Photonic multiple microwave frequency measurement based on a swept frequency silicon microring resonator

Feng Zhou[1,3], Hao Chen[1,3], Xu Wang[1], Linjie Zhou[2], Jianji Dong[1], and Xinliang Zhang[1]
[1] Wuhan National Laboratory for Optoelectronics, School of Optical and Electronic Information,
Huazhong University of Science and Technology, Wuhan, 430074, China
[2] State Key Laboratory of Advanced Optical Communication Systems and Networks, Department of Electronic Engineering,
Shanghai Jiao Tong University, Shanghai 200240, China
[3] These authors contributed equally to this work
Corresponding author e-mail address: jjdong@mail.hust.edu.cn

Abstract: A photonic multiple microwave frequency measurement system is presented based on a swept frequency silicon microring resonator. The measurement bandwidth, accuracy and multi-frequency resolution are 25 GHz, ±510 MHz and 5 GHz, respectively.

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1. Introduction

Microwave frequency measurement (MFM) technique has aroused lots of research interests for its application on electronic warfare, radar warning and electronic intelligence systems [1]. Compared with conventional electronics solutions, photonic MFM systems offer advantages including large instantaneous bandwidth, electromagnetic immunity, light weight and so on [2]. Many photonic MFM systems based on frequency-to-time mapping [3, 4] have been demonstrated, offering the unique advantage of multi-frequency measurement ability.

Here, a simplified photonic MFM system with a wide measurement range and a multi-frequency measurement ability is presented. A high-Q microring resonator (MRR), driven by a sawtooth voltage signal, serves as a periodic bandpass scanning filter. By scanning filtering, unknown frequency information is mapped into time interval and unknown frequencies can be derived using the frequency-to-time mapping function.

2. Principle of operation and experimental set-up

Figure 1(a) shows the schematic diagram of the proposed MFM system based on MRR. The continues-wave (CW) light carrier generated by a tunable laser (TLS) is launched into an intensity modulator (IM), modulated by the unknown microwave signal. After modulation (i.e., linear modulation), there are three frequency components in the signal, i.e. f_0 and $f_0 \pm f_1$. Here, f_0 is the frequency of CW light and f_1 is the frequency of input microwave signal. Two polarization controllers (PC1, 2) are placed before the IM and the MRR to optimize the polarization state of the incident light. Two erbium doped fiber amplifiers (EDFA1，2) are placed before and after the MRR to compensate the link loss, respectively. The output from the drop-port of MRR is detected by a low-speed PD (BW: 200 MHz) and the photocurrent is observed with an oscilloscope.

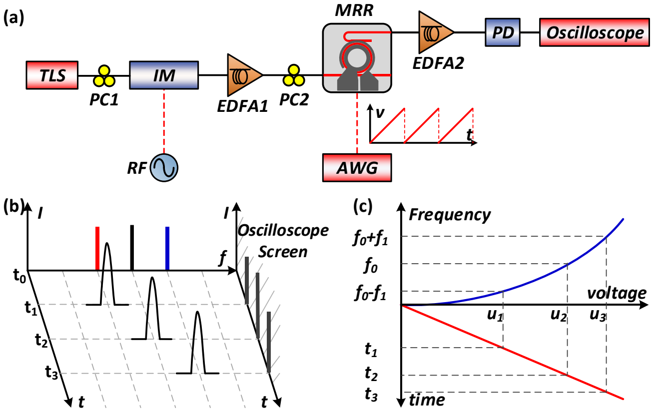

Fig. 1. (a) The schematic of the proposed MFM system. (b) The Scanning filtering principle of the MRR. (c) The process of frequency-to-time mapping.

We select one of the resonant peaks of the MRR, with a relatively narrow 3 dB bandwidth (5 GHz) and a high extinction ratio (20 dB) as the narrowband filter. Based on plasma dispersion effect, the resonant peak will be blue shifted periodically when a sawtooth voltage signal is applied on the electrodes of the MRR, revealing a periodic scanning filter. Figure 1(b) illustrates the scanning filtering process in a single period. At different time of t_1, t_2 and t_3, the frequency components of f_0-f_1, f_0 and f_0+f_1 are selected to pass through the filter, respectively. Thus three intensity peaks will show up on the oscilloscope, respectively. Therefore, frequency components are mapped into time sequences. The frequency-to-time mapping function is illustrated in Fig. 1(c), which can be written as

$$f_1(t) = f(at_2 + b) - f(at_1 + b). \tag{1}$$

Here a and b are constants and determined by the properties of applied sawtooth voltage signal. Note that the function relationship $f(u)$ is dependent on the electrical characteristic of individual MRR in practical use, and should be measured and fitted in advance.

3. Experimental results

The sawtooth voltage, generated by a low-speed arbitrary waveform generator (AWG), is set with a repetition rate of 1 MHz and a voltage range from 415 mV to 530 mV. In this voltage range, the filter has a distinct frequency shift and only the lower sideband and carrier are scanned so that the scanning period is fully utilized.

We tune the microwave frequency from 5 GHz to 30 GHz with a step of 1 GHz. After obtaining the intensity-time waveforms, the input microwave frequency can be calculated by measuring the time interval between the two intensity peaks and using Eq. (1). Figure 2(a) shows the measurement results from 5 GHz to 30 GHz. Excellent agreement between the estimation values and the input values can be seen. The measurement error is within ±510 MHz for different frequency microwave signals, as illustrated in Fig. 2(b).

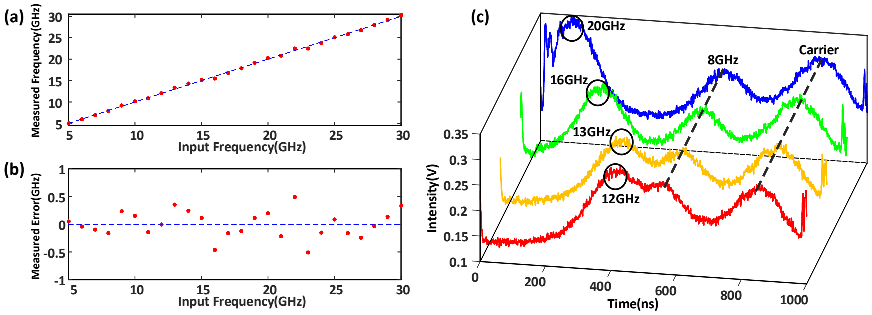

Fig. 2. (a) Frequency estimation results from 5 GHz to 30 GHz. (b) Measurement errors for different frequency microwave signals. (c) Intensity-time waveforms on the oscilloscope of multi-frequency signals.

To verify the capability of multiple frequency measurement, two microwave signals with different frequencies are mixed and loaded into the IM simultaneously. Figure 2(c) shows the measured results for the mixed frequency cases of 8 GHz and 12 GHz, 8 GHz and 13 GHz, 8 GHz and 16 GHz, as well as 8 GHz and 20 GHz. One can see when the frequency difference between two signals is lower than 5 GHz, i.e. for the case of 8 GHz and 12 GHz, the measured intensity peaks are hardly to be distinguished from each other. This indicates that the multiple frequency resolution is about 5 GHz, limited by the 3 dB bandwidth of the selected filter.

In conclusion, we have presented a frequency-to-time mapping MFM system that enables measurement of multiple frequency signals in a relatively wideband. Frequency estimation in a range of 5-30 GHz with a measurement error under ± 510 MHz is achieved. Besides, the resolution is about 5 GHz for multi-frequency measurement. Our scheme offers a simple structure, low cost solution, capability of multiple frequency measurement and potential of chip-integration.

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