A gap-free, real-time radio frequency spectrum analyzer with 233 MHz frame rate

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***Abstract*—A gap-free, real-time radio frequency spectrum analyzer based on chirped fiber Bragg grating is experimentally demonstrated. The bandwidth and the resolution are up to 30 GHz and 800 MHz with a 233 MHz frame rate.**

***Keywords*—radio frequency spectrum analysis, ultrafast optics, spectroscopy, time-resolved**

I. INTRODUCTION

The photonics-based microwave frequency spectral analysis has provided excellent performance[1]. The frequency-domain characteristics of the given temporal signal can be more intuitively and rapidly resolved with the joint time-frequency (T-F) distribution[2]. The degree of the signal gap, or signal capture rate, is an important parameter in the real-time analysis[3]. Talbot effects can realize lossless radio frequency (RF) spectrum monitoring, but its bandwidth is limited[4]. The scheme based on time-domain convolution has been demonstrated. The 2.2 THz bandwidth with a 20 MHz frame rate has been demonstrated by the frequency domain light intensity spectrum analyzer (f-LISA)[5]. The scheme based on Mach–Zehnder modulator (MZM) and chirped fiber Bragg grating (CFBG) has verified a bandwidth of 40 GHz with an 11.25 MHz frame rate[6]. However, schemes mentioned above do not realize the gap-free analysis, which means part of the signal information is lost during the time-frequency analysis of continuous RF signals. On the other hand, in this paper, a gap-free, real-time radio frequency spectrum analyzer is experimentally demonstrated through the reasonable design of CFBG dispersion. It achieves a bandwidth of 30 GHz, a resolution of 800 MHz, and a frame rate of 233 MHz. The dynamic frequency identification capability for RF signals of the analyzer is demonstrated, indicating that it has promise toward real-time analysis and processing of high-speed temporal waveforms.

II. PRINCIPLE AND EXPERIMENTAL SETUP

Fig. 1a shows the schematic diagram of the gap-free, real-time RF spectrum analyzer based on CFBG. The three CFBGs are designed with a total dispersion of Φ = 4320 ps^2 and a negligible third-order dispersion. Therefore, when the optical spectrum of the probe pulse with a 233 MHz repetition frequency is mapped to the time domain by CFBG, its spectrum partially overlaps, showing up as interference fringes (Fig. 1b). In this case, when the RF signal such as 5 GHz cosine signal generated by an RF arbitrary waveform generator (AWG) is loaded onto the probe pulse through the electro-optic modulator (EOM), the gap-free loading can be realized (Fig. 1c). The modulator operates at a carrier suppressed state so that two symmetrical pulses are formed when the opposite ports of the CFBGs (Φ = – 4320 ps^2) compress the modulated signal back into pulses. Finally, the RF spectrum can be temporally resolved by a 40 GHz PD and a 33 GHz real-time oscilloscope (Fig. 1d). According to the conversion relationship:

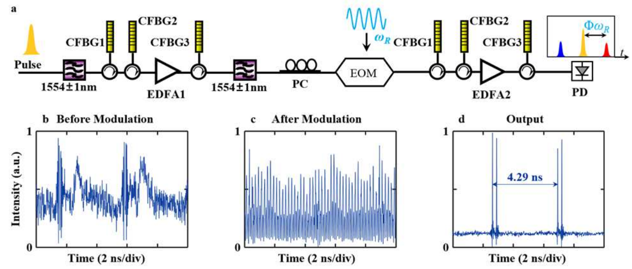

Fig. 1. Schematic diagram of the gap-free, real-time RF spectrum analyzer. (a) Experiment setup, CFBG: chirped fiber Bragg grating. (b) The mapped optical spectrum of the probe pulse before modulation in the time domain. (c) The mapped optical spectrum of the probe pulse after modulation. (d) The output of the system.

$$\Delta t = \Phi \Delta \omega \tag{1}$$

the rapid measurement of the RF spectrum can be realized.

III. RESULTS AND DISCUSSION

Several samples are used to characterize the RF measurement capability of the system, and the experiment results are shown in Fig. 2. Firstly, the signal consists of 2, 10, and 12 GHz cosine signal, and the measured values in the system are 1.99, 10.06, and 11.88 GHz, respectively (Fig. 2a), according to the mapping relationship. Noting that when the AWG generates signals of multiple frequencies at the same time, the distribution of power will be uneven, resulting in the relatively low intensity of 10 and 12 GHz. Subsequently, RF signal is swept from 2 GHz to 30 GHz stepped by 2 GHz to characterize the bandwidth and resolution. Due to the high loss of the RF cable at high frequency and the limited bandwidth of the AWG, the temporal pulses exceeding 20 GHz have a distinct attenuation (Fig. 2b). But over the 30 GHz range, the RF signal is accurately mapped and well resolved. Owing to the elimination of third-order dispersion, the pulse width is around 21 ps in the bandwidth range, corresponding to the resolution of 800 MHz.

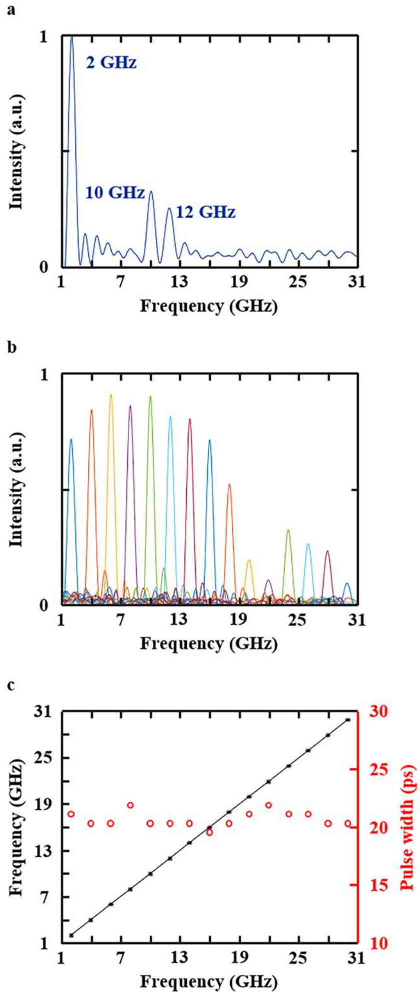

Fig. 2. Frequency identification results of the gap-free, real-time RF spectrum analyzer. (a) 2, 10 and 12 GHz. (b) 2~30 GHz, stepped by 2 GHz. (c) The measured frequency versus the input frequency and the pulse width.

In addition, the dynamic frequency identifications of different types and combinations of RF signals are also demonstrated experimentally. Fig. 3a shows the combinations of the chirped frequency (CF, 6-14 GHz) and the single frequency (SF, 10 GHz), each round trip represents a time interval of 4.29 ns, which means a frame rate of 233 MHz. At any given moment, the frequencies of the two signals can be accurately identified. Fig. 3b shows the frequency recognition results of the round trips corresponding to the three dotted lines in Fig. 3a. The two signals can be precisely identified and measured, and when the chirp frequency is close to the single frequency, there is an obvious interference phenomenon. Finally, the combinations of the chirped frequency (CF, 2-6 GHz) and the frequency hopping (FH, 8-12 GHz, stepped by 1 GHz) are demonstrated in Fig. 3c. The two types of signals can also be well resolved and read out readily (Fig. 3d).

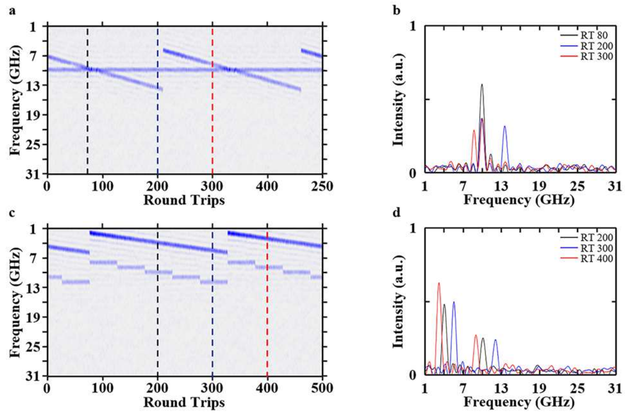

Fig. 3. The dynamic frequency identification of RF signals. (a) Simultaneous SF signal and CF signal. (b) The frequency recognition results of the round trips corresponding to the three dotted lines in (a). RT: round trips.(c) Simultaneous FH signal and CF signal. (d) The frequency recognition results of the round trips corresponding to the three dotted lines in (c).

IV. Conclusion

A gap-free, real-time RF spectrum analyzer based on CFBG with a reasonable dispersion design has been proposed and experimentally verified. Limited by the bandwidth of AWG, the analyzer has been verified to have a bandwidth of more than 30 GHz. Moreover, dynamic frequency identification for different types and combinations of RF signals is realized successfully with an 800 MHz frequency resolution and a 233 MHz frame rate. The gap-free, real-time RF spectrum analyzer can provide more precise characterization of numerous ultrafast applications, e.g. modern radar and wireless communication.

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