Ultrawide-band microwave amplification in the optical domain

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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. © 2007 Society of Photo-Optical Instrumentation Engineers.

In the traditional optical modulation scheme, the MZM is biased at the linear modulation point, \( V_{DC} = V_s / 2 \), where \( V_s \) 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 \( V_s / 2 \) and \( V_{DC} \). 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.

3 Results and Discussion

In the traditional optical modulation scheme, the MZM is biased at the linear modulation point, \( V_{DC} = V_s / 2 \), where \( V_s \) 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 \( V_s / 2 \) and \( V_{DC} \). 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 waveform 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.
At 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 power range are limited by the gain curve and SNR.

**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.

**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.
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