A Pattern Effect Compensator

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Degradation of high power signals is observed at bitrates comparable to the gain recovery time in Semiconductor Optical Amplifiers (SOA). The device studied here reduces this pattern effect of SOAs. It is a non-linear Mach-Zehnder interferometer with a SOA in each branch. It has an unequal input power distribution over the branches, which themselves are identical. This causes destructive interference at the output for low power inputs. Conversely, different phase shifts for high power inputs result in constructive interference. Therefore, gain saturation is observed for much higher input powers. This results in reduced pattern effects. Simulations and experiments confirm the performance.

Introduction

A number of advantages of SOA's, such as a wide gain spectrum and possibilities of integration with other devices, are making them very attractive not only for amplifying the signal, but also for optical signal processing. A serious restriction on the operation of SOAs is caused by the gain saturation effect. This effect is caused by carrier depletion and results in the optical gain reduction at high input powers. In optical transmission systems this can lead to a serious waveform distortion, also known as the pattern effect [1, 2]. It is observed when an intense input signal is applied to the SOA at the bitrates comparable to the gain recovery time.

If the bitrate is lower than the gain recovery, the leading part (see fig.1, part I) of the pulse is amplified with unsaturated gain, and the output of the trailing part subsequently decreases as the SOA gain approaches saturation (fig. 1, part II). At high bitrates the amplifier gain does not return to the unsaturated value and even a leading part is amplified with a partially saturated gain value [2].

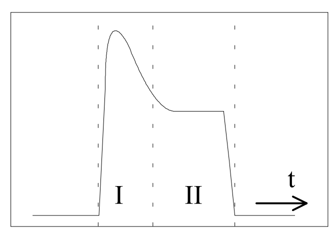


Fig. 1. Distorted pulse from a SOA.

In the present paper we demonstrate a device that is aimed to reduce the unwanted pulse form distortion.

Concept of the device

The interferometric suppression of the pattern effect was proposed in [3], where unequal branches in the Mach-Zehnder (MZ) structure were used. In the device proposed here equal branches can be used, leading to more stable and simple operation. The pattern effect compensator is schematically presented in figure 2. It is a MZ Interferometer (MZI) with Semiconductor Optical Amplifier in each branch. The optical signal is applied to one of two input ports. An unbalanced 2-to-2 coupler (coupling ratio different from 0.5) distributes the input signal unevenly over the branches of MZ interferometer. Another 2-to-2 coupler with coupling ratio 0.5 is placed at the output of the interferometer [4].

In the considered device optical power is injected into the input port 1 and detected at the output port 3. The 85/15 coupler induces a 90˚ phase shift and distributes the light unevenly over the branches. SOA2 is then working in the unsaturated regime and does not induce an additional phase shift. The leading part of the optical pulse injected in SOA1 is also amplified with unsaturated gain. The output coupler induces additional 90˚ phase shift and the total 180˚ phase difference between signals from either of the branches at the output port 3 lead to destructive interference.

Because of the unequal power distribution over the branches the destructive interference is incomplete and some signal will still be present at the output. With higher optical power injected, SOA1 comes in the saturation regime (region II, fig.1) and therefore both waveform distortion and additional phase shift are induced. If the obtained phase shift is 180˚, signals from both branches then interfere constructively. The net effect is that the leading edge of the pulse (fig. 1, region I), when no carrier depletion is present, shows a lower signal because of destructive interference, the trailing edge on the other hand (region II) experiences carrier depletion and thus constructive interference, so there a higher signal is obtained. In this way the pulse distortion can be compensated.

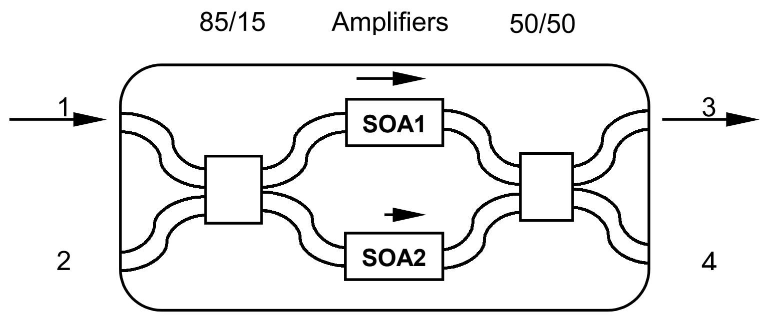


Fig. 2. Schematic layout of the pattern effect compensator.

Simulation results

The simulations of the proposed circuit were performed with *Virtual Photonics Inc.* software. A transmission-Line Laser Model technique has been applied to model the Semiconductor Optical Amplifiers with anti-reflection coated facets [5]. One of the key parameters that defines the non-linear phase shift in the SOA as a function of gain saturation is a linewidth enhancement factor α. In the simulations the value of α was chosen to be 11, which is from the typical values range.

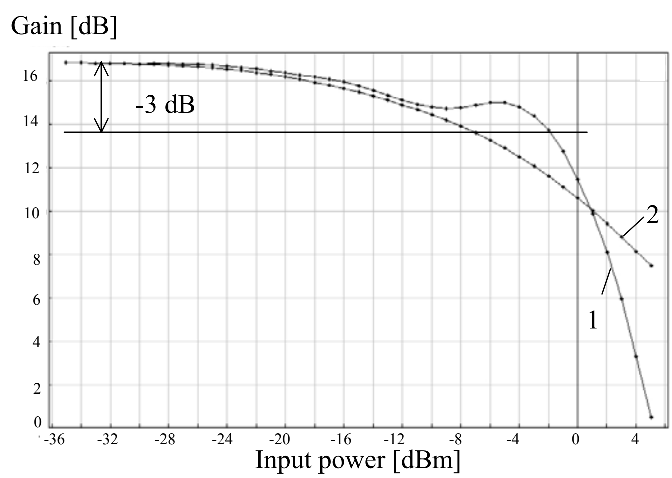
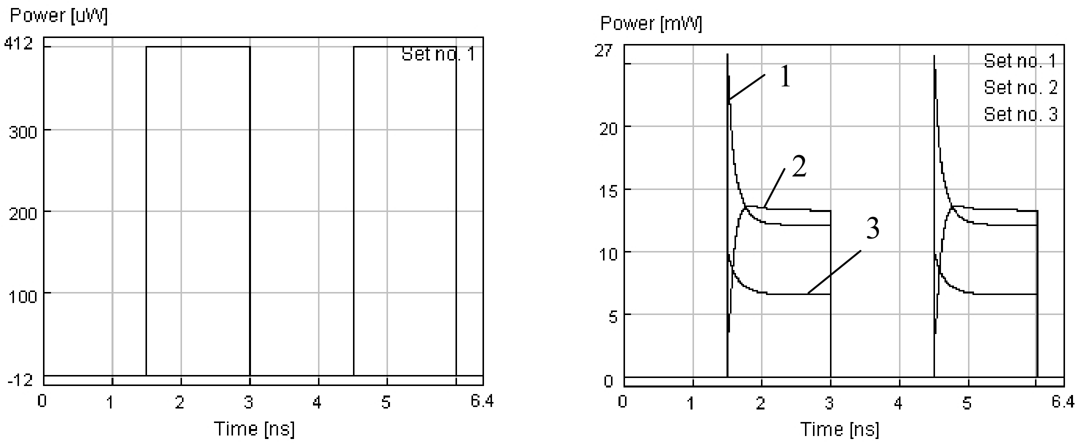


Fig. 3. Gain saturation curves: 1- interferometric structure, 2- SOA with the same small-signal gain. Input power extension is 5 dB.

The calculated gain saturation curve of the interferometric structure is presented in figure 3. A saturation curve of a SOA with comparable small-signal gain is also calculated and presented in figure 3.

The pattern effect compensation function of the device is studied with a pulsed optical input signal applied to the input port 1 (fig. 4 (a)). A power range for which the compensation can be obtained is from 0.3 to 0.7 mW (about 3.7 dB).

The output signal at the compensator's port 3 is shown in figure 4 ((b), curve 2).



(a) (b)

Fig. 4. Input (a) and output (b) pulses of the interferometric structure and SOAs. Curves: 1-output of SOA used in the branches of MZ-interferometer, 2-output of the compensator, 3-output of a SOA with the equal to the device small-signal gain.

The compensated output is compared with the pulses from the SOA from the high power branch of the MZI, and with a SOA with the small-signal gain equal to that of the interferometer. In the first case the calculated gain improvement is 0.5 dB, in the second case 3 dB.

Experimental results

The pattern effect compensation function is verified with a fiber-based interferometric structure [4]. The set-up used in the experiments is shown in figure 5. The two SOAs placed in the arms of the MZI are JDS-Uniphase SOA-type CQF 872 with a measured linewidth enhancement factor of 7.2 [4].

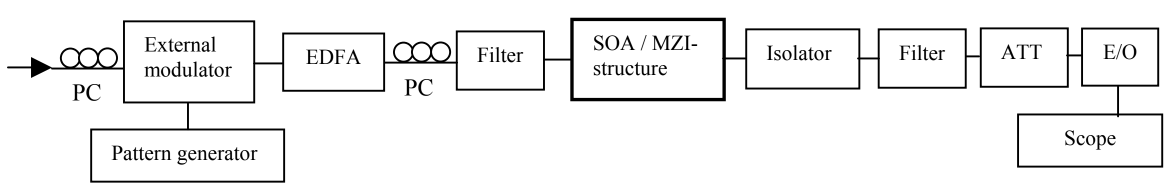


Fig. 5. The experimental set-up EDFA: Erbium Doped Fiber Amplifier, PC: Polarization Controller, ATT – Attenuator, O/E – Opto-Electronic converter.

Measurements are performed at λ=1554.13 nm to compare the waveforms at the output of the single SOA and the interferometric structure (Fig. 6). It appeared that there was a length difference in the arms of the MZI. To compensate for the induced time delay of 1.42 ns between the signals from both arms, the pattern 10101010 is chosen at frequency 1.4084 GHz. In this case bit "1" and bit "0" length is 0.71 ns, so that "1"-s are obtained simultaneously from both branches.

The stability of the experimental set-up is one of the main problems [4]. The phase shift value resulted from the length difference drifted during the experiment because of changes in environmental conditions and therefore the conditions for destructive and constructive interference at the output coupler are not always satisfied. This resulted in slow changes of the pattern amplitude. The results of the measurements in figure 7 correspond to the constructive interference condition, when the trailing part of the pulse has a maximum value.

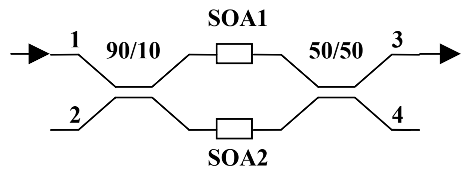


Fig. 6. The MZI-structure used in the experiments.

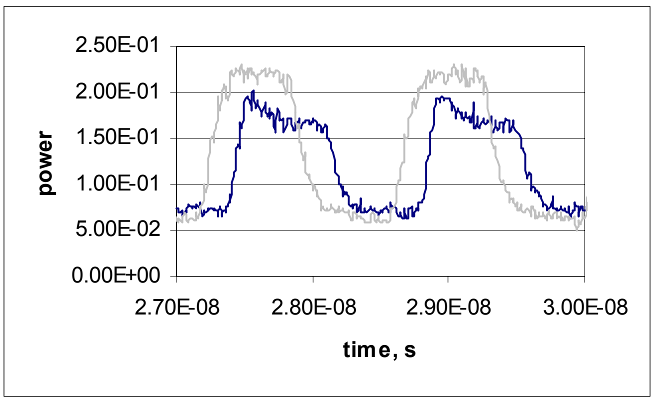


Fig. 7. Compensated (light line) and uncompensated (dark line) waveforms for an input power of –0.54 dBm (0.88 mW).

Although the device clearly requires integrated realization, its compensation capabilities are shown in the fiber-based measurement set-up.

Conclusions

A symmetrical MZ structure has been proposed as a pattern effect compensator. Simulation results have shown its high compensation capabilities for a range of input powers of 3.7 dB. An input power range extension is 5 dB. A fiber-based pattern effect compensator has been made and experiments show the compensation behavior of the interferometric structure. The problem of instable operation can be solved by integrated technique.

Acknowledgement

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