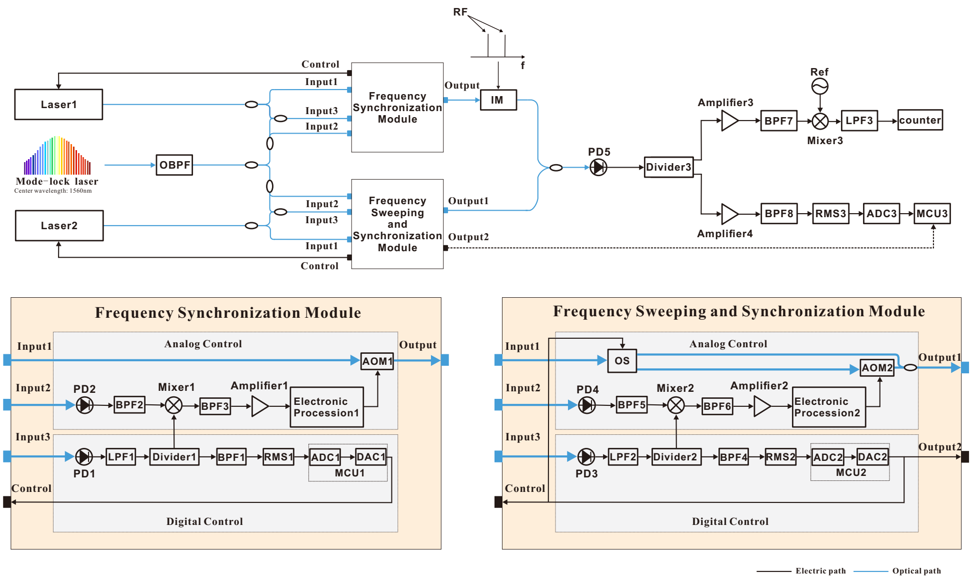
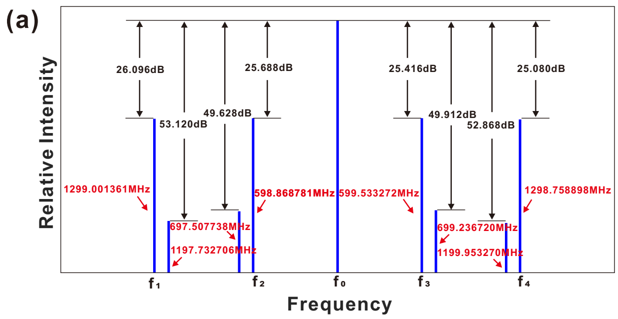


Fig. 2. The Schematic diagram of spectrum detection and signal down-conversion system. OBPF : optical band pass filter, BPF : band pass filter, LPF : low pass filter, RMS : root mean square detector, MCU : micro-controller unit, OS : optical switch.

This paper proposes a system for frequency detection and down-conversion of unknown RF signals based on an OFC. After synchronizing the source laser with the OFC, the detector laser is swept to achieve modulation frequency detection and spectrum recovery, and the frequency error of detection is less than 1.3 MHz.During the sweeping process, the detector laser is synchronized with the OFC to achieve down-conversion by switching the control loop, and the stability of the frequency conversion signal is 1-hour STD $<$ 1.4 Hz. The system can achieve arbitrary modulation frequency detection within the spectral range of the OFC, and the intermediate frequency signal can be adapted to the requirements of the subsequent processing system. The frequency of the downconversion signal can be changed to match the signal processing speed of the back-end electronic system.

II. Experimental and Results

As shown in Fig.1 (a) is the Modulated Signal Direct Detection System Diagram and Fig.1 (b) is the spectrum diagram of the signal to be measured directly into the PD after frequency tapping, which shows that the modulated RF is 600 MHz and 1300 MHz, as a comparison of the spectrum detection scheme in the text. As shown in Fig.2, the black solid line indicates the electric path and the blue solid line indicates the optical path. The reference for synchronization is a homemade OFC which contains a homemade mode-locked laser (MLL) and repetition frequency stabilization system. The MLL's center frequency is 1560 nm and the repetition frequency (f_{rep}) is 100 MHz. The output of OFC is coupled to a carrier light, laser 1, through a band-pass filter and enters the digital-analog hybrid frequency-locked system, frequency synchronization module (FSM), so that a certain comb tooth of the OFC is locked to Laser1. In the digital locking part of FSM, the light from laser 1 and OFC is coupled into PD 1 and passes through the low pass filter (LPF) 1 to obtain the beat frequency signal. After passing through the power divider, one signal is transmitted to the analog locking section, and the other one goes to band pass filter (BPF) 1, which is filtered, and then the error signal is extracted through root mean square detector (RMS) 1 to complete the digital locking in cooperation with micro-controller unit (MCU) 1. In the



(b)

Error(MHz)	
f1	0.998639
f2	1.131219
f3	0.466728
f4	1.241102

Fig. 3. (a) Spectrum of the signal recovered by the spectrum detection system, (b) frequency error

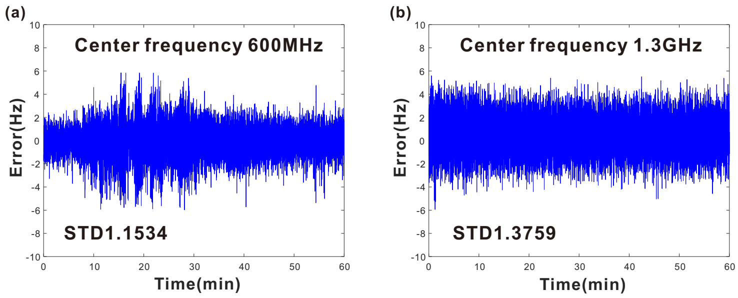


Fig. 4. (a) Downconverted signal frequency for 600 MHz modulation sideband, (b) Downconverted signal frequency for 1300 MHz modulation sideband

analog control section of FSM, PD 2 and BPF 2 extract the third harmonic of f_{rep}, which is mixed with the beat frequency signal from the digital locking section and added to the acoustic-optic modulator (AOM) to lock laser 1. To simulate the radio frequency (RF) signal received by the antenna, and limited by the bandwidth of the intensity modulator (IM) and PD, we choose 600 MHz, and the RF signal of 1300 MHz is modulated by the IM to the locked Laser1 to form the signal to be measured. laser 2 and the output of OFC enter frequency sweeping and synchronization module (FSSM). There are optical switch (OS) and acousto-optic modulator (AOM) in FSSM. By controlling OS, the conversion of FSSM frequency locking mode and frequency sweeping mode can be realized. In the next step, the outputs of FSM and FSSM are optically coupled into PD5, which generates the beat frequency signal. The beat frequency signal is divided into two paths through the power divider, one path through the amplifier 4, BPF 8 by the RMS 3 to detect the signal strength, through the analog-to-digital conversion into the MCU 2 to realize the frequency detection. The other channel is mainly used to monitor the stability of down-conversion. Control OS and laser 2's PZT to make it sweep, MCU 2, 3 synchronization records laser 2 respectively with OFC, Laser 1 beat frequency detected by the RMS signal when RMS 3 has a signal, it shows that laser 2 sweeps to the modulating signal near the carrier band, so when you need to extract the modulating signal, then switch OS to make laser 2 lock, then by PD 5 beat frequency. Realize the down-conversion of the carrier band. If there is no need to extract the signal, then continue to scan to the next side of the band and repeat the above process until the completion of spectrum detection and signal down-conversion.

As shown in Fig.3 (a) is the spectrum of the signal recovered by the spectrum detection system, which is a typical intensity modulation signal spectrum, assuming that the carrier (f0) is 0 Hz, the frequencies of the two sidebands on the left side are f1 = 1299.001361 MHz, f2 = 598.868781 MHz, and the frequencies of the two sidebands on the right side are f3 = 599.533272 MHz, f4 = 1298.758898 MHz. As shown in the Fig.3 (b), the maximum error is 1.241102 MHz. As shown in Fig.4, after down-conversion, the standard deviation (STD) for the 600MHz modulation sideband in one hour is 1.1534 Hz, and for the 1300 MHz modulation sideband is 1.3759 Hz. Since the OFC used has a wide frequency spectrum, modulation frequency detection is possible throughout its coverage area, and the IF signals used to downconvert the signals can be selected with different combs to satisfy the frequency adaptability requirements with the subsequent processing system.

III. Conclusion

We propose a high-resolution spectrum detection and RF signal down-conversion system that utilizes an optical frequency comb and wavelength-tunable lasers for multi-frequency measurement and spectrum recovery. The frequency deviation of the recovered spectrum using the spectrum recovery algorithm is below 1.3 MHz. Additionally, using a high-precision OFC-based synchronizing module, the down-conversion frequency of modulated signals has a signal stability of 1-hour STD $<$ 1.4 Hz.

References

[1] Liu Jun and Chen Qiang. Research on integrated detection and identification technology of radar and communication signals. In *2022 IEEE 10th International Conference on Information, Communication and Networks (ICICN)*, pages 421–426, 2022.

[2] Mingjiang Zhang, Yongning Ji, Yongning Zhang, Yuan Wu, Hang Xu, and Weipeng Xu. Remote radar based on chaos generation and radio over fiber. *IEEE Photonics Journal*, 6(5):1–12, 2014.

[3] M. Crisp, R. V. Penty, I. H. White, and A. Bell. Wideband radio over fiber distributed antenna systems for energy efficient in-building wireless communications. In *2010 IEEE 71st Vehicular Technology Conference*, pages 1–5, 2010.

[4] Jianping Yao. Microwave photonics. *Journal of Lightwave Technology*, 27(3):314–335, 2009.

[5] Scott A. Diddams, David J. Jones, Jun Ye, Steven T. Cundiff, John L. Hall, Jinendra K. Ranka, Robert S. Windeler, Ronald Holzwarth, Thomas Udem, and T. W. Hänsch. Direct link between microwave and optical frequencies with a 300 thz femtosecond laser comb. *Physical Review Letters*, 84(22):5102, 2000.