Global Journal of Researches in Engineering: F
Electrical and Electronics Engineering
Volume 15 Issue 2 Version 1.0 Year 2015
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Multicasting Characteristics of All-Optical Triode based on Negative Feedback Optical Amplifiers

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GJRE-F Classification : FOR Code: 090699

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Multicasting Characteristics of All-Optical Triode based on Negative Feedback Optical Amplifiers

S. Aisyah Azizan [α], M. Syafiq Azmi [σ] & Yoshinobu Maeda [ρ]

Abstract- We introduce all-optical multicasting characteristics with wavelength conversion based on all-optical triode using two full bands tunable distributed-feedbacklaser diode module at a transfer speed of 10 Gbps to a non-return-zero 2^{31}-1 pseudorandom bit sequence system. This multi-wavelength converter device can simultaneously provide two channels of output signal with the support of non-inverted and inverted conversion. We reported an all-optical multicasting wavelength conversion accomplishing cross gain modulation is effective in a semiconductor optical amplifier in order to provide an inverted conversion thus negative feedback. The relationship of received power of back to back signal and output signals with bit error rate was investigated. It was found that the output signal wavelengths were successfully converted and modulated with a power penalty of less than 5 dB. It was realized that all-optical multicasting and wavelength conversion using an optical triode with a negative feedback by two channels at the same time at a speed of 10 Gbps is possible.

Keywords: semiconductor optical amplifier; multicasting; optical triode; negative feedback optical amplifier; cross gain modulation.

I. Introduction

Demand for the wavelength division multiplexing (WDM) in wider band has progressed especially in the future technology of photonic networks. As the cost and power consumption of WDM network nodes are in a large amount, it is fundamental to discard the conventional optical/electrical/optical (O/E/O) to optical/optical (O/O) by using all-optical wavelength converter device. Optical wavelength conversion is anticipated to be an essential function for the emerging bandwidth-intensive applications (video conferencing, video-on-demand services etc.) of high speed WDM optical networks by enabling rapid resolution of output-port contention and wavelength reuse [1].

In addition, all-optical wavelength converter becomes a key functional element in WDM optical network due to its capabilities of transparent interoperability, contention resolution, wavelength routing and, in general, better utilization of the fixed set of wavelengths [2].

Nowadays, multicasting is a potentially useful networking function that involves the same data stream from a single node to several destinations nodes. This network is also called as photonic network. Photonic network is commonly enforced via IP digital routers in electrical domain. Photonic network effectiveness will be encouraged when the multicasting can be performed all-optically. The optical routers will be able to multicast an input signal to different wavelengths.

There is bulk of wavelength conversion and multicasting techniques that have been proposed so far. The techniques include a nonlinear semiconductor optical amplifier (SOA) based interferometer, an injection locking of a Fabry-Perot laser [3], and SOA with cross gain modulation (XGM) or SOA with cross phase modulation (XPM) [4].

In this paper, we investigated the new wavelength converter technology technique based on the negative feedback optical amplification effect. This will result an output signal whose gain, waveform, and, baseline which stabilized automatically. Wavelength conversion and switching characteristics was investigated by introducing a control light together with input signal light [5].

The optical amplifier consists of an InGaAsP/InP SOA and an optical add/drop filter. It is equipped with a negative feedback function. In the negative feedback SOA, the output modulation degree will be substantially higher and the distortion of the waveform was extremely small in wide input signal [6].

We demonstrated the conversion wavelength by using two SOAs based on optical triode, and measured the bit error rate (BER) characteristics for each wavelength. As a result, this device has been realized that all-optical multicasting and wavelength conversion by using two channels at the speed of 10 Gbps at the same time is possible.

As mentioned above, negative feedback optical amplifier consists of a SOA and an optical add/drop filter. The basic theory of negative feedback is explained below.

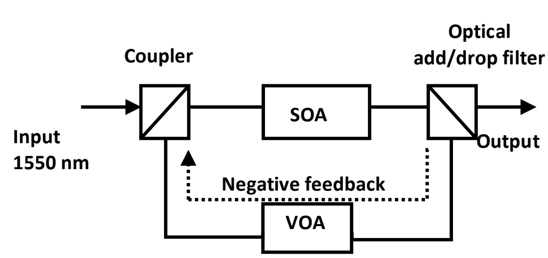

Figure 1 : Block diagram of a negative feedback SOA.VOA: Variable optical attenuator

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SOA is structured based on the ridge waveguide of InGaAsP/InP material. The composition of the InGaAsP active layer is chosen to have gain peak wavelength around 1550 nm. The maximum small signal fiber to fiber gain is around 15 dB and the output saturation power is approximately 2 mW measured at 1550 nm with a bias current of 250 mA [6].

Fig. 1 shows the diagram of a negative feedback SOA circuit.As shown in Fig. 1, a wavelength of 1550 nm is set as an input signal by a tunable laser then is modulated by the mean of electro-optic modulator.

The modulated input signal is fed into the SOA by using a coupler. An optical add/dropfilter is located in order to extract an output signal light of the wavelength 1550 nm. The XGM mechanism in SOA will provide the spontaneous emission contain an inverted replica of the information carried by input signal. The inverted replica information is fed back and injected together with the input signal back into the SOA by using a coupler.

The output average power was around 6.4 mW, which the SOA was without negative feedback while in the SOA with negative feedback, the output average power was approximately 1.9 mW. These were experimented when the negative feedback average power was 0.12 mW[6].

Fig. 2 shows the concept diagram of a negative feedback optical amplification effect. The straight-line represents the case where the SOA was used with negative feedback while the dotted line represents the case of the SOA without negative feedback.

Fig. 2(a), (b), and (c) show the waveforms of the input signal, the negative feedback, and the gain in SOA respectively. In the SOA that has a XGM mechanism, spontaneous emission lights, which have wavelengths near awavelength λ_1, the input signal have an intensity varying in response to a variation in the intensity of that input signal. Characteristically, the intensity variation of the spontaneous emission lights are inverted with respect to the variation in the input signal then the spontaneous emission lights are outputted from the SOA as reported in Fig. 2(b).

In the past, it is common that the spontaneous emission lights as well as the surrounding light that have wavelengths other than the wavelength λ_1 are removed by a band pass filter, since it becomes a factor of noise generation [6]. In this situation, a negative feedback optical signal amplification phenomenon in which characteristics of the gain of the SOA is drastically changed by feeding back the separated surrounding light to the SOA so that the gain is modulated as shown in Fig. 2(c).

Therefore, noise reduction is realized all-optically with a negative feedback SOA. It can be concluded that the output signal waveform is exceptionally improved over that without negative feedback. In addition, the baseline of the output signal waveform is supressed because the gain in the SOA is low when the power of input signal is at the low logical level, whereas the output signal is stressed because of the high SOA gain when the input signal power is high as shown in Fig. 2[6]. In this paper, we created an all-optical triode based on the negative feedback SOA theory.

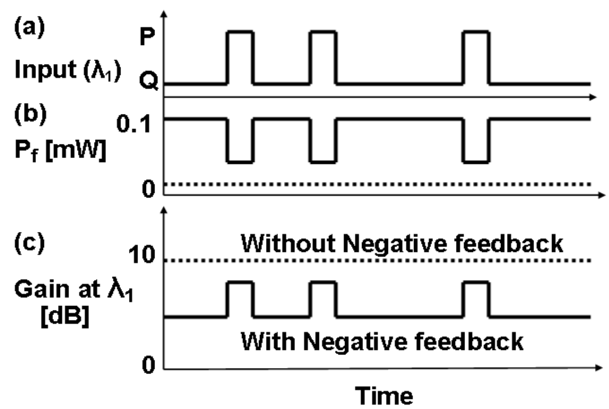

Figure 2 : Concept diagram of negative feedback optical amplification effect. The straight-line represents the case where the SOA was used with negative feedback, and the dotted line represents the case of the SOA without negative feedback

II. Experimental Setup

In this experiment, we used full band thermally tunable distributed-feedback (DFB) laser diode module as the SOA. To cover the full band, the laser was designed to integrate the 12 different DFB lasers and wavelength spacing 3.45nm with consideration given to fabrication variations. Fig. 3 reported the optical micrograph of the integrated device.

In addition, in the DFB laser array, an optical amplifier for compensating the loss of the optical coupler within the optical coupler couples the output from the DFB lasers each were also integrated. The size of the element is 500 μm× 2600 μm, the length of this DFB laser is 600 μm, and the length of the optical amplifier is 900 μm. By applying a non-reflective coating and a bend waveguide, the end surface is controlled by the reflection from another end surface. This device is used as the SOA and laser diode (LD) as shown in Fig. 4.

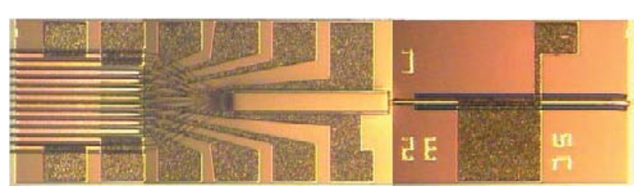

Figure 3 : Optical integrated chip of full-band tunable laser (DFB laser array, coupler and SOA)

The isolator from the device has been taken out in purpose to allow any reflection of the signal light from

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the SOA. The experimental setup is reported in Fig. 4. The operating circuit of negative feedback optical amplification by using optical triode is explained as follows.

We created an optical triode by using two SOAs forming two stages of SOAs, SOA-1 for the first stage and SOA-2 for the second stage of the circuit with two optical add/drop filters (1550 nm ± 6.5 nm).

An optical signal that has been modulated by the external optical modulator (O.M) enters the SOA-1 via an optical add/drop filter (1550 nm ± 6.5 nm). Due to the XGM mechanism in SOA-1, the probe light, which is set in the SOA-1, is modulated into a signal then provide the spontaneous emission contain an inverted intensity to the optical signal which fed in SOA-1.

This inverted optical signal then passes through an optical add/drop filter (1550 nm ± 6.5 nm) thenceforth it flew into the SOA-2 based on the negative feedback theory. The input signal is amplified with gain modulation by inverted optical signal in the SOA-2.

In this research, an optical signal with wavelength 1552 nm is set by a laser source as the input signal. This optical signal is modulated to a non return zero (NRZ) 2^{31}-1 pseudorandom bit sequence (PRBS) with a transfer speed of 10 Gbps by the O.M then is amplified by the Erbium doped fibre amplifier (EDFA) before fed into the optical triode. Additionally, probe light with wavelength of 1551 nm is set in SOA-1.

In order to perform multicasting in wavelength conversion through this experiment, two different wavelengths are set as the control signal in SOA-2. Five different wavelengths are chosen as the control signal to be used in this research. They are 1530 nm, 1540 nm, 1545 nm, 1555 nm, and 1560 nm.

These control signals (two wavelengths at a time) will be fed into the SOA-2, which have undergone XGM and wavelength conversion is occurred. Consequently, the two different optical signals will be amplified by the SOA-2 thus pass through an optical add/drop filter. After that the optical signals passed a VOA and a band pass filter (BPF).

As the two control signals are in different wavelengths, a BPF is needed for wavelength separation to recognize the output signals. Thenceforth, the optical signals are inserted into the bit error rate tester (BERT) hence the relationship of received power of back to back signal (B to B signal/BER of input signal) and output signals which is controlled by the VOA, with BER is measured.

III. Results and Discussion

Fig. 5 shows the eye diagrams obtained in this experiment. Fig. 5(a) shows the input signal eye diagram whereas (b), (c), (d), (e), and (f) show the eye diagram for output signals of 1530 nm, 1540 nm, 1545 nm, 1555 nm, and 1560 nm respectively. The eye diagram of input and output signals are recorded when their average power is 150 µW. Zero level from baseline (from ground) of input signal is 27 µW. Eye aperture, extinction ratio and zero level from the baseline of each output signal eye diagram are measured and are summarized in Table 1.

As reported in Fig.5, the baseline of output signal eye diagrams arose gradually compared to the input signal eye diagram. As shown in Table 1, zero level from baseline of output signals increase when wavelength becomes longer, from 1530 nm to 1560 nm. In addition, the degradation in eye aperture of output signals is clearly reported in Fig. 5 and Table 1. The obtained results show that, the highest extinction ratio is 7.39 dB when the output signal wavelength is 1530 nm.

Based on the reported results, it proved that during the conversion of wavelength conducted in the SOAs consumed large amount of power and noise has been found due to the distortion of the eye diagrams as clearly shown in Fig. 5especially in Fig.5(e) and (f).

We understood that a conventional optical amplifier merely has a simple amplification function that is almost constant gain. The amplifier disadvantageously amplifies not only the signal but also the noise.

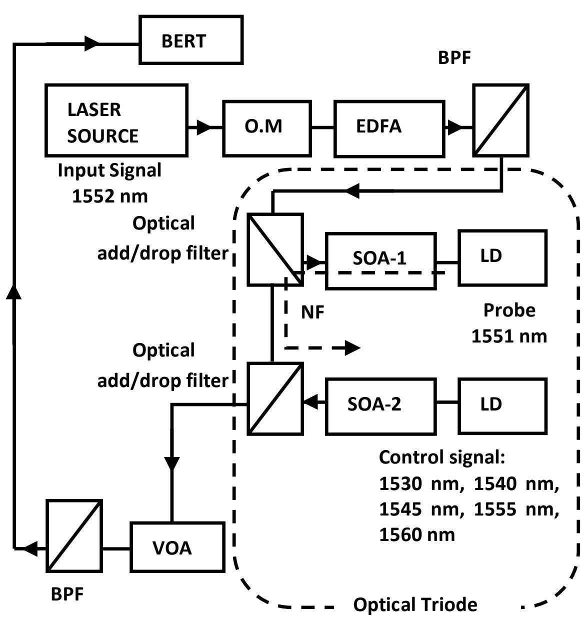
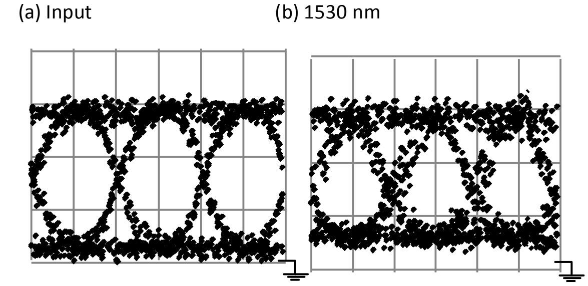


Figure 4 : Experimental setup



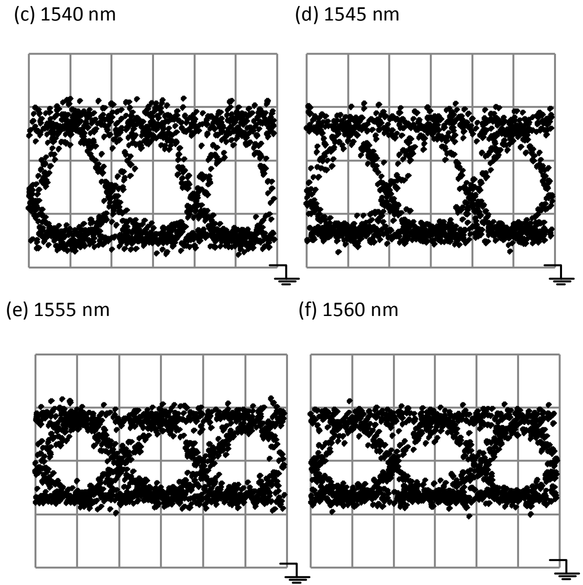


Figure 5 : Eye diagrams of input and output signals (50µW/div, 50ps/div)

Table 1 : Summarization of Measurement Result

Wavelength [nm]	Eye aperture[dB]	Extinction ratio [dB]	Zero level[µW]
1530	4.35	7.39	49
1540	3.90	6.97	54
1545	3.45	6.19	63
1555	2.22	4.40	83
1560	2.12	4.28	84

Therefore, the eye diagram and baseline of the output signal cannot be improved basically in relation with the noise, thereby making difficult to achieve an advanced signal processing. In spite of all, it is understood that the eye aperture of optical signals declines as the wavelength increases.

In order to assess multicasting characteristics, we measured the relationship between received power and BER and reported in Fig.6. We have measured the BER for B to B signal (also called as back to back signal), output signals 1530 nm, 1540 nm, 1545 nm, 1555 nm, and 1560 nm.

It was found that the smaller the received power of the signals, the bigger the BER will be. We studied that it may be an effect of the dependence of the speed propagation light through the medium during the conversion of wavelengths that produce errors. From the result of BER test, relationship of power penalty with respect to B to B and control signals when the BER is 10^{-9} is summarized. The summarization result is shown in Fig.7.

It is understood that the BER and power penalty with respect to B to B signal become worse as the control signal wavelengths increase. The control signal wavelength were successfully converted and modulated with a power penalty less than 5 dB. The highest power penalty is 4.7 dB at 1560 nm while the lowest is 2.2 dB at 1530 nm. Therefore, we found that BER for output wavelength of 1530 nm is the nearest to the B to B signal than output wavelengths of 1540 nm, 1545 nm, 1555 nm, and 1560 nm. In this experiment, we used SOAs that have a peak gain wavelength around 1530 nm. Based on wavelength conversion in XGM, we understood that, wavelength conversion can be successful when the gain is high. Thus, we assumed that 1530 nm has the biggest gain compared to the other longer wavelengths and produced better result than the other wavelengths. Moreover, we understood in shorter wavelength, the carrier density of SOA is sufficient thus, wavelength conversion due to the XGM can be done successfully and produced better result.

IV. Conclusion

We investigated multicasting characteristics by using an optical triode, which has been set up with two stages of SOAs that constitute a negative feedback optical amplifier with two optical add/drop filters. Based on the BER measurement result, output signal of 1530 nm produced the least error compared to the other output signals after undergone wavelength conversion. Thereby, we concluded that 1530 nm has the smallest power penalty than the other output signals when the BER is 10^{-9}.

Therefore, we understood that when the wavelength becomes longer, the BER becomes worse. Hence, this device also proved that all-optical multicasting and wavelength conversion with two channels at a time with a transfer speed of 10 Gbps is possible.

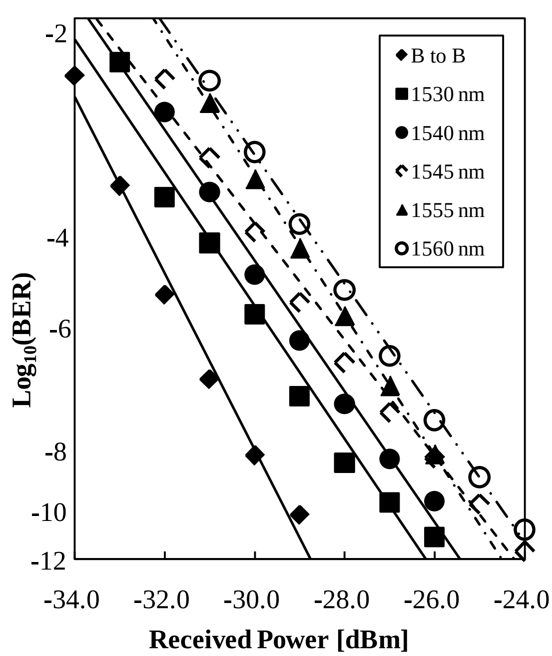


Figure 6 : Result of bit error rate test

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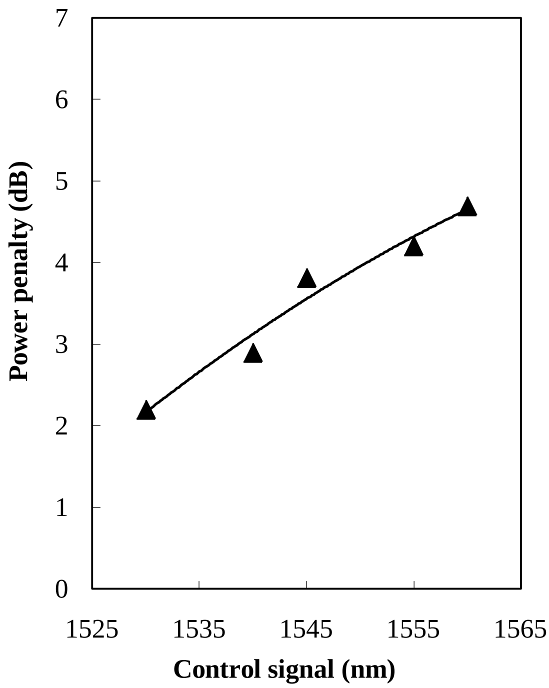

Figure 7 : Relationship of power penalty with respect to B to B and control signal

Furthermore, we found out that, by this experiment, it is possible to achieve negative feedback optical amplification by SOA with the insertion of input and control signal into the SOA. It also proved that the conversion of wavelength (O/E/O) through electronic circuit can be innovated to all-optical signals (O/O) and are applicable in our optical triode.

Multicasting characteristics are recognized and the conversion of one wavelength to more than one different wavelengths by injecting input and control signal with a speed of 10 Gbps at the same time in this device has been proved.

V. Acknowledgment

This work was supported in part by the Ministry of Education, Culture, Science and Technology of Japan, a Grant-in-Aid (21560048) for scientific research (C).

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