Multi-wavelength Semiconductor Optical Amplifier With Automatic Power Control

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Abstract: Enhanced IPDR performance of a digitally controlled of an SOA is demonstrated for 1, 5 and 10 λ 10Gb/s data. Automated output power control is demonstrated within 0.5dB over a 20dB dynamic range.

1 Introduction

A new generation of multi-element multi-path photonic circuits for optical space switching, regeneration and all-optical packet routing relies on cascades of semiconductor optical amplifier (SOA) switches. The SOA switch has advantages of broad spectral performance, high extinction ratio, signal amplification, and a compact footprint, which offer the potential for low loss, complexity and power consumption in future optical networks. Recent studies on SOA based switch fabrics have indicated low penalty operation may be achieved for high levels of cascading for high capacity wavelength multiplexed packets [1].

To cascade the SOA switches, it is helpful to set the output power irrespective of the input, polarisation fluctuation, routing path losses and the non-uniformities of active and passive components. Power fluctuations pose a problem to the implementation of optical network as it will affect the decision circuit of optical receivers, and active lightwave components often have a specific regime of input power dynamic range. For large scale SOA switch fabric, as the optical packet progresses through the switching stage, the SOA switch may be driven into saturation if the gain between each switching stage is uncontrolled. All these lead to degradation of bit error rate (BER) performance.

Several power equalisation schemes in SOA using on-the-fly electronic control have been demonstrated The schemes include the use of external pumping to exploit the saturation regime of SOA [2], using on-the-fly electronic control of SOA gain by means of direct photocurrent detection in a preceding detector [3], by means of narrowband voltage monitoring at the controlled SOA [4], and using controlled gain clamped SOA [5]. These schemes are complex [2,5], incur additional delays and have scalability issues [3,4,5]. We have proposed a modular per-packet power control scheme for SOA switches which has the potential for scalability without the high level of complexity. The results have been submitted to the ECOC 2006 conference [6]. This scheme utilises a two phase approach – calibration and operation phase– and power equalisation is achieved by controlling the switching current of the SOA.

In this paper, the performance of power equalization by dynamically controlling the SOA switching current in a multi-wavelength transmission system is presented. The test bed used in the experiment is presented in the next section, and the results in section 3. This is followed by a discussion of the input power dynamic range (IPDR) behaviour, penalties incurred and how this concept can be used in a switch fabric for per packet power equalisation.

2. Experiment Test bed

The test bed for investigation into the performance of the SOA power equalisation under multi-wavelength condition is shown in Figure 1. Power equalisation is achieved by controlling the switching current to modify the optical gain of the SOA. The temperature of the SOA is fixed so that the optical SOA gain will be dependent only on the switching current. Before applying the switching current, the input power into the SOA must be known. This is achieved by sampling 10% of the input optical power using a photodetector. The output analogue voltage from the photodetector is converted into a digital signal before being processed by a look up table (LUT) that resides in the FPGA. The LUT correlates the appropriate SOA switching current for a given sampled input power. The output power is set to be equalised to 0dBm. A custom-made current buffer is used to set the SOA switching current based on the output from the FPGA. The SOA output power of 0dBm is chosen as this does not drive the SOA into saturation, yet provides the required output power that is needed to cope with the passive losses that may be present if the SOA switch is to be cascaded to a larger switch fabric [7].

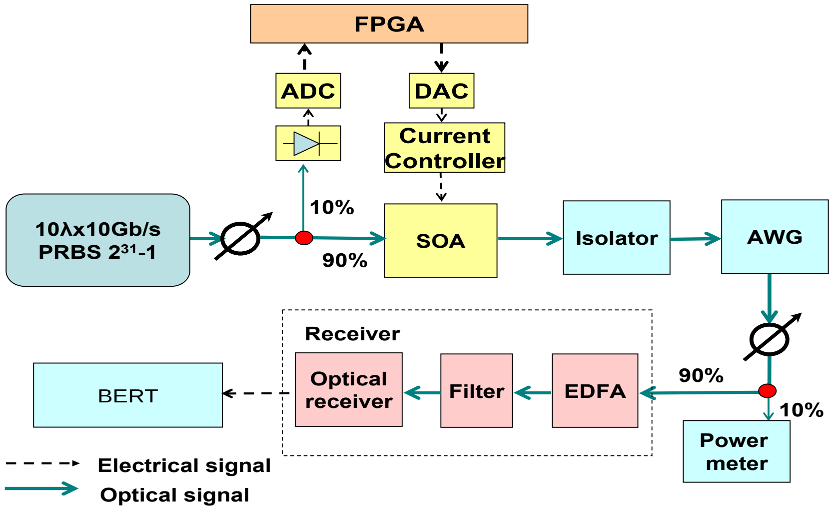

Figure 1: Experiment Test Bed for SOA Power Equalisation Under Multi-wavelength Environment

The Kamelian OPA SOA is used as the SOA switch. Up to ten DFB lasers, with wavelengths spanning from 1548nm to 1555.5nm and spacing ranging from 0.65nm to 0.93nm are used as the input into the SOA switch module. Each laser is modulated with PRBS sequence of 2^{31}-1 at data rates of 10Gb/s. The modulation data for the wavelength channels are decorrelated using data scramblers prior to modulation. A variable optical attenuator (VOA) is used to set the input over a range of power. The isolator is used to prevent any reflection back into the SOA. The array waveguide grating (AWG) is used before the receiver to select a channel (1552.05nm) from the middle of the transmitted wavelengths for bit error rate (BER) measurement. The input power dynamic range (IPDR) performance of the SOA under one, five and ten transmitted wavelength channels is measured.

3. Results

Power equalisation of 0dB with variation of +-0.5dB for a range of 20dB is achieved. This result is shown in Figure 3a, where the controlled output power is compared to the uncontrolled fixed switching current. For one, five and ten wavelength channels, a wider IPDR curve can be observed when the output power of the SOA is controlled. For controlled current at power penalty of 2dB, Figure 2a (1λ) shows IPDR of 16dB, Figure 2b (5λ) shows IPDR of 16dB and Figure 2c (10λ) shows IPDR of 8dB. As the number of wavelength increases, the IPDR for the case of fixed switching current becomes more restrictive, rendering the current control in the SOA critical for multi-wavelength system. In multi-wavelength system, the minimum power penalty increases with the magnitude of SOA switching current. For the five and ten wavelength system, the minimum power penalty is obtained with a low switching current of 32mA. However, as can be seen in Figure 3a, the advantage of low penalty obtained with low switching current is offset by the reduction in output power. Therefore, the low switching current may be unable to meet the power budge requirement that is needed in a switch fabric.

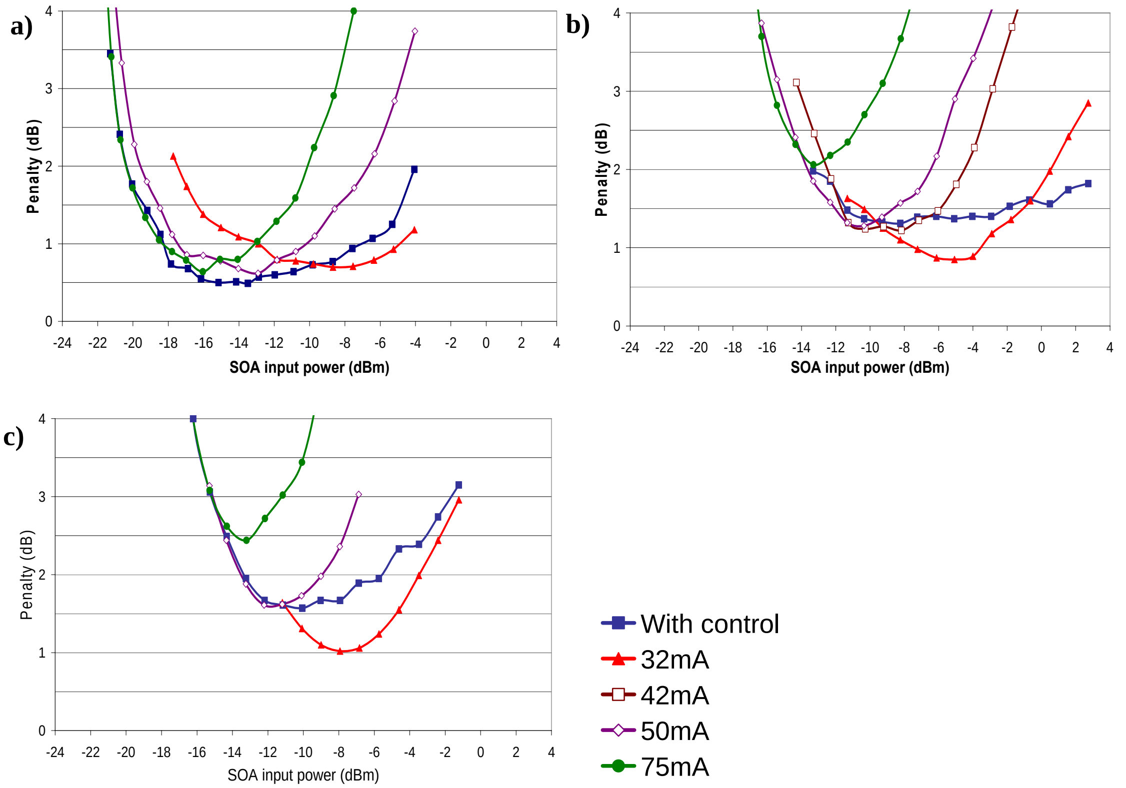

Figure 2: IPDR curve of SOA under (a) one wavelength and (b) five wavelengths and c) ten wavelengths

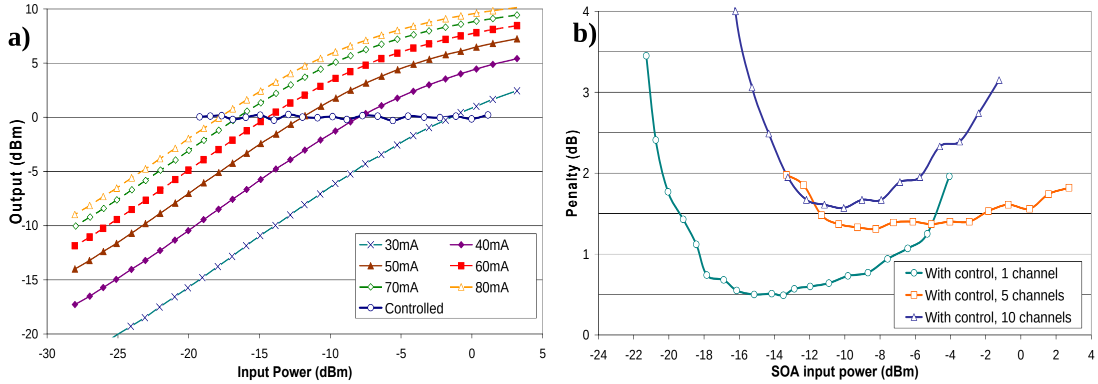

Figure 3: (a) Output power against input power for SOA module under a variety of switching current. Also shown in the graph is output power for a controlled switching current. (b) Comparison of SOA IPDR for controlled current case between one, five and ten wavelengths.

4. Discussion

In this system, the sources of power penalty can be attributed to quantization error and noise in the control electronics, the SOA patterning effect from a PRBS sequence with length of 2^{31}-1, the observed gain ripple during measurement, the ASE noise contribution from the SOA. The increase in penalties with the number of wavelength can be attributed to crosstalk and four-wavelength mixing in the SOA. The IPDR take a ‘fish-bowl’ curve for the following reasons. At high input powers, the SOA is saturated and additional power penalties are induced by the patterning effect and non-linear distortion. At low input powers, the signal is degraded by the additive ASE noise, which reduces the signal to noise ratio (SNR). There is significant patterning owing to the 2^{31}-1 bit pattern length of PRBS sequence and the 10Gb/s bit rate which is comparable to the SOA carrier lifetime.

IPDR curve shift can be observed from the plots. This is because high switching currents provides better output signal to noise ratio (OSNR) at region of low input powers, while at regions of high input powers, the lower switching current provides better penalty performance as the SOA will be less likely to be saturated. The control circuitry can be designed such that it follows the switching curve with the least penalty. However, this is constrained by the power budget requirement as the lower switching current may not provide the required gain to the optical signal.

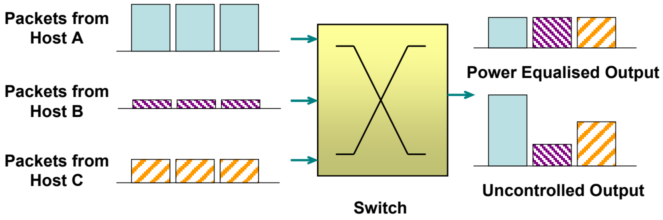

Figure 4: Application of SOA power equalisation in packet switched optical networks.

The concept of controlling the SOA switching current for power equalisation can be extended to equalise per packet power fluctuations. Variation in input powers and routing paths cause packets with different optical power to arrive at the SOA switch fabric. Without current control, the difference in power between subsequent packets will increase because of the inherent gain of SOA switches, leading to large power fluctuations at the switch output port as shown in Figure 4. After calibration, the losses of each routing path though the switch will be known. Thus the appropriate SOA current can be applied without the delay needed to sample the incoming optical power. This allows fast per-packet power equalisation that is scalable without the cost of high complexity components.

5. Conclusion

Power equalisation of 0dBm with variation of +-0.5dB for a range of 20dB is achieved. With power equalisation, the IPDR of transmitted data through SOA based switch is improved. This improvement is more obvious as the number of transmission wavelength increases. Power equalisation by controlling the SOA switching current is an effective scheme as it adds minimal complexity to the system while offering IPDR improvements.

References

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