Application of Semiconductor Optical Amplifiers to Microwave Signal Processing

Hiroyo Ogawa, Kohji Horikawa, Hideki Kamitsuna
Osamu Kobayashi, Yutaka Imaizumi and Ikuo Ogawa

NTT Wireless Systems Laboratories
1-2356 Take, Yokosuka-shi 238-03 Japan

Abstract
This paper proposes an application of semiconductor optical amplifiers (SOAs) to RF-to-optical and optical-to-RF convertors, microwave filters and microwave samplers. The SOA convertor can make it possible to realize a compact and cost-effective radio repeater for RF signal distribution. The SOA filtering and sampling expands application areas of fiber optics to microwave signal processing. The basic performance is experimentally investigated at microwave frequencies and good performance is obtained.

INTRODUCTION

Semiconductor optical amplifiers (SOAs) have been studied for optical amplification devices [1][2]. The advantage of SOAs is an integration with other optical devices. Additionally, SOAs have the functions of not only optical amplification but also modulation and detection[3]-[5]. Recently, the SOA-based subcarrier add-drop multiplexer has been proposed for dual-bus digital systems[6]. In this paper, this idea is extended for microwave signal processing, i.e. RF-to-optical and optical-to-RF conversions, microwave filtering and microwave sampling.

Fig.1 shows the blockdiagram of the radio repeater which utilizes two functions of the SOA device. The subcarrier frequency is detected by the SOA and amplified by the RF high-power amplifier, then radiated to the radio zone through the antenna. The received RF siganl is first amplified by the RF low-noise amplifier and supplied to the SOA to modulate an optical carrier. Since the only one optical device, i.e. the SOA is used in the radio repeater, this makes the radio repeater compact and cost-effective.

MICROWAVE SIGNAL PROCESSING

RF-to-Optical Conversion

The SOA modulation performance is compared using a Mach-Zehnder LiNbO3 external optical modulator (EOM). Fig.2 shows the comparison between the SOA and EOM modulation characteristics. The EOM has an optical insertion loss of 8.7dB, while the SOA has an optical gain of 13dB at an optical input power of -10dBm. An approximate 40-dB detected power difference at lower frequencies in Fig,2 is caused by the optical loss of the EOM and the optical gain of the SOA. It is known that SOAs have relatively larger noise than erbium-doped fiber amplifiers [7]. In order to evaluate the noise performance as well as linearity of the SOA, the CNR and IM3 are measured. Fig.3 shows the measurement results. In spite of the high gain characteristics of the SOA, the CNR of the SOA is

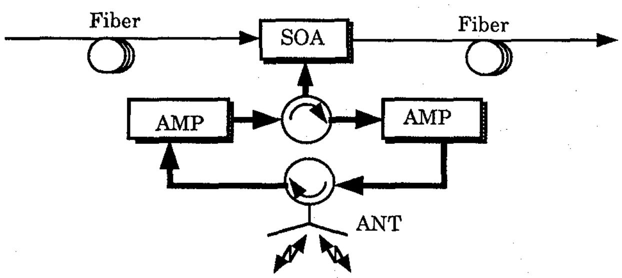

Fig.1. Blockdiagram of radio repeater composed of semiconductor optical amoplifier whose functions are optcal amplification, modulation and detection.

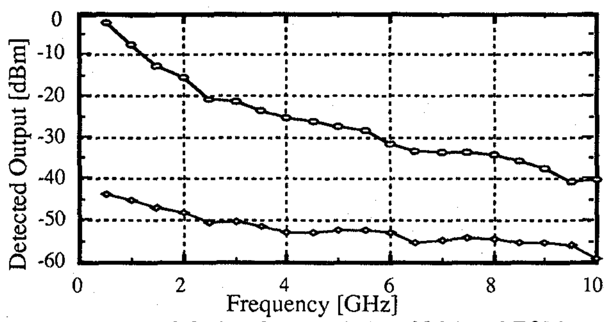

Fig.2. Modulation characteristics of SOA and EOM.

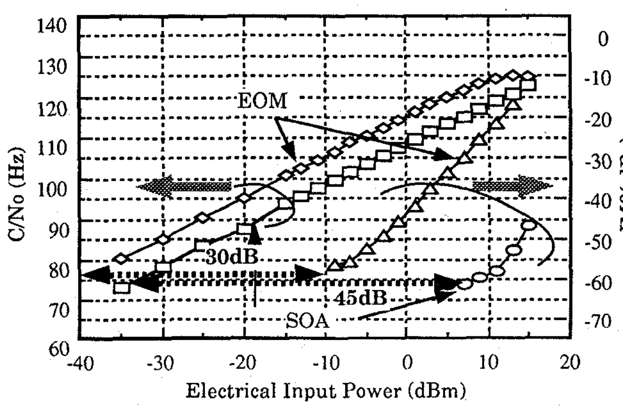

Fig.3. CNR and IM3 comparison between SOA and EOM modulators.

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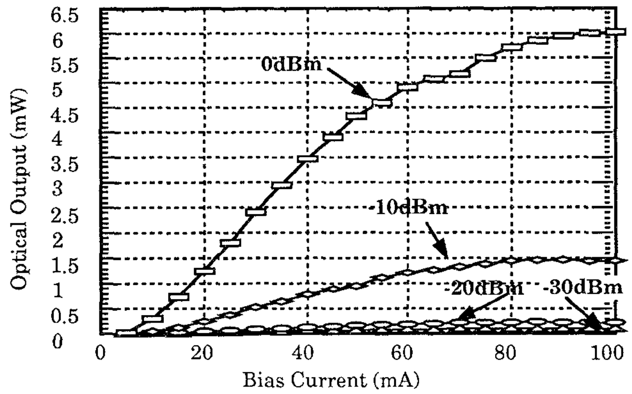

Fig.4. Optical power output characteristics of SOA. Input optical power is changef from 0dBm to -30dBm.

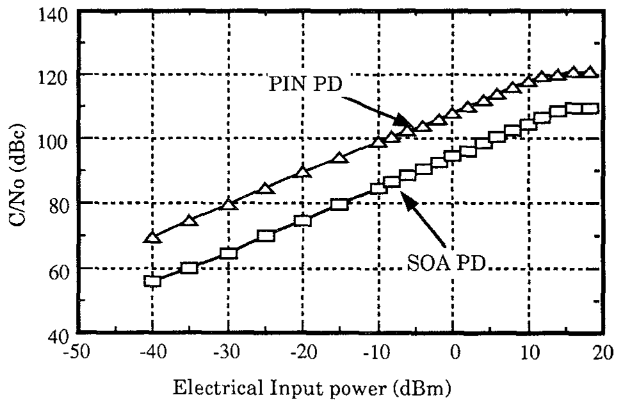

Fig.7. CNR characteristics comparison between SOA and conventional PIN photodiode.

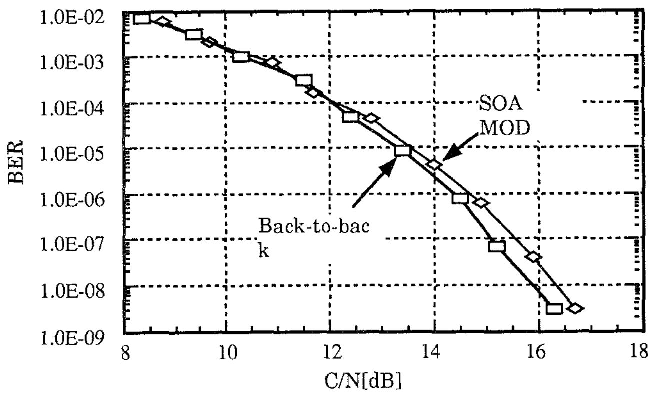

Fig.5. BER characteristics of SOA modulation link.

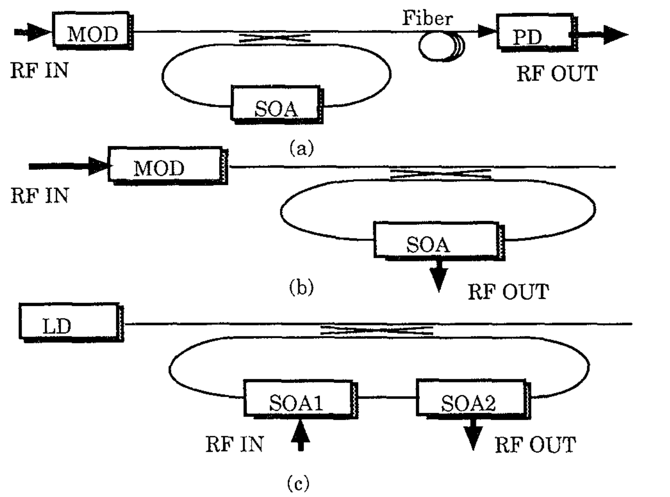

Fig.8. Recirculating delay line processing for microwave filtering. (a) Conventional recirculating filter. (b) Recirculating filter with SOA output. (c) Recirculating filter with SOA input and output.

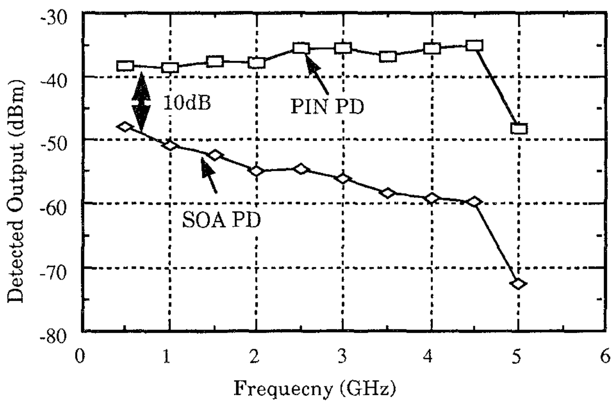

Fig.6. Detected output performance of SOA and conventional PIN photodiode.

worse than that of the EOM becasue of the SOA noise [8]. However, the inter-modulation product ratio of the SOA is better than that of the EOM due to the linear optical output characteristics, as shown in Fig.4. Although the CNR of the SOA is 5-dB worse than that of the EOM, the intermodulation product ratio is 20-dB better than that of the EOM. As a result, the SOA has a wider dynamic range than the EOM does. Fig.5 shows the BER performance of the SOA modulator where the subcarrier frequency is 1.7GHz which carriers the QPSK modulated signal. No deterioration of the CNR is observed in the experiment.

Optical-to-RF Conversion

The photodetection characteristics of the SOA are compared with a conventional PIN photodiode. Fig.6 shows the frequency response of each device. The SOA has a 10-dB worse responsivity than the PD device at lower frequencies. The responsivity becomes worse as the frequency increases. The noise as a photodetection device is also evaluated using the CNR. Fig.7 shows the comparison between the SOA and PIN detectors. A CNR degradation of 15dB is observed in the SOA PD link.

Microwave Filtering

Recirulating delay line processing has been studied for microwave filtering [9]. Optical amplifiers are also introduced for this signal processing network [10]. Fig.8 (a) shows the conventional recirculating

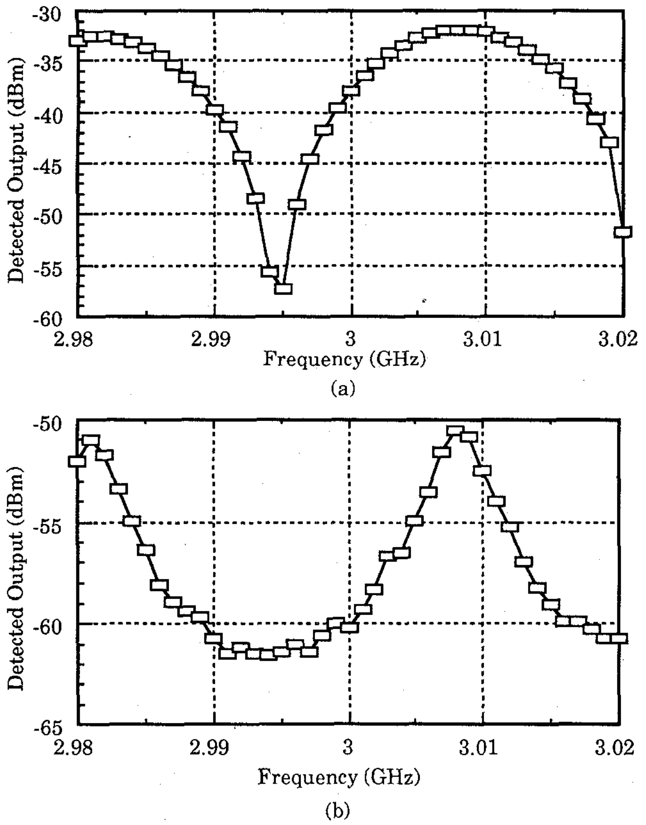

Fig.9. Frequency response of recirculating filter. (a) Conventional recirculation filter characteristics. (b) Recirculation filter with SOA output.

filter configuration. This configuration requires a photodetector to convert the optical carrier to microwave frequencies. In this paper, new link configurations are introduced for recirculating filters using the SOA modulation and detection functions. The configuration shown in Fig.8(b) utilizes the SOA detection capability. Fig.8(c) shows the different filter configuaration which utilizes the SOA modulation and detection capabilities. Fig.9(a) shows one example of the conventional recirculating filter characteristics, i.e. notch filtering. The proposed configuartions achieve bandpass filtering, as shown in Fig.9(b). Thus, the bandpass characteristics are feasible by using the SOA detection.

Microwave Sampling

Digital optical pulse transmission can be considered as one of ways to transmit anolog microwave signals by fiber. Several configurations for microwave AD conversion have been proposed using guided-wave structures [11]. SOAs have not been used for microwave sampling, as far as we know. In this paper, the basic characteristcis of microwave sampling will be shown using commercially available SOA, LD and PD devices. Fig.10 shows the microwave sampling architecture using the SOA. Optical pulses are generated by the laser diode which

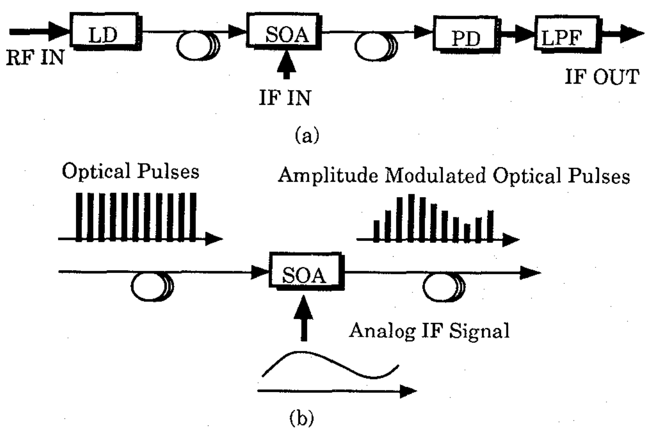

Fig.10. Microwave sampling architecture for microwave transmission. (a) Link configuration.
(b) Schematic illustration of input/output signals.

is biased in the vicinity of the threshold current. The analog IF signal is supplied to the SOA and modulates the optical pulses. The amplitude modulated optical pulses are then obtained from the SOA output. The amplitude of the modulated pulses is detected by the photodiode and the IF siganl is obtained through the lowpass filter. Fig.11 shows the experimental results. The pulse speed and the IF frequency is 2GHz and 500MHz, respectively. The 2-GHz pulse and the amplitude modulated pulse waveforms are shown in Fig.11(a) and (b), respectively. The spectrum of the detected 500-MHz IF signal is shown in Fig.11(c). No degradation of the spectrum is observed.

CONCLUSION

Several microwave functions are introduced using the SOA device. The RF-to-optical and optical-to-RF functions can be used for realization of the radio repeater for RF signal distribution. Simultaneous two functions of the SOA devices will enable us to make the cost-effective radio equipment. The microwave filtering and sampling functions can expand the application areas of fiber optics to microwave signal processing. Microwave sampling techniques will play an important role in radio high-way networks [12].

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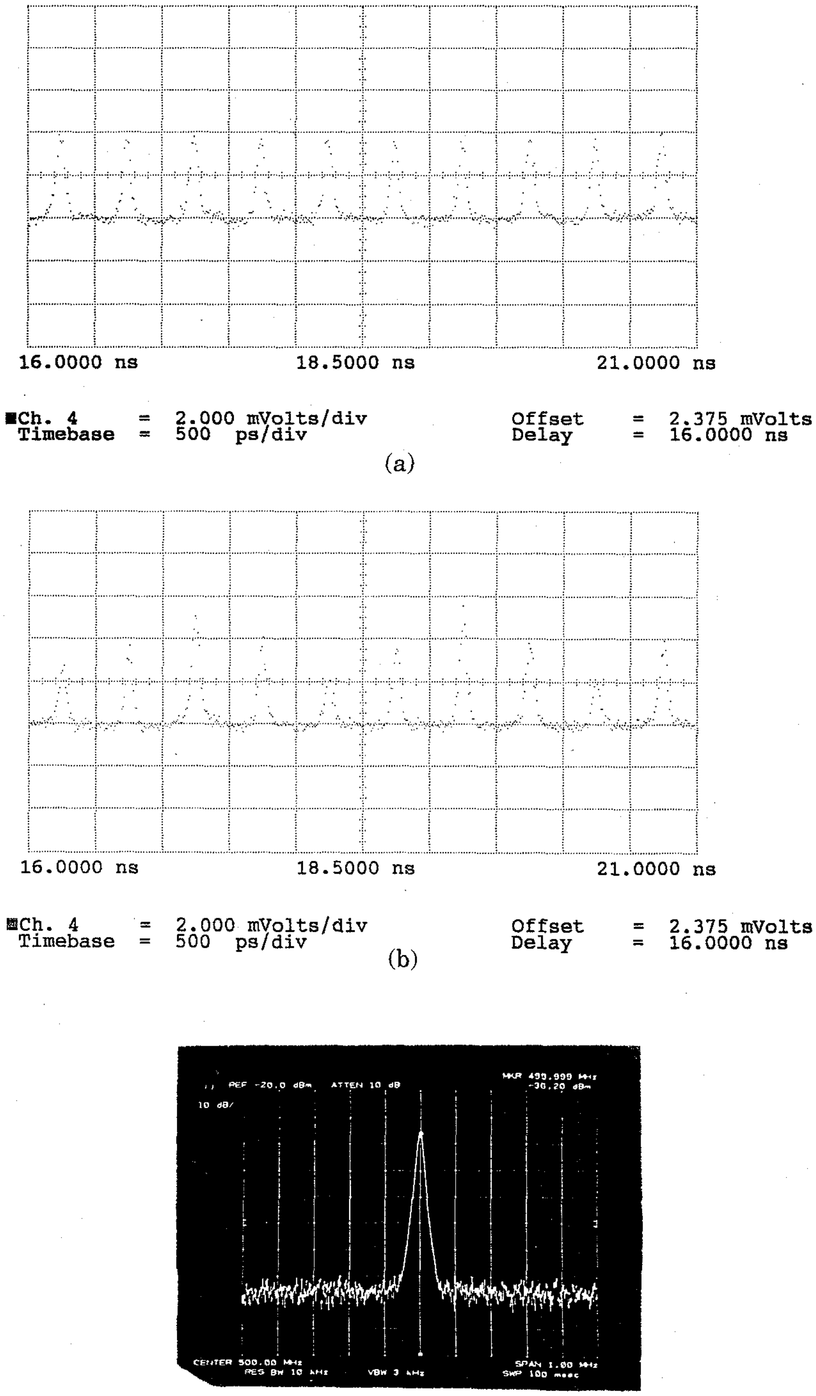

Fig.11. Microwave sampling performance. (a) 2-GHz pulse waveform. (b) 500-MHz IF signal sampling. (c) Detected IF signal spectrum.