Static extinction ratio bandwidth of Mach-Zehnder interferometer wavelength converters

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In this paper, the effect on the optical bandwidth of couplers and the current settings used in SOA-MZI WLC is presented. The optical bandwidth is found from the extinction ratio versus the wavelength. The bandwidth limitation found experimentally from an SOA-MZI with 1x2 couplers is in good agreement with the simulated bandwidth. The simulation shows that this limitation disappears in case 2x2 couplers are used.

I. Introduction

All-optical wavelength converters (WLCs) are key devices for future optical telecommunication networks. They can be used for dynamically routing signals, for data regeneration and to avoid wavelength blocking [1]. The Semiconductor Optical Amplifier based Mach-Zehnder Interferometer (SOA-MZI) is one of the most promising WLC devices. It has a low chirp and a high extinction ration (ER) of the output signal [2]. Due to the monolithic integration the device is stable and compact. The wavelength conversion in a SOA-MZI is obtained by splitting the new wavelength signal P_{cw} (probe) equally between the two arms of the MZI. In one of the arms, the phase of the optical field is modulated by the old data signal P_s (control). Hence, interference of the light coming from the two arms at the output of the MZI will generate the data sequence on the new wavelength. To operate within WDM systems and to allow the cascading of WLCs in high-capacity transmission systems, WLCs are required to work in the non-inverting mode, also they should operate over the entire EDFA range.
Several efforts have been done to improve the bandwidth and the quality of the converted signal. In [3], work on the improvement of ER in SOA-MZI is reported. Unfortunately no result on the bandwidth has been shown. A bandwidth of 15 nm with a penalty below 0.5 dB has been demonstrated in [4] using a SOA-MZI in non-inverting mode operation. By means of a SOA-MZI with 2x2 asymmetrical MMIs in inverting mode operation, 30 nm bandwidth is reported [5]. Larger bandwidth of 80 nm is achieved by [6] using a SOA-MZI in non-inverting mode operation.
This range in bandwidth values is due to the design of the SOA-MZI and/or to its setting. The required setting of the SOA-MZI WLC can be achieved by tuning the SOA currents. For some cases, the device will work at one new wavelength, but requires a new setting if this wavelength is changed. Implying a narrow bandwidth for fixed current setting. Tuning the current setting for the new wavelength is very undesirable, since it requires extra management functionality and limits the speed of the wavelength switching. In this paper we investigated the origin of this narrow bandwidth and propose how the configuration should be amended to allow for a fixed setting, high bandwidth operation. This makes it possible to combine the device e.g. with a tunable laser.

The bandwidth limitations are determined with a realized WLC, which is described in detail in [7]. A schematic of the device is shown in figure 1. The input/output couplers used in this device are 1x2 MultiMode Interferometers (MMIs).

II. Experimental results

For non-inverting operation, the SOAs are biased in such a way that a low output power P_{out} from the WLC is obtained when no data signal is launched in the interferometer: $P_s=0$. This optimization is done for a probe wavelength of 1550 nm. It has been seen that P_{out} increases abruptly for wavelengths around 1550 nm and shows other minimas less strong in the wavelength range 1515-1600 nm. The P_{out} in this case describes the behavior of bit 0. In case when P_s is on (bit 1), a higher P_{out} is obtained for wavelengths around λ =1550 nm. The difference between P_{out} in the cases of bit 1 and 0 gives the ER. The ER curve is presented in figure 2. It can be seen from this curve that the ER has a 10 dB ER window of only 13 nm around λ = 1550 nm. The optical bandwidth of the SOA-MZI is not limited by the carrier density-dependent refractive index change, which is nearly wavelength independent in the operation range. Other smaller peaks can be seen on the curve. Those peaks are most likely due to mode beating. The narrow ER bandwidth is not suitable for application in WDM. A wider bandwidth can be obtained in this case by tuning the currents of the SOAs to minimize P_{out} when the wavelength changes, but this needs a large effort from the network management.

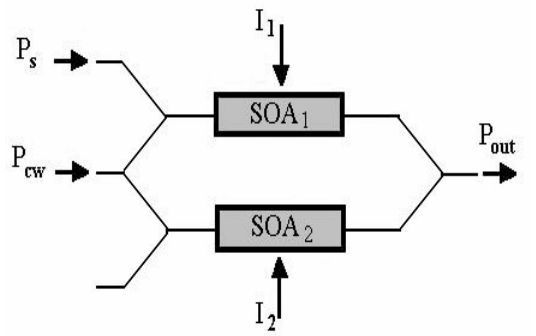

Fig. 1 : MZI-WLC with 1x2 3 dB couplers, P_{cw} is the continuous wave power coming from a local laser, P_s is the signal power, I_1 and I_2 are the injected currents in SOAs, and P_{out} is the output power from the MZI-WLC

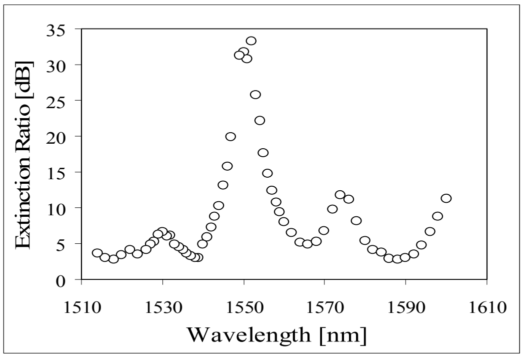

Fig. 2 : measured ER versus wavelength in case of 1x2 MMI MZI-WLC

III.Simulation results

A simulation study of the device is carried out to understand the origin of the narrow bandwidth. The theoretical model used for the simulation of the Semiconductor Optical Amplifier (SOA) is the same as used by Yabin et al [8]. Only the steady state is considered, which means the carrier density has no time dependence in the SOA sections. The parameters from [4] are used for the simulation of the SOA. The output power from the SOA-MZI with 1x2 couplers is given by

$$P_{out} = \frac{P_0}{8}\left(G_1 + G_2 + 2\sqrt{G_1 G_2}\cos(\varphi_1 - \varphi_2)\right) \qquad (1)$$

Where P_0 is the CW input power in the SOA-MZI. G_1, φ_1 and G_2, φ_2 are the power gain and optical phase for the SOA_1 and SOA_2 respectively.
The experimental setting procedure is repeated in the simulation. After launching P_{cw} at 1550 nm wavelength in the SOA-MZI, P_{out} is minimized for $P_s = 0$ (case of bit 0). Then the behavior of P_{out} in the 1500-1600 nm wavelength range is determined. The P_{out} curve is found again in case of P_s is on: bit 1. The difference between the two curves gives the ER in the 1500-1600 nm range. The result is shown in figure 3-a. Negative values of the ER correspond to inverting mode operation of the interferometer. The 10 dB ER window in this case is 15 nm wide around λ=1550 nm. The ER curve is comparable to the experimental result, the difference is probably due to the choice of simulation parameters used for the SOA. Nevertheless, the behavior of both curves is similar and shows clearly the limitation in ER bandwidth in this case. The narrow optical bandwidth seems to be caused by the strong unbalancing of the SOA-MZI. This unbalancing is needed to set the WLC in the non-inverting mode. To avoid this unbalancing, 2x2 3 dB couplers can be used. The advantage of this is that by choosing the appropriate port; non-inverting mode can be obtained without unbalancing the interferometer.
A simulation study is carried out to determine how this affects the ER. For the SOA-MZI with 2x2 couplers the bar state is chosen. The output power is calculated in this case using equation (2)

$$P_{out} = \frac{P_0}{8}\left(G_1 + G_2 - 2\sqrt{G_1 G_2}\cos(\varphi_1 - \varphi_2)\right) \qquad (2)$$

Since no output power will be obtained when P_s=0 (because both the gain and the phase shift in the two SOAs is identical then), only P_{out} when P_s is on is calculated, which corresponds to bit 1. The result is shown in figure 3-b. The curve reflects the ER behavior in this case. The bandwidth is very wide, mainly because the destructive interference condition for P_s=0 is now obtained with the phase properties of 2x2 couplers, making a balanced operation of the SOAs possible.
From results it is clear that the narrow bandwidth is due to the unbalancing of the MZI interferometer. Optimizing the SOA-MZI to have low output power around a given wavelength will change the phase-difference in such a way that the cosine function in equation (1) will have it lowest value at this wavelength. The cosine curve is wide, but after taking into account the gain values which are, wavelength and current dependent, a narrow ER bandwidth is obtained. To overcome this problem, 2x2 couplers can be used. In this case, the MZI is working in the bar state, hence having low output power with P_s=0, even when the wavelength changes. Therefore a wider bandwidth can be obtained.

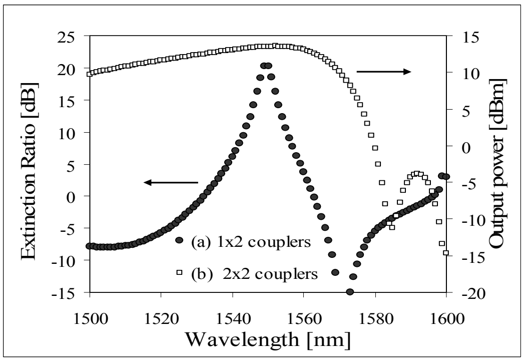

Fig. 3: (a) ER obtained in case of SOA-MZI with 1x2 couplers. (b) output power/ER of a SOA-MZI with 2x2 couplers MZI-WLC

It should be remarked that the simulated 2x2 device represents an ideal case. In reality there can be loss and phase differences between the MZI-branches, which require a slight unbalancing of the SOAs. This is however much less than in the 1x2 case, so a much wider optical bandwidth will nevertheless be obtained.

IV. Conclusion

The origin of the experimentally found narrow ER bandwidth is successfully identified using numerical simulations. The narrow bandwidth is a result of the unbalancing of the MZI interferometer. The simulation study shows that 2x2 couplers are more suitable for the MZI-WLC. Since the unbalancing is not needed in this case, they offer the possibility to have a wide optical bandwidth.

V. ACKNOWLEDGMENT

This work is done in the framework of the European IST-project STOLAS. The European commission is acknowledged for financing the project.

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