Real-time Temporal Signal Stitching Using Polarization-Dependent Optical Wave Mixing

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Abstract: A real-time temporal stitching technique is proposed and experimentally demonstrated based on polarization-dependent four wave mixing. The technique can operate over tens of GHz frequency range and with transition time of less than 50 *ps*.

OCIS codes: (190.4380) Nonlinear optics, four-wave mixing; (350.4010) Microwaves; (060.7140) Ultrafast processes in fibers; (060.5625) Radio frequency photonics.

1. Introduction

Fast switching of signal properties is essential to satisfy the high-capacity demand of emerging wireless systems that operate at the tens of GHz frequency band. One important application of fast switching of signal is frequency hopping (FH) signal generation. FH signals have been extremely important for modern radio frequency (RF) communications [1] due to its unique advantages such as immunity to inter-symbol interference and anti-jamming capability [2]. However, due to the intrinsic speed and bandwidth limitations of electronics, electronics-based FH techniques usually have a low hopping speed, and can only support system with low data rate and narrow bandwidth, hindering its ability to generate FH signal at high frequency band. Photonic approaches are attractive because it solves the above issues in electronics. The use of a polarization maintaining-phase shift fiber Bragg grating based OEO [3] can generate FH signal with hopping speed of 10 MHz, limited by the time for the establishment of a stable oscillation. Furthermore, FH signal can be generated by an optically injected semiconductor laser [4], resulting in a hopping speed of 100 MHz. Recently, a high-speed microwave photonic filter based on stimulated Brillouin scattering has been used to generate FH signals with hopping speed of hundreds of picoseconds [5]. Although existing photonic-based FH schemes solved some of the challenges in their electronic counterparts, their hopping speed are still limited to hundreds of picoseconds.

In this paper, we present a new approach to achieve real-time temporal stitching of RF signals for FH signal generation that works well for low-, mid-, to high-frequency bands. The proposed scheme is based on four-wave mixing (FWM), which has instantaneous response time and is frequency, phase, and amplitude transparent [6], enabling temporally stitching of signals with potentially zero transition time. We have experimentally demonstrated the generation of FH signal with hopping speed of 50 *ps* – which is the fastest so far to our knowledge, governed by the speed of the control signal.

2. Experimental Setup and Operation Principle

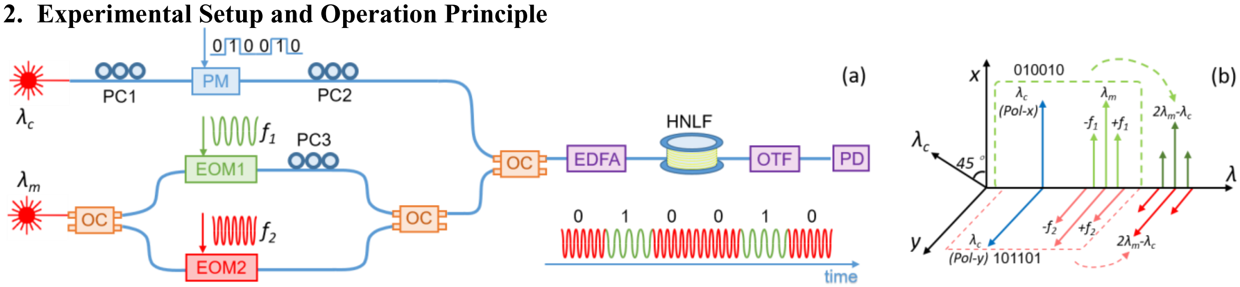

Fig. 1. (a) Experimental setup of the temporal stitching scheme. (b) Operation principle of the proposed real-time temporal stitching system for FH signal generation. OC: optical coupler; PC1-3: polarization controller; PM: phase modulator; EOM: electro-optic intensity modulator; EDFA: Erbium-doped fiber amplifier; HNLF: high nonlinear optical fiber; OTF: optical tunable filter; PD: photodetector.

Figure 1(a) illustrates the experimental setup of the proposed real-time temporal stitching technique for FH signal generation. Two laser sources at 1550.12 nm (λ_c) and 1533.32 nm (λ_m) are used as the optical carriers for the control signal and microwave signals, respectively. The control signal is modulated onto the polarization of λ_c via a 10-Gb/s phase modulator (PM) by aligning the optical carrier at 45º with respect to the PM axis. The λ_m is split into two branches and intensity modulated by the two microwave signals at f_1 and f_2 via a 10-Gb/s intensity modulator (EOM). The three modulated optical signals are combined and amplified to ensure four wave mixing (FWM) is induced in the dispersion shifted high nonlinear optical fiber (HNLF). The 200-m HNLF has dispersion slope of

0.022ps/nm^2/km and nonlinear coefficient of 20 W^{-1}km^{-1} in the vicinity of 1550 nm. A 0.5-nm wide optical filter (OTF) at 1556.52 nm and a 10-Gb/s photodetector (PD) are used to extract the FWM output and convert it into the desired electrical RF signal. Since FWM is a polarization sensitive process, polarization controllers (PC) are used to make sure the polarization is optimized to obtain the best temporal stitching results. In our experiment, x-polarization is used for f_1 and y-polarization is used for f_2. In degenerate FWM, FWM efficiency is the strongest if the input signal λ_m is of the same polarization as the control signal λ_c, as illustrated in Fig. 1(b). On the other hand, when the polarization of the input signal is orthogonal to the control signal, no FWM will occur. In our scheme, the control signal is represented by the polarization of λ_c, i.e. bit 1 is represented by x polarization and bit 0 is represented by y polarization, therefore, FWM will only occur between bit 1 and f_1, as well as between bit 0 and f_2. Thus, f_1 and f_2 are temporally stitched together into "$f_2, f_1, f_2, f_2, f_1, f_2$" when a control pattern "010010" is used.

3. Results and Discussion

To demonstrate temporal stitching, two signals with f_1 = 5 GHz and f_2 = 8 GHz are applied to the intensity modulators. As shown in Fig. 2(a), a FH signal that consists of both 5-GHz and 8-GHz components are observed at the output of the photodetector. The generated FH signal is hopping between 5 GHz and 8 GHz according to the control signal pattern "1011010010". Fig. 2(b) is a zoom in view of the FH signal which shows that no significant transition time is observed between the 5-GHz and 8-GHz sections. Since FWM has instantaneous response, the only limitation of the hopping speed is the rise/fall time of the control signal and the modulator bandwidth. To study the hopping speed of resultant FH signal, the two microwave signals f_1 and f_2 are removed, leaving just the two orthogonally polarized CW light at λ_m and the control signal λ_c to undergo FWM. A polarization beam splitter is used to demodulate the FWM output, as shown in Fig. 2(c)-(d). The rise/fall time in each of the FWM output indicate how fast the proposed system can switch on/off the microwave signal. A 50 *ps* rise/fall time is measured as shown in Fig. 2(e)i-ii. The temporal stitching scheme works well for a wide range of frequency. Fig. 3(f) shows the switching between a 3-GHz and a 10-GHz signals with a frequency hopping pattern "11101000110101100100". The spectral waterfall is shown in Fig. 2(g), while the retrieved frequency pattern is shown by the red curve.

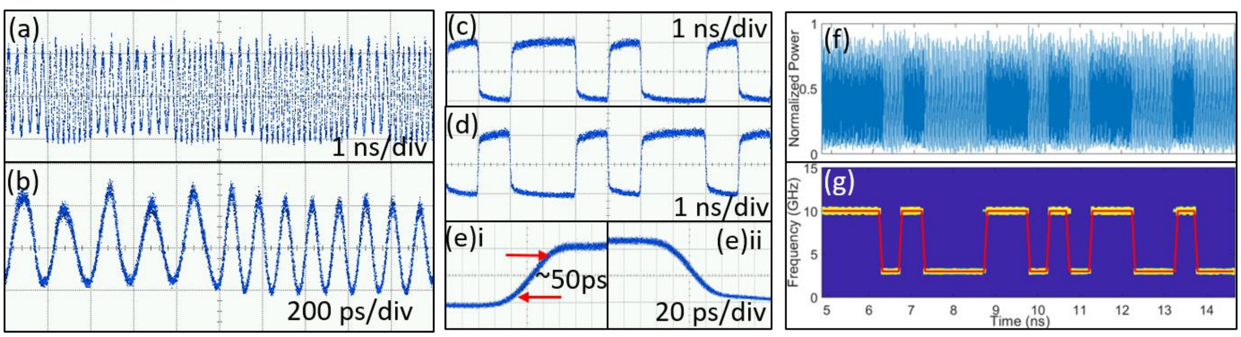

Fig. 2. (a) FH signal with 5GHz and 8GHz frequencies and a "1011010010" hopping pattern; (b) Zoom-in waveform; (c)-(d) Demodulated FWM outputs with complementary pattern; (e)i. Rise time and ii. fall time measurement; (f) 3 GHz and 10 GHz FH signal with a "11101000110101100100" hopping pattern; (g) Spectral waterfall of the FH signal and the corresponding retrieved frequency pattern in red.

4. Conclusion

We propose and demonstrate a real-time temporal signal stitching technique that has instantaneous response time and has a wide operation frequency range of tens of GHz. The approach utilizes the polarization-dependent nature of four-wave mixing to achieve fast switching time as well as frequency, amplitude, and phase transparency. The temporal stitching technique can be used to generate frequency hopping signal and we have observed a hopping speed of 50 *ps*, governed by the rise/fall time of the control signal

Acknowledgment

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