Optical Burst Equalisation in Next Generation Access Networks

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Abstract: This paper presents an experimental demonstration of optical burst equalisation based on two stage amplification for next generation access networks. It also explores the possibility of reducing the non-linear effect produced under optical amplifier saturation.

1. Introduction.

A number of existing passive optical networks (PON) use packet data transmission to make efficient use of the bandwidth available. Packets at the receiver are at different amplitudes due to different optical power loss due to the packets being transmitted through different paths. Current optical networks require burst mode receivers, which adjust the detection threshold on a packet by packet basis. We propose a method for using a Semiconductor Optical Amplifier (SOA) to act as optical limiting amplifier. The difference in burst amplitudes can be reduced, allowing the bursts to have the similar detection threshold as shown in figure 1. The benefits of our method are that the need for a highly variable threshold detection is removed, possibly allowing standard receivers to be used, the detection system is simplified and the cost of the optical network unit (ONU) in the customer's premises is reduced. Although a simulation in [1] has shown a 16dB equalisation, it did not consider the heavy distortion to the signal by non-linear effects under SOA saturation. We showed that a form of optical filtering needs to be implemented to fully recover the signal.

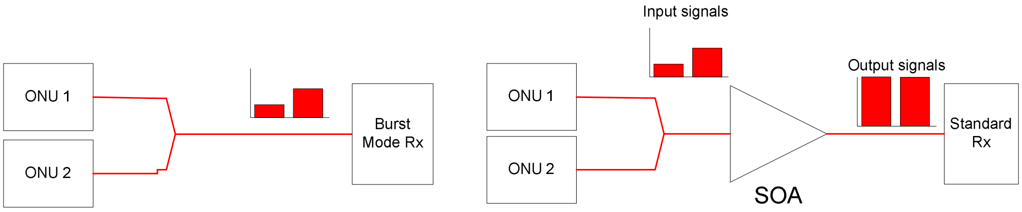

Figure 1 Optical Burst Equalisation allowing standard receiver to be used

2. SOA Saturation Characteristics

An SOA is a device similar to the semiconductor laser, its operation is also based on the stimulated emission process. The photons of the incoming signal will interact with the carriers in the conduction band (also known as level 2 or the excited state) and stimulate it to decay to the valence band (also known as level 1) in this quasi-two-level system, emitting another photon which can in turn cause another stimulated emission. Such a chain reaction will produce greater number of photons at the output of the amplifier than at the input, hence the unsaturated gain. The term unsaturated applies when there are enough excited carriers exist in the conduction band to provide gain to a small signal.

The important factor for stimulated emission to occur on a massive scale within the active medium of the SOA is population inversion, which requires the carriers in the SOA to be electrically pumped to the conduction band. When the input signal is so large that there are an insufficient number of carriers in the excited state, not all the photons in the incoming signal cause the stimulated emission, then the total gain of the with a large-signal case will be less than that of the small-signal case. The SOA is considered in saturation because the rate of carriers to be pumped to the excited state is limiting the rate of photon emissions and therefore limiting the gain [2].

SOAs therefore are non-linear devices, often used for signal processing because of its gain saturation characteristics. It can also be used as a device for all-optical power equalisation, also known as the Self Gain Modulation (SGM). In this case, the higher input powers experiences less gain due to the SOA's gain saturation, the lower input powers experiences normal gain so that these different levels of power can be equalised [3].

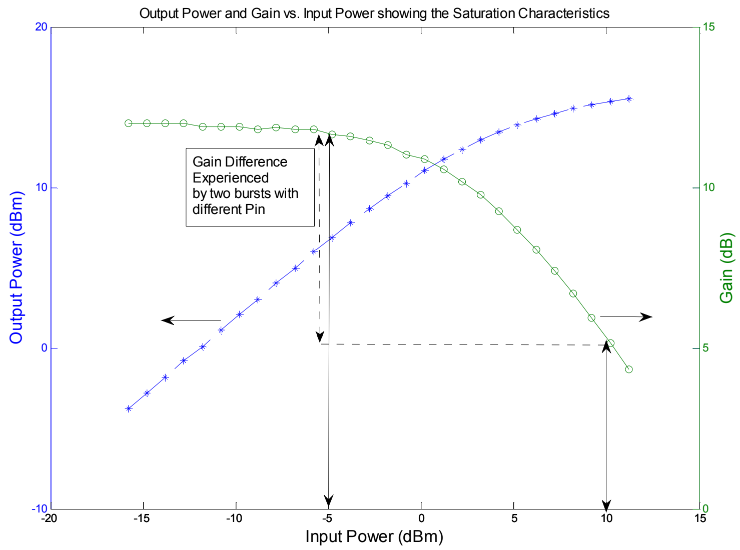

Figure 2 Output power and Gain vs. Input Power showing the saturation of the Booster SOA

The saturation characteristics of the SOAs used in the experiment were measured and presented in Figure 2. The booster amplifier result in Figure 2 shows that an input signal of power -5dBm will experience a gain of 11.8dB; and an input signal of power 10dBm will experience only 5dB gain, the two power difference between the two signals is reduced from 15dB to 8.2dB.

Modulated optical signals contain the energies carried by the binary “0s” and binary “1s”, for semiconductor lasers the energy emitted in the binary 0 bit period is larger than zero, with the value depending on the bias, threshold and drive current of the laser. This is due to the spontaneous emission from the laser when it is biased just below the threshold [4]. The Extinction Ratio (ER) is defined as the ratio between P_1, the power associated with the “1s” and P_0, associated with the “0s”. The SOAs amplifies both the energies of the “1s” and the energies of the “0”s and more so for the “0s” because of the Amplified spontaneous emission (ASE) noise, therefore keeping the ER high while amplifying/levelling the signals is desirable but will be difficult.

3. Reduce the effect of spectrum broadening

The combined effect of chirp in SOA and fibre dispersion resulted in spectrum broadening is shown in Figure 3. The broadening is a shift in frequency of the “0s” away from the centre peak frequency which is the energy of the “1s”, this may allow us to fully recover the data from the amplified signals, since a sharp optical filter can be placed before the standard receiver to remove the energy of the “0s” from the spectrum, effectively increasing the output signal’s extinction ratio.

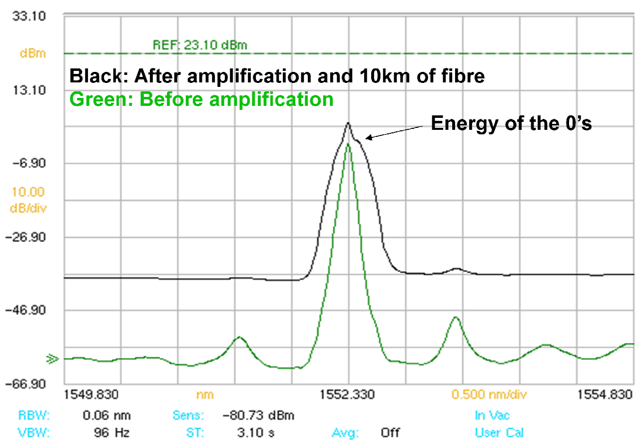

Figure 3 Spectral Broadening caused by nonlinear effects in SOA saturation

4. Experiment

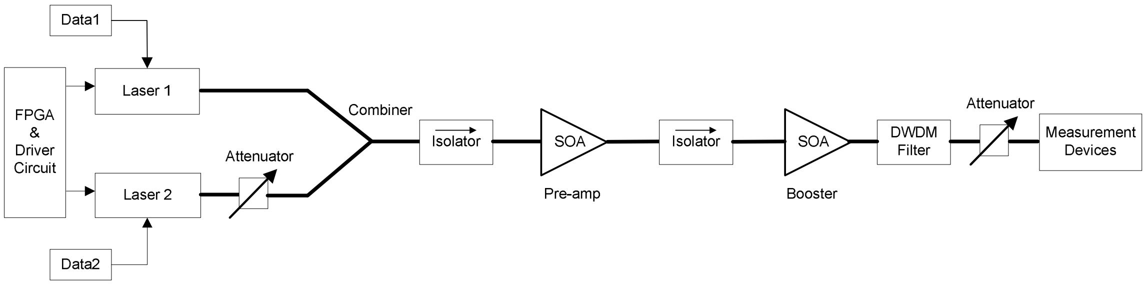

Figure 4 Burst equalisation system setup showing the two stage amplification

The test system configuration is shown in Figure 4. Two lasers are gated by two outputs from a Field-programmable gate array (FPGA) to simulate the burst from ONUs. Each packet is 125µs long, modulated by a data signal from a 10Gb/s Pseudo random bit sequence (PRBS) generator, 500ns guard time between the two bursts was used to prevent overlapping. A 5dB optical attenuator was placed after one of the laser output to simulate the optical path loss of a distant ONU, thus providing the power difference between the two ONUs. The two signals merge at the splitter/combiner just like they would in a real PON. The isolator before each SOA was there to prevent noise from the SOA travelling back to the laser. As described before, an optical filter is used to remove the energies of the "0s" from the received signal. In a real network the filter can be custom made or picked therefore it will be optimised for the network condition and will have better performances. A 10dB attenuator was place before the Digital Communications Analyser (DCA), because the power from the output of the SOA was too high for the photodetector in the DCA.

The aim of the system is to level the bursts and reduce the non-linear distortions in the signal, therefore being able to maintain or even improve the Extinction ratio at the output is desired.

Selecting the optimal filter cut-off frequency for the best ER is required. Since the AOC tech DWDM filters used in this experiment have a fixed filter characteristic and cut-off frequency, the filter is not frequency tuneable. By changing the laser diodes' control temperature with-in a reasonable range (25°C ± 20°C), we can tune the laser wavelength linearly to find the best ER near the cut-off of the optical filter, that wavelength (frequency) will be the optimal for our system.

5. Results and the effect of filtering

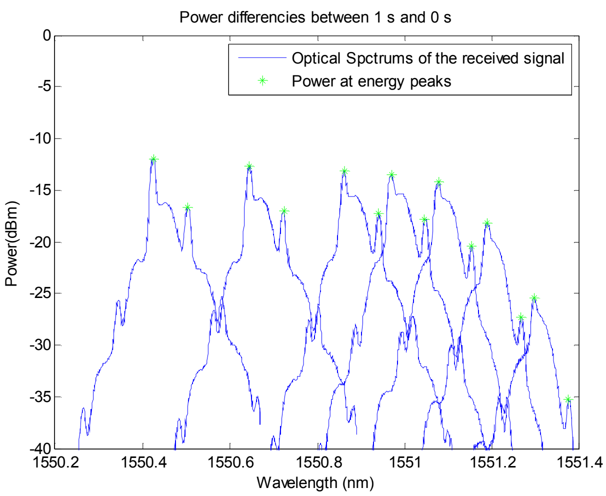

Figure 5 Optical power spectrum at detuned wavelengths

The results in Figure 5 are spectrums of the output optical signal measured by a spectrum analyser as the wavelength of the laser is tuned towards the optical filter edge. The difference between the energies of the "1s" and the energies of the "0s" is increasing towards the filter edge. A quantitative analysis of this data provides us with Figure 6, it compares the power differences and extinction ratio measured from the DCA with the measured filter response.

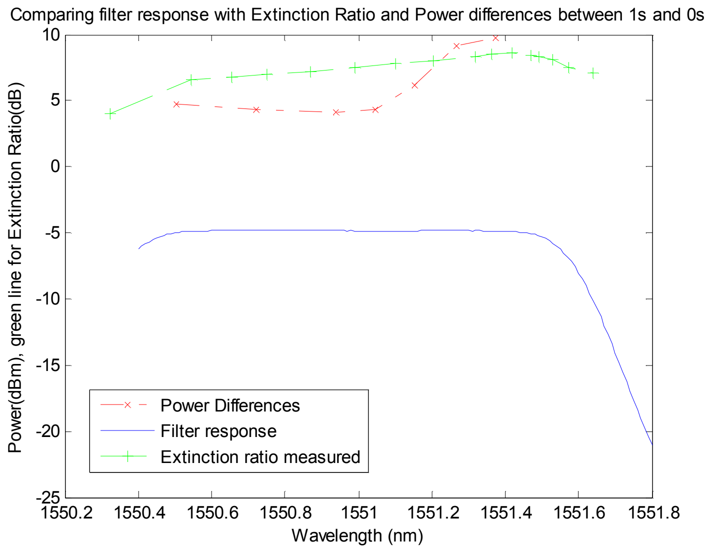

Figure 6 Comparing filter response with ER and Power differences between energies of the "1s" and "0s"

From Figure 6, it can be seen that the Extinction Ratio increased by 2dB near the edge of the filter cut-off at about 1551.5nm. The Extinction Ratio then decreases because of the wavelength has move further into the filter cut-off resulting in the data being filtered, causing a reduced Extinction Ratio. The power difference is plotted as the X in the figure showing a significant rise of the difference in power near the filter edge.

6. Conclusions and future work

In this experiment we tested the idea of using SOA as a limiting amplifier to level the bursts that had a 5dB difference in input power, which translates to about 25km of fibre distance between two ONUs assuming we used a 0.2dB/km loss single mode fibre. The dynamic range of the system at 5dB is still not high enough, considering the split loss and fibre loss of a real PON network can be as high as 22dB or more. A SOA model will need to be developed so that it can successfully model the nonlinear effects as well as the gain saturation characteristics of the real device. By using a SOA model in OptSim we hope to test a PON access network in simulation with the implementation of the burst equalisation mechanism in place.

References

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