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COMPENSATION OF GAIN SATURATION IN SOA-GATES BY INTERFEROMETRIC MACH-ZEHNDER WAVELENGTH CONVERTERS

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Abstract: Compensation of signal degradation in SOA-gates for optical switch nodes using all-active integrated Mach-Zehnder interferometric wavelength converters is experimentally demonstrated at 2.5 and 10 Gb/s. More than 10 dB improvement of the dynamic range is obtained compared to a stand-alone SOA-gate.

Introduction: Wavelength converters can be used in optical switching networks to reduce blocking probabilities of optical switches and thereby increase the throughput of the total network as well as to allow wavelength reuse and flexible management [1,2]. Based on this, optical switch nodes that include interferometric all-optical wavelength converters (IWCs) [3] have been proposed [4]. Additionally, fast (~1 nsec switching time) semiconductor optical amplifier (SOA) gates are attractive for space switching since they feature extremely high on-off ratios of 40 - 50 dB [4] needed to overcome the severe penalty induced by crosstalk in the optical switch block [5] and to simultaneously compensate for loss. However, the input power dynamic range of the SOA-gates is limited due to noise as well as gain saturation [6]. This leads to a limited cascadability causing severe restrictions for the number of switch nodes that can be cascaded. Here, it is demonstrated that switch blocks using a combination of interferometric wavelength converters and SOA-gates as shown in Fig. 1 exhibit an improved power penalty performance compared to switch blocks

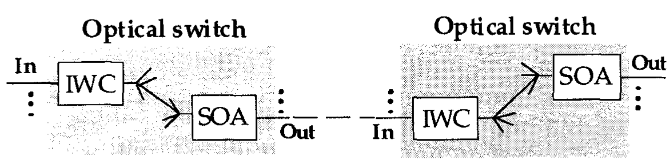

Figure 1. : Cascade of optical switch blocks that utilise interferometric optical wavelength converters (IWCs) for routing and to avoid blocking as well as semiconductor optical amplifier (SOA) gates for space switching.

without interferometric converters. The capability of IWCs to enhance the extinction ratio of an input signal compensates for the signal degradation caused by the SOA-gate and thereby increases the dynamic range. Experiments are carried out at 2.5 and 10 Gb/s for a SOA-gate alone and for a gate followed by a speed optimised 10 Gb/s multiquantum-well (MQW) all-active integrated Mach-Zehnder interferometer wavelength converter. With the IWC, more than 10 dB increase of the input power dynamic range is attained.

Experimental set-up: To show the enhanced performance with IWCs, the experimental set-up in Fig. 2 is used to measure the dynamic range at 2.5 and 10 Gb/s of the SOA-gate and the gate followed by an interferometric wavelength converter. The gate is a polarisation independent bulk type 1200 μm SOA based on the M-DCPBH structure [7] operated at a fiber-to-fiber gain of 20 dB. At the output of the gate an EDFA is used to boost the signal before entering the receiver or the wavelength converter. Thereby, the input power at 1555 nm to the converter remains constant at ~10 dBm while the CW input power to the converter at 1560 nm is kept at ~8 dBm. The converter is an integrated Mach-Zehnder interferometer wavelength converter based on an all-active MQW structure [3]. The conversion scheme relies on cross-phase modulation where the signal at 1555 nm modulates the refractive index in the upper Mach-Zehnder arm. Thereby the relative phase change and consequently the output power of the CW signal at 1560 nm is modulated according to the input signal at 1555 nm when coupled through the IWC.

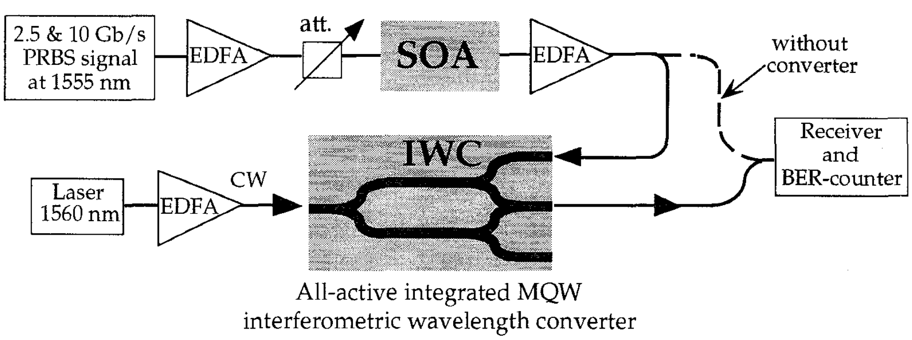

Figure 2: Experimental set-up for gating as well as gating followed by interferometric wavelength conversion. Without the converter the gated signal is coupled directly to the receiver.

Results: At 2.5 Gb/s the improvement of the dynamic range due to the IWC is illustrated in Fig. 3 that gives the power penalty (@BER=10^{-9}) (left) as well as the signal extinction ratios (right) versus the input power to the SOA-gate. The penalty is shown after the SOA-gate and after the signal has passed both the gate and the converter. For the SOA-gate alone the 1-dB input power dynamic range is ~ 10 dB. At low input power levels the penalty for the SOA-gate originate from added spontaneous noise while the penalty at high input power

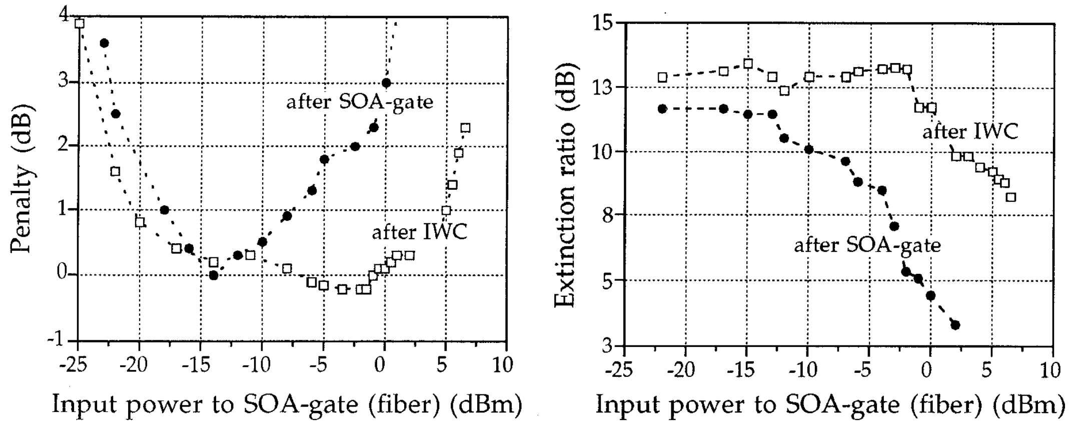

Figure 3: 2.5 Gb/s dynamic range measurements (@BER=10^{-9}). *(left):* dynamic range for the SOA-gate and the SOA-gate followed by the interferometric wavelength converter (IWC). *(right):* signal extinction ratio after the SOA-gate and after the SOA-gate followed by the IWC.

levels is due to gain saturation, which leads to a reduction of the signal extinction ratio. When the gate is used in connection the IWC the 1-dB input power dynamic range increases to as much as ~25 dB. This is ascribed to the extinction ratio enhancement in the IWC [3]. As an example, the extinction ratio after the gate is ~9 dB at an input power of -5 dBm while it is more than ~13 dB after the converter. Although the main factor that causes the larger dynamic range is due to these high extinction ratios, we note an improvement also at low input power levels. As recently demonstrated [8] this can be explained by the non-linear transfer function of the interferometric converter.

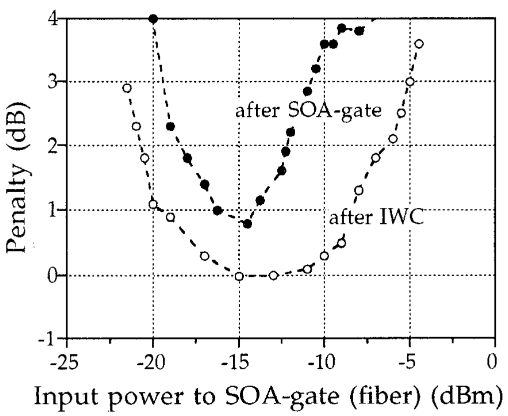

Figure 4: 10 Gb/s dynamic range (@BER=10^{-9}) measurements after the SOA-gate and for the SOA-gate followed by the interferometric wavelength converter (IWC).

At higher bit rates the dynamic range of the SOA-gates is lower [6] and thus cascadability of the gates and switch blocks becomes more critical. Again, the wavelength converter being the first all-active integrated Mach-Zehnder converter operating at 10 Gb/s, improves the dynamic range at this high bit rate as well. This is seen in Fig. 4 giving the power penalty versus the input power to the SOA-gate for the gate alone and with the gate succeeded by the IWC. In the latter case the 1-dB dynamic range is enhanced from 2 to 12 dB.

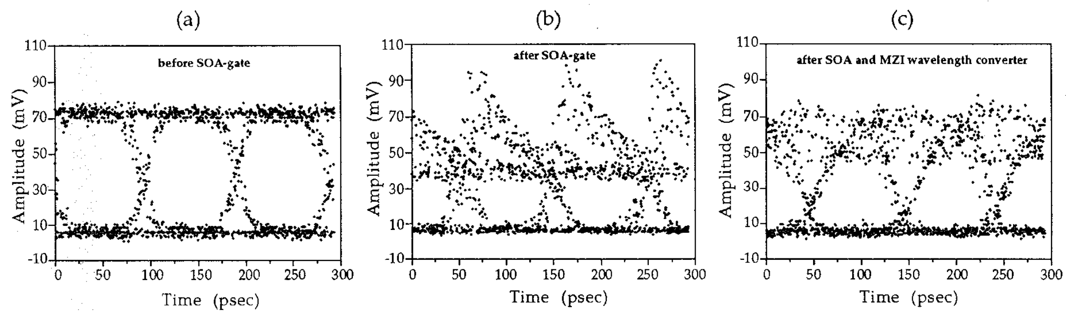

Figure 5: 10 Gb/s eye-diagrams for an input power of -10 dBm to the SOA-gate at (a): SOA-input, extinction ratio is ~11 dB, (b) output of the SOA-gate, extinction ratio is ~7.5 dB and at the interferometric converter output, extinction ratio is ~10 dB.

The important role of the converter is further documented by the eye-diagrams in Fig. 5 for an input power to the SOA-gate of -10 dBm: (a) is for the initial signal at the input of the SOA-gate (extinction ratio is ~11 dB), (b) is at the SOA-gate output (extinction ratio is ~7.5 dB) while (c) shows the extinction ratio enhanced signal at the IWC output (extinction ratio is ~10 dB). As seen from Fig. 4 the higher extinction ratio after the IWC reduces the penalty from ~3.5 to ~0.5 dB. Hence, the advantage of using interferometric wavelength converters in photonic switch blocks is clearly illustrated: the converters do not only improve the traffic and management performance, but will also result in a larger dynamic range and therefore allow more switch nodes to be cascaded.

Conclusion: The problem with a limited dynamic range of SOA-gates that are used because of their very high gating on-off ratios of 40 - 50 dB is greatly reduced when the optical switch nodes use interferometric wavelength converters. Due to the efficient wavelength conversion, 10 dB improvement of the dynamic range is obtained at a high bit rate of 10 Gb/s using an optimised all-active integrated MQW Mach-Zehnder wavelength converter. Consequently, high-speed interferometric wavelength converters can be considered as key elements to realise high-performance optical switch nodes.

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