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A Simple Optical Power Limiter for 40 GHz Pulses based on SOA Saturation

G. Contestabile, M. Presi, R. Proietti, N. Calabretta and E. Ciaramella
Scuola Superiore Sant'Anna, Via Moruzzi 1, 56124, Pisa (Italy), tel. +390505492142, fax. +390505492194 email: contesta@sssup.it

Abstract— **We experimentally characterize a simple optical power limiter made by an SOA and a bandpass-filter working on 40GHz pulses. We find a very large (25-33dB) amplitude-modulation-reduction factor for input modulating frequencies in the range 100kHz-1GHz.**

Future transmission networks will benefit of new circuits operating transparently in the optical domain. Semiconductor Optical Amplifiers (SOAs), which show high non-linearity in a compact device, are largely employed in the realization of all-optical functions [1]. Unfortunately, signal distortions due to the semiconductor dynamics force to adopt interferometric or differential architectures to work at multi-gigabit data rates [1]. On the other hand, in case of periodic signals the saturation effects can be usefully exploited without pattern distortions. One application is the all-optical power limiting function for short periodic pulses. An all-optical power limiter can be very useful in a number of applications where it is necessary to reduce the amplitude jitter of periodic pulses. As an example, it could be used to reduce spurious amplitude modulations in mode-locked lasers, [2] and to equalize clock signals in clock recovery circuits [3, 4]. Several techniques have been proposed for power limiting, but, they are generally complex [2], and/or require high optical powers [4]. On the contrary, the saturated amplification in SOAs exploited together with a band-pass filter is very effective in a simple optical circuit working at low input power. Here, we give a comprehensive quantitative characterization of the potentialities of such a scheme for 40 GHz pulse trains.

The experimental set-up is reported in fig. 1. 6 ps-pulses were carved on an optical carrier at λ= 1551.5 nm by means of an electro absorption modulator driven by a 40 GHz electrical signal. An amplitude modulation was superimposed by an additional intensity modulator driven by a sinusoidal signal from a wide-band waveform generator. The modulation depth and the frequency of the additive signal were controlled by adjusting both the bias of the modulator and the frequency of the electrical signal. The two electrical waveform generators were not synchronized in order to avoid any fixed phase relation among them. This guarantees an effective amplitude modulation also for high frequency modulations that are comparable with the pulse repetition rate. The signal was then amplified by an erbium doped fiber amplifier and power controlled. The limiting circuit was composed by an optical isolator, an SOA and a 0.8 nm tunable band-pass filter. The SOA was a polarization-insensitive pigtailed device with about 28 dB small signal gain, around 200 ps recovery time and 6 dBm output saturation power at 200 mA driving current.

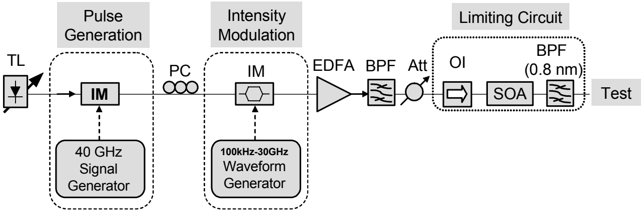

Fig. 1. Experimental set-up. IM: Intensity Modulator; OI: Optical Isolator: BPF: Band Pass Filter

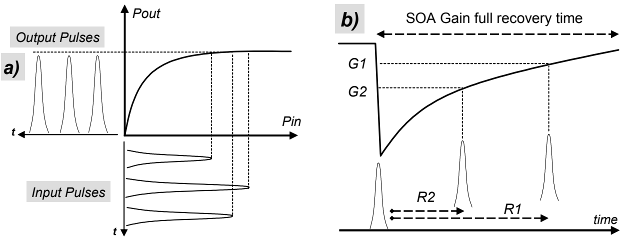

Fig. 2. a) Scheme of the limiting saturation process. b) Scheme of the gain recovery in a saturated SOA.

The output signal was analyzed by usual test instruments. The amplitude equalization process can be qualitatively described as a limiting effect due to the saturation of the SOA gain ruled by the semiconductor gain dynamics. Indeed when the gain of the SOA is saturated, input pulses with different power exceeding a certain threshold value, are practically amplified to the same limiting value (see fig.2a). The frequency response of this process is mainly governed by the gain dynamics, whilst the strength of the effect is related mostly to the gain compression. Indeed, by increasing the input power, the amplifier gain compression increases and the effect becomes more pronounced. At the same time, when short pulses propagate through the SOA, self phase modulation and intra-band four wave mixing lead to spectral spreading of the signal. Red chirp is generated in correspondence of gain depletion during the saturation whilst blue chirp corresponds to the gain recovery process [5]. The spectral spreading leads to pulse distortion that can be mitigated by the band-pass filter placed at the SOA output. The filter bandwidth should be large enough to select only part of the output spectrum. We found it has a twofold action both on shape and frequency response of the process (a detailed description of this will be included in the conference presentation). As it is described in fig.2b, depending on the repetition rates (e.g. R1< R2), the pulse sequence can enter the SOA before the gain fully recovers: in this case the recovered gain decreases at increasing the repetition rate (G2< G1). Nevertheless, due to the pulse periodicity, the technique works also with partial gain recovery without suffering any pattern effect.

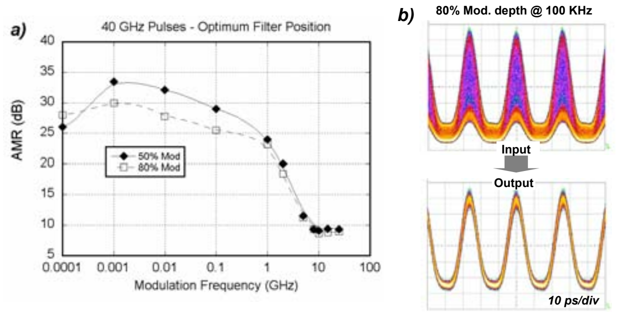

Fig. 3. a) AMR vs. Modulation Frequency; b) Typical complete waveform reshaping by limiting amplification.

For this reason, the circuit is effective also when operated with pulse repetition rates exceeding the inverse of the SOA recovery time. In this case the strength of the effect becomes weaker. However, this implies that pulse trains with repetition rate exceeding 100 GHz might be managed by this technique [6]. To quantify the amount of amplitude modulation reduction obtained by the circuit, we define the amplitude modulation reduction (AMR) parameter, as the input/output ratio (in dB) of the frequency components at the superimposed amplitude modulation (measured on an electrical spectrum analyzer). The frequency response of the AMR for the 40 GHz pulses is reported in fig.3a in case of 50% and 80% modulation depths, by using 5 dBm average input power, and without detuning of the output band-pass filter. We found an AMR in the range 25-33 dB from 100 kHz up to 1 GHz, a cut-off point at a few GHz, and, still an AMR flat response of around 10 dB for modulating frequencies up to 25 GHz. According to our qualitative physical description, the cut-off frequency of the response should be related to the inverse of the SOA recovery time. On the other hand, a certain amount of limiting effect can be expected for modulation frequencies exceeding the cut-off. In this case a weaker effect is due to the partial gain recovery obtained from ultrafast carrier-carrier and carrier-phonon scattering working at sub and picosecond time scale [6]. To visualize the large effectiveness of the limiting effect, we report as an example in fig.3b the case of a pulse train modulated at 100 kHz with 80% modulation depth. It experiences around 27 dB AMR and is completely reshaped to a pattern free condition. We characterized the limiting effect also as a function of the modulation depth. The results are summarized in fig.4a. We fixed a 5 GHz modulating frequency and varied the modulation depth. The AMR response is nearly flat and starts to decline once exceeded the 80%. The efficiency of the effect reduces when the modulation depth is so large that the weakest pulses in the sequence approach the threshold level of the input-output transfer function (see fig.2a). To show this, in fig.4b we report an ultimate case of 86% modulated pulses at 5 GHz. The traces show that the limiting effect still occurs but that is not complete. Finally, in order to characterize the effect of the filter position on the shape of the output pulses and on the efficiency of the limiting effect, we performed a systematic study for a fixed over-modulation condition. The results are reported in fig.5.

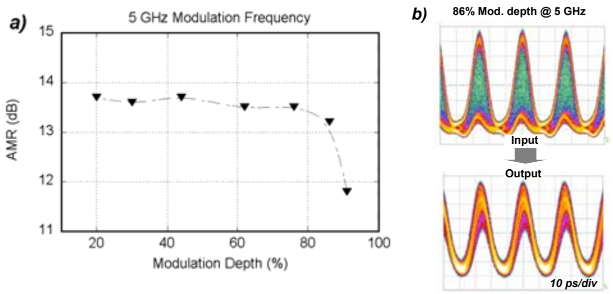

Fig. 4. a) AMR vs. Modulation Depth for a 5 GHz modulating frequency. b) Partial waveform reshaping for 86% modulation at 5 GHz.

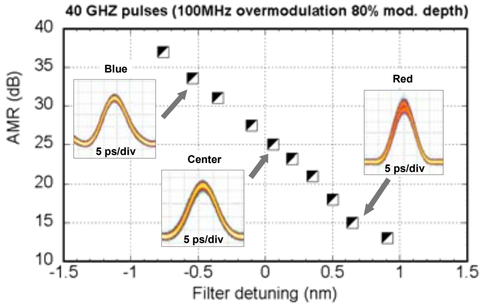

Fig. 5. AMR vs. filter position. In the insets, corresponding pulse shape.

The input pulses are modulated at 80% with a 100 MHz signal. As can be seen from the insets, moving from the red to the blue-shifted position, the AMR significantly increases at the expenses of a degradation of the pulse shape. When filtering the red-shifted part of the spectrum the output pulses are shorter and better shaped (pulse compression can potentially be obtained in this case [5]) in respect of the blue filtering case. However red filtering shows a lower limiting effect (note the residual amplitude modulation on the pulse in the inset). Symmetric pulses are obtained for filter positions closed to the center input wavelength having larger AMR factors and the largest AMR values result for blue-shifted positions. However, in this last case pulse distortions and Extinction Ratio degradation are apparent. We can then infer that this technique allows to balance the strength of the limiting effect and the quality of the output pulses depending on the application requirements by simply moving the filter detuning. This work was partially supported by the European Commission FP6 program (I.P. NOBEL II).

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