All-Optical Sampling in a Multiple Quantum Well Saturable Absorber

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Abstract: The use of multiple-quantum-well saturable absorbers in all optical sampling of high repetition rate pulse trains is presented. Measurements of a 40GHz pulse train were made using a device with a response time of 5ps.

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1. Introduction

With the increasing line rates in communications systems the development of simple and accurate characterization techniques with high temporal resolution is of great importance. The standard approach of characterizing high-speed optical signals involves the use of fast photodiodes in conjunction with high-bandwidth oscilloscopes, which are currently limited to a maximum data rate of 40Gbit/s.

All optical sampling offers the potential for measurements with much higher resolution, being limited only by the duration and jitter of the sampling pulse and the speed of the nonlinear effect used to implement them. A large variety of nonlinear processes have been investigated for this application including Self Phase Modulation (SPM) in Nonlinear Amplifying Loop Mirrors (NALM)[1], Four-Wave Mixing (FWM) both in fiber [2] and Semiconductor Optical Amplifiers (SOA)[3], Sum Frequency Generation (SFG) in $LiNbO_3$[4], and Two Photon Absorption (TPA)[5-6].

In this paper, for the first time to our knowledge, we propose a new technique using a nonlinear mirror based on a vertical microcavity saturable absorber. This technique presents a number of advantages such as its low peak power requirements and its compatibility for use in a multi-wavelength system.

2. Principle

The saturable absorber was packaged in a module with 8 input channels and only one channel is used in our experiment [7]. The saturable absorber chip contains 7 MOCVD-grown InGaAs/InP quantum wells embedded in a microresonator. The quantum wells are located at the antinodes of the intracavity intensity. The bottom mirror is a broadband high reflectivity metallic based mirror (Ag) and the top mirror is a multilayer dielectric mirror (2x[TiO_2/SiO_2]). A heavy-ion-irradiation shortens the absorption recovery time down to 5ps. The device operates in a reflective mode, the reflectivity being small at low signal levels, and high at high signal levels.

The intensity dependent loss of the Multiple Quantum Well Saturable Absorber (MQW-SA) is shown in Fig. 1. This was measured using a 10GHz 2ps Tunable Modelocked Laser (TMLL) at 1558nm in conjunction with an Erbium Doped Fibre Amplifier (EDFA). In saturation, the insertion loss of the device is ~7dB with 5dB of additional loss due to coupling. The unsaturated loss was 19dB, giving a contrast of 7dB. In the sampling experiments the signal under test on its own did not have sufficient intensity to saturate the MQW-SA and therefore experiences a large loss when incident on the device (19dB). However, in the presence of the sampling pulse the MQW-SA saturates allowing the signal to be reflected with reduced loss (12dB). This allows for the sampling of a short temporal section of the signal under test. Note that the 3dB saturation threshold of the MQW-SA is as low as 5dBm at the operating wavelength and repetition rate; consequently, the sampling can be operated at a high repetition rate (10GHz in this experiment), opening the possible use of this technique in real-time sampling [8].

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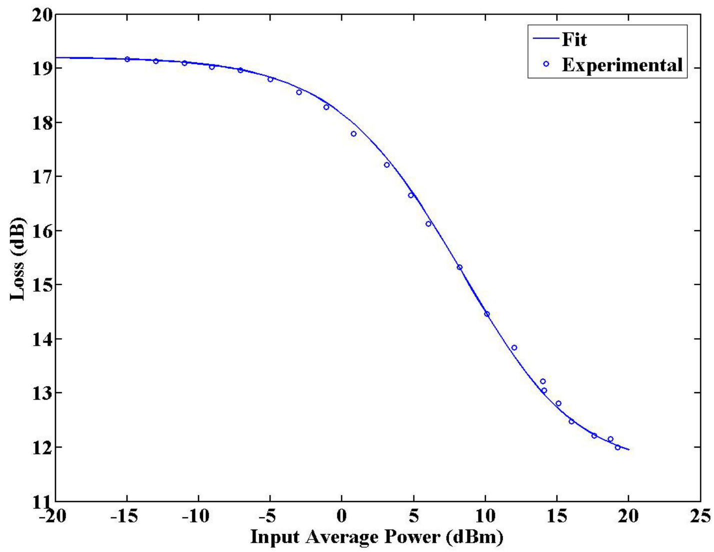

Fig. 1. Response of saturable absorber's loss to increasing average input power from a 10GHz ~2ps TMLL pulse at 1548nm.

2. Experimental Setup

The sampling setup used is shown in Fig. 2. The setup employed a 10GHz 2ps sampling pulse from a TMLL at 1558nm which was combined (using a 50/50 coupler) with the signal under test. The combined signal was then reflected off the saturable absorber via an optical circulator. An optical filter with a 5nm bandwidth centred at 1548nm was then used to remove the sampling pulse before the final measurement with a low speed detector. An Optical Delay Line (ODL) was used to adjust the delay between the sampling pulse and the signal under test and an EDFA was used to provide the necessary average power in the sampling pulse (12.7dBm). Computer control of the ODL and detector allowed measurements with a refresh rate of ~1Hz.

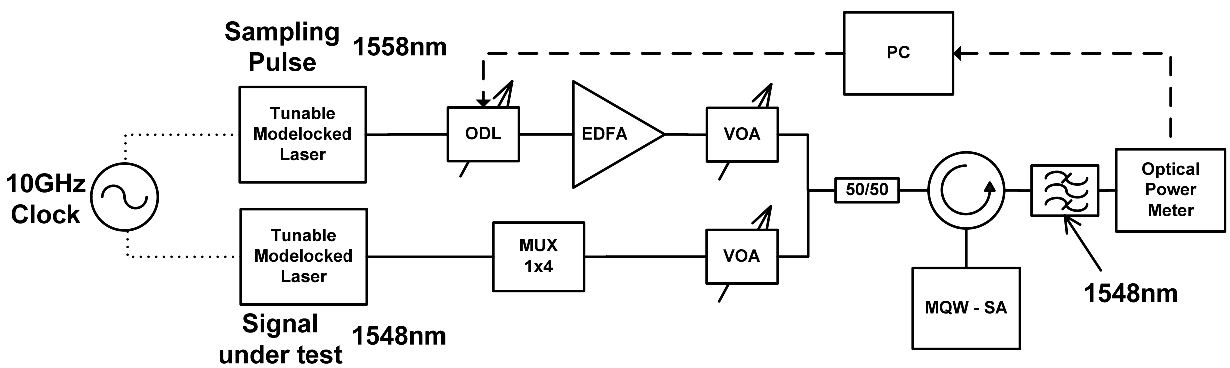

Fig. 2. Experimental setup used for the sampling of a 40GBit/s pulse train using a saturable absorber.

The signal under test was generated using a second 10GHz 2ps TMLL which was tuned to the saturable absorbers resonant wavelength of 1548nm. A 1x4 optical multiplexer was used to increase the line rate to 40GHz and allowed the relative position and amplitude of the multiplexed pulses to be adjusted. Variable Optical Attenuators (VOA) were used on both the sampling and signal pulses to control the optical power incident on the saturable absorber.

3. Results

Examples of the measurements of the 40GHz pulse train using both the MQW-SA and a commercial optical sampling oscilloscope (from Picosolve Inc.) are given in Fig. 3. In Fig. 3(b) bits 3 and 4 have been attenuated to study the behaviour of the optical sampling towards peak power variations thus highlighting the linearity of the measurement. For the MQW-SA setup the pulse width is overestimated because of the limited response time of the saturable absorber (5ps) and the short duration of the pulses (~2ps). This could be improved with the use of a faster saturable absorber such as those reported by M. Gicquel-Guezo et al. [9], which have response times of 290fs.

However, this experiment clearly shows the suitability of the technique for optical sampling as the measured pulses peak power of both techniques are in good agreement. In Fig. 3 the average sampling power was 12.8dBm while the average signal power was -10dBm, although measurements were made with reasonable signal to noise ratios with signal powers down to -20dBm.

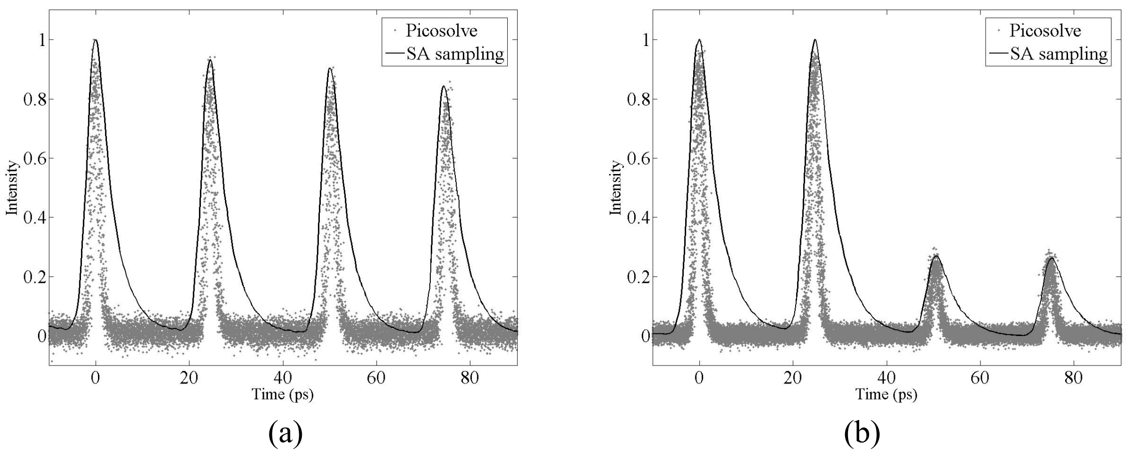

Fig. 3. Sampling of a 40Gbit/s pulse train using a saturable absorber. Results are compared with a commercial sampling oscilloscope that employs FWM (Picosolve).

4. Conclusion

We present for the first time the use of a multiple quantum well saturable absorber in a simple setup for the optical sampling of a 40GHz pulse train. The setup has several advantages over other techniques including its simplicity, polarization insensitivity and the potential for integration. The results were compared with a commercial sampling oscilloscope and showed good agreement. The use of the 7 additional channels on the saturable absorber allows for the possibility of simultaneous and independent sampling of multiple wavelength channels. By employing a faster saturable absorber this technique offers the potential to implement a simple optical sampling oscilloscope with a bandwidth approaching 500GHz.

5. References

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