Ultrawide-band microwave amplification in the optical domain

Hongwei Chen, Minghua Chen,
Jian Zhang, MEMBER SPIE, **and Shizhong Xie**
Tsinghua University, Department of Electronic Engineering,
Beijing, 100084 PR China
E-mail: chenhw@tsinghua.edu.cn

Abstract. Ultrawide-band microwave amplification in the optical domain is proposed that covers the frequency range from 10 MHz to 10 GHz with over 10 dB gain. A partly carrier-suppressed optically carried microwave signal is generated and amplified by erbium-doped fiber amplifier (EDFA) in this scheme.
[DOI: 10.1117/1.2750664]

Subject terms: microwave amplification; optical domain; erbium-doped fiber amplifier (EDFA).

Paper 070228LR received Mar. 17, 2007; revised manuscript received Apr. 19, 2007; accepted for publication Apr. 25, 2007; published online Jul. 2, 2007.

1 Introduction

Recently, a new technique area known as microwave photonics has been proposed to serve many microwave and optical applications.[1] Most investigations are focused on optical microwave signal generating,[2,3] filtering,[4–6] frequency converting,[7–9] etc. In fact, many advantages of optical signal processing, such as low loss and wide band operation, can be utilized in future microwave systems. In traditional microwave amplifiers, the signal gain decreases with increased bandwidth.[10] In this paper, an optical amplification system is used to amplify the optically carried microwave signal. The original weak microwave signal is modulated on an optical carrier by a partly carrier-suppressed method and amplified by a commercial erbium-doped fiber amplifier (EDFA). The output microwave signal is obtained from a photodetector. With this method, a broad band covering 10 MHz to 10 GHz microwave signal amplification is achieved, the gain of signal is more than 10 dB, and the 3-dB bandwidth is about 7 GHz, which is mainly limited by the bandwidth of the photodetector.

2 Experiment

The experimental setup is shown in Fig. 1. An optical source in the wavelength of 1557 nm is fed into a Mach-Zehnder modulator (MZM) after a polarization controller. The MZM is biased with proper direct current and driven by the input radio frequency (RF) signal to generate a partly carrier-suppressed optical signal embedded with the microwave signal. This signal is sent into a commercial EDFA. An optical bandpass filter (OBPF) is connected after the EDFA to block amplified spontaneous emission (ASE) noise. The amplified signal can be obtained at the output of a 10-GHz commercial photodetector (PD) and measured by an electrical spectrum analyzer (ESA; Agilent PSA E4446A). Thus, the RF signal from the source to the ESA experiences an optically carried and amplified process. If the original RF signal is a small one, it can be amplified by the EDFA and has a massive output after the PD. Because the gain spectrum of EDFA is wide enough to cover more than 40 nm and the small signal gain is more than 30 dB, this method can amplify the RF signal with ultrawide bandwidth.

3 Results and Discussion

In the traditional optical modulation scheme, the MZM is biased at the linear modulation point, $V_{DC}=V_\pi/2$, where V_π is the half-wave voltage. In this case, the output of MZM is shown in Fig. 2(a). The optical carrier holds most of the signal energy. If the driving RF signal is very small, nearly all the optical energy is focused on the carrier, which may cause the saturation of the EDFA and the photodetector. That means the carrier can be amplified except for the small RF signal. In order to improve the small RF signal gain, the MZM is biased at the partly carrier-suppressed point, which is between $V_\pi/2$ and V_π. The output of MZM is shown in Fig. 2(b). The carrier is suppressed to have much lower power than the linear bias case. Thus, when the signal passes the EDFA, the carrier and sidebands will be both amplified with nearly the same gain. After the O/E converter, the amplified RF signal is achieved by the beat signal.

First, the amplification of the small signal at RF frequency of 10 GHz is measured. Figure 3(a) and 3(b) shows the wave form and spectrum of the source RF signal, respectively. The peak power at 10 GHz is about −23 dBm and the noise floor is about −90 dBm. Figure 3(c) and 3(d) shows the waveform and spectrum of amplified RF signal, respectively. The amplified RF signal has the peak power at 10 GHz is about −13.8 dBm. However, the noise floor increases to near −60 dBm, which mainly depends on the beat noise between the signal field and the ASE noise. In addition, the spectrum purity of the source and the amplified RF signal are almost the same.

In order to measure the RF gain spectrum of the proposed method, we tuned the RF signal frequency from 10 MHz to 12 GHz. The RF signal power and signal-to-noise ratio (SNR) are measured with bandwidth of 10 MHz. Figure 4(a) shows the RF signal gain spectrum. In this figure, one can see that the small signal gain of this method is more than 20 dB. When the RF frequency is near

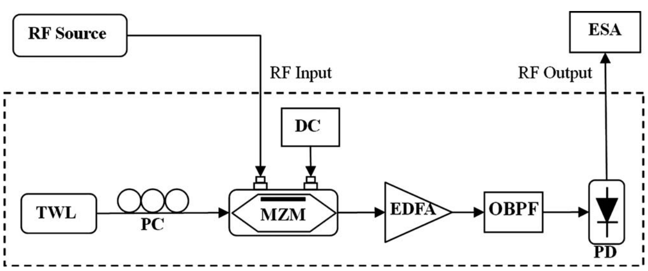
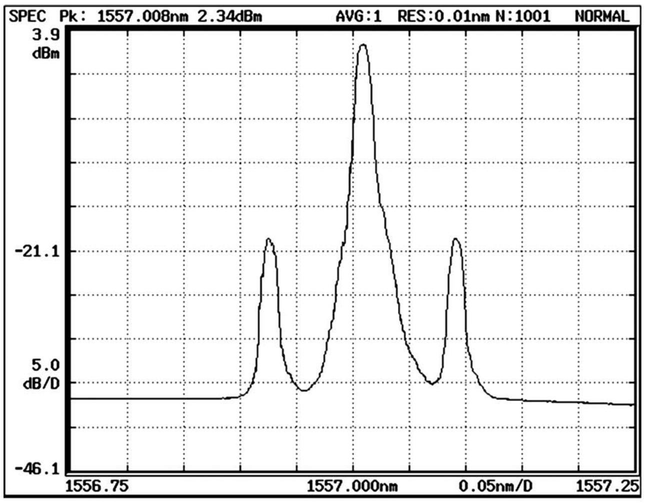
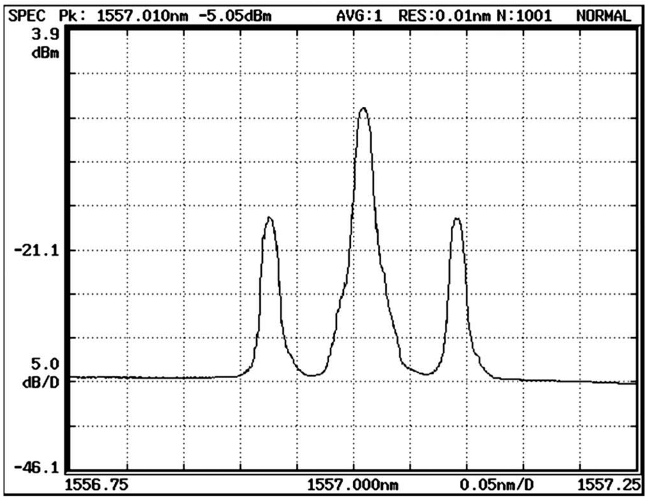


Fig. 1 Experimental setup. TWL: tunable wavelength laser; PC: polarization controller; RF: radio frequency; MZM: Mach-Zehnder modulator; DC: direct current; EDFA: erbium-doped fiber amplifier; OBPF: optical bandpass filter; PD: photodetector; and ESA: electrical spectrum analyzer.



(a)

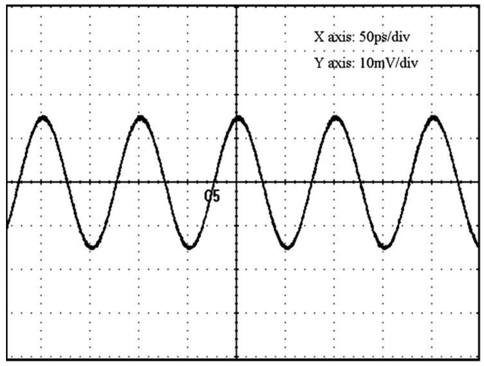


(b)

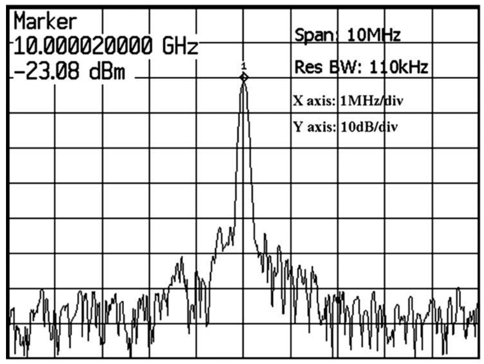
Fig. 2 Optical spectra out of the MZM. (a) DC biased at the linear modulation point, and (b) DC biased at the partly carrier-suppressed modulation point.

10 GHz, the signal gain is still larger than 10 dB. The 3-dB bandwidth is about 7 GHz, which is mainly limited by the photodetector and modulator bandwidth. The gain curve and SNR of the source and amplified signal at 10 GHz are measured, respectively, as shown in Fig. 4(b). In this figure, we can see that the gain is stable, with the RF source signal power variation from −60 dBm to −10 dBm. The SNR of the source and amplified signal both increase with the input power. However, the SNR penalty is about 10 dB, which is caused by the ASE noise of the EDFA and the noise in the photodetector.

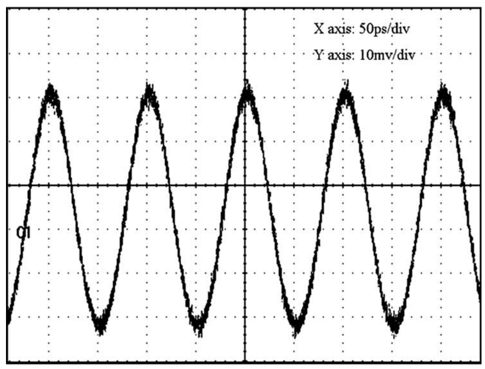
This method provides a simple optical technique to amplify ultrawide-band microwave signals. The system can be easily built with commercial optical devices, such as MZM modulators and optical amplifiers. We have tested 10 MHz to 10 GHz optically carried microwave signal amplification, and the gain is larger than 10 dB, notably 20 dB in low-frequency RF input signal cases. The noise character of this method is mainly limited by the EDFA and photodetector noise. The gain bandwidth and maximum output



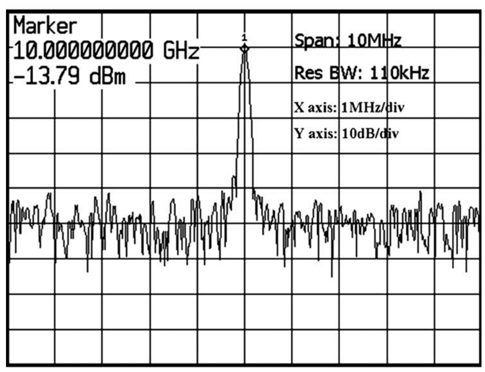
(a)



(b)



(c)



(d)

Fig. 3 Comparison of source RF signal and amplified RF signal. (a) Source RF signal waveform; (b) source RF signal spectrum; (c) amplified RF signal waveform; and (d) amplified RF signal spectrum.

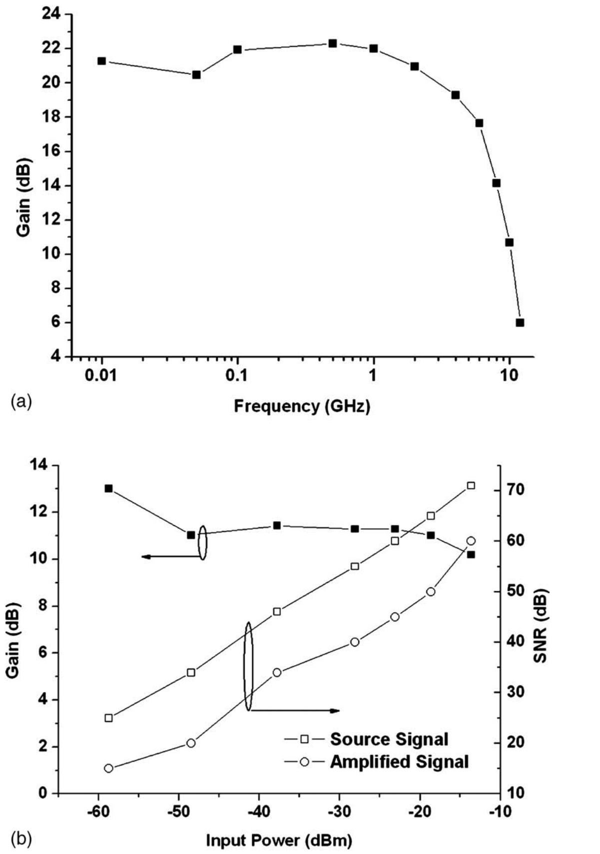


Fig. 4 (a) Gain spectrum and (b) gain curve at frequency of 10 GHz and SNR comparison of source and amplified signal.

quantity are limited by the photodetector bandwidth and saturation output. If low-noise EDFA and high-quality PD, such as UTC-PD, are employed, the system performance can be improved greatly.

4 Conclusion

An ultrawide-band microwave amplification method in the optical domain is proposed. This method utilized the large bandwidth capacity of optical devices to amplify optically carried microwave signals. The amplification range covers from 10 MHz to 10 GHz, with gain larger than 10 dB, and this method can work with an input RF signal less than −60 dBm. The subsystem is made up of commercial devices and easily realized. The system performance can be improved greatly using high-quality devices.

References

1. A. J. Seeds, "Microwave photonics," *IEEE Trans. Microwave Theory Tech.* **50**, 877–887 (2002).
2. J. J. O'Reilly, P. M. Lane, R. Heidemann, and R. Hofstetter, "Optical generation of very narrow linewidth millimeter wave signals," *Electron. Lett.* **28**, 2309–2310 (1992).
3. D. Wake, C. R. Lima, and P. A. Davies, "Optical generation of millimeter-wave signals for fiber-radio systems using a dual-mode DFB semiconductor laser," *IEEE Trans. Microwave Theory Tech.* **43**, 2270–2276 (1995).
4. J. Capmany, B. Ortega, D. Pastor, and S. Sales, "Discrete-time optical processing of microwave signals," *J. Lightwave Technol.* **23**, 702–723 (2005).
5. J. Wang, F. Zeng, and J. Yao, "All-optical microwave bandpass filters implemented in a radio-over-fiber link," *IEEE Photonics Technol. Lett.* **17**, 1737–1739 (2005).
6. J. More, J. Capmany, A. Loayssa, and D. Pastor, "Novel technique for implementing incoherent microwave photonic filters with negative coefficients using phase modulation and single sideband selection," *IEEE Photonics Technol. Lett.* **18**, 1943–1945 (2006).
7. Y. K. Seo, C. S. Choi, and W. Y. Choi, "All-optical signal upconversion for radio-on-fiber applications suing cross-gain modulation in semiconductor optical amplifiers," *IEEE Photonics Technol. Lett.* **14**, 1448–1450 (2002).
8. H. J. Song, J. S. Lee, and J. I. Song, "Signal up-conversion by using a cross-phase-modulation in all-optical SOA-MZI wavelength converter," *IEEE Photonics Technol. Lett.* **16**, 593–595 (2004).
9. C. S. Park, C. K. Oh, C. G. Lee, D. H. Kim, and C. S. Park, "A photonic up-converter for a WDM radio-over-fiber system using cross-absorption modulation in an EAM," *IEEE Photonics Technol. Lett.* **17**, 1950–1952 (2005).
10. K. B. Niclas, W. T. Wilser, R. B. Gold, and W. R. Hitchens, "The matched feedback amplifier: ultrawide-band microwave amplification with GaAs MESFETs," *IEEE Trans. Microwave Theory Tech.* **28**, 285–294 (1980).