Derivation of the amplitude histogram of an optical signal using an optical 2R regenerator

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Abstract *We propose a novel method to construct asynchronous histograms of optical signals using the non-linearity of a 2R regenerator. Simulation results based on experimental regeneration curves are presented, and a quality factor is defined.*

Introduction

It is obvious that optical signal monitoring is a key to the realisation of the future all optical network (AON). It can be used in fault localisation, to guarantee service level agreements, to support the network management, etc.

It has been shown that amplitude histograms can be very useful for the extraction of signal quality measures [1]-[3]. This in contrast with e.g. the monitoring of the OSNR, since the relation between the OSNR and the BER disappears once non-linear components (e.g. wavelength converters) are used on the communication link.

In general there are two different types of histograms, asynchronous and synchronous histograms. Synchronous histograms represent the probability distribution of the amplitudes of a signal on a certain, fixed moment within a bit, an asynchronous histogram on the other hand is a collection of the distributions on all possible moments within a bit. This means that the latter contains a fraction of redundant information (e.g. the flanks of the bits), but more important is that no timing information is needed for its construction, in contrast with the synchronous case. Asynchronous histograms have been shown useable for the detection of signal degradations due to crosstalk, noise and pulse distortion [1], even an estimate of the BER can be calculated in some cases [2], [3].

All the methods for constructing a histogram presented so far made use of sampling systems, complex data processing and/or high frequency electronics, e.g. [2]. Our method suffers from none of these limitations, since we derive an asynchronous histogram in a fairly simple way, making use of the non-linear transfer characteristic of an optical 2R regenerator. This method has the property of being bit rate and coding format independent, and is therefore a potential candidate for monitoring in the AON.

Principle of the monitoring

Our technique is based on sending the optical signal through a 2R regenerator with nearly ideal decision characteristic. Detection of the DC component of the output signal gives a measure of the fraction of time during which the signal power is higher than the decision threshold.

If this procedure is repeated for different decision thresholds (if this is possible), or for different attenuations, or for different CW signals added to the signal, one can then after some calculations derive the time fractions during which the signal power is in a certain power range. These time fractions are taken as a measure for the probability, and together make up the histogram. Figure 1 illustrates the method, based on a combination of signal amplification and CW power addition. After N measurements this results in a system of N linear equations in N unknowns, the probabilities.

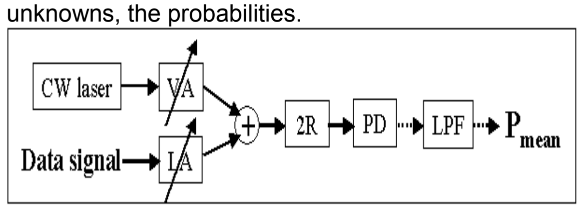

Figure 1: Illustration of the used configuration. VA: variable attenuator, LA: linear amplifier, 2R: a 2R regenerator, PD: photodiode and LPF: low pass filter.

With a perfect step-like regenerator function and accurate power measurements one can theoretically obtain the histogram to any degree of accuracy. In practice however, regenerators don't provide step-like transfers and power measurements show some inaccuracy.

Feasibility study

Simulations were carried out to check the feasibility of the above-described algorithm, and to define the requirements that have to be fulfilled such that a practical component could be useful. In those simulations we always used experimentally obtained transfer characteristics.

From the simulations it became clear that the robustness of the method depends heavily on the specific part of the regenerator curve covered by the signal power during the different iterations. This is caused by the fact that the system-matrix is completely determined by the regenerator curve, in combination with the chosen intervals. Intuitively it's clear that the stronger the non-linearities felt by the signal during the sweep, the more accurate the resulting histogram will be.

Mathematically we can express the robustness of the method by means of the condition number K of the system-matrix. The value of K represents the extent of the influence of errors made in the system-matrix and the measured mean powers on the solution of the system. [4] From the simulations a distinct correlation was observed between the accuracy of the obtained histogram and the value of the corresponding condition number.

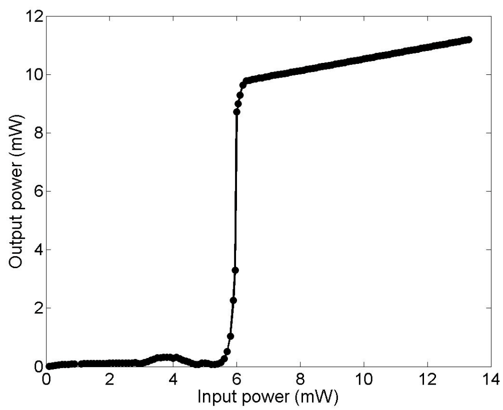

Figure 2: Experimental obtained transfer characteristic of the 2R regenerator described in [5] based on a MZI with a GCSOA in each arm.

After examination of the condition number of different regenerator configurations, it turned out that the one described in [5] was the most appropriate. The experimentally obtained regenerator characteristic we used in our simulations is depicted in figure 2. The great potential of this component in the described configuration is twofold. First there is a very steep transition between the digital ‘0’ and a digital ‘1’ and in addition the power difference between both output levels is rather large. This results in significant differences between subsequently measured mean powers, and thus enhances the robustness.

Assuming we decrease the added CW power during the different steps of the algorithm, we found that the best initial power range of the signal is such that the minimum power of the signal is more or less equal to 6 mW. For the maximum power, it’s sufficient that this is larger than e.g. 10 mW. The larger this is chosen, the more intervals can be calculated, because the minimum interval width is fixed. So, in practical applications, one should amplify or attenuate the original signal, and add some CW power afterwards, such that the resulting power range is mapped onto this power range.

The fact that the optimal initial minimum is located right on the transition between ‘1’ and ‘0’ is logical, because in this way the whole signal is swept over this transition during the measurement cycle.

An example of a histogram, obtained with the above mentioned regenerator characteristic is depicted in figure 3. The low bit rate, PRBS-NRZ signal was generated using Matlab and the exact histogram is depicted by the full line in figure 3. We used a realistic signal with gaussian distributions on both zero and one level, and with rise and fall times of 1/10 of the bit period. The interval width was chosen to be 0.15 mW, which in combination with the initial power span of approximately 5 mW results in a good, meaningful histogram. The obtained histogram must be accurate enough to detect signal degradations due to crosstalk, noise and pulse distortion, similar to [1].

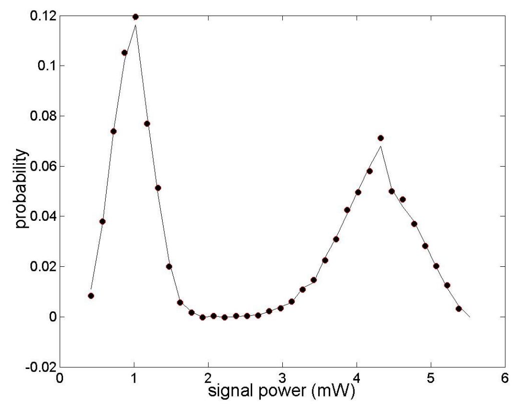

Figure 3: Example of an obtained signal histogram (dots). The full line represents the exact histogram as obtained by Matlab.

Figure 2 and hence also figure 3 were obtained at very low bit rates. The maximum bit rate at which the described method will work, will be limited to the speed at which the used regenerator still works well.

Conclusion

We proposed a fairly simple method to derive an asynchronous amplitude histogram. A quality measure for the method is defined, which can be used to identify potential useful regenerator configurations. Simulation results, but based on experimental regeneration curves were presented, and full experimental verification will follow.

Acknowledgement

Part of this work was carried out in the context of the IST-STOLAS project supported by the European Union and of the Belgian IAP PHOTON network.

Sam Verspurten thanks the Flemish Institute for the industrial advancement of scientific and technological Research (IWT) for a doctoral grant.

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