Optimization of an Optical Single Sideband Transmitter

Tiago Maia, Rui Ribeiro, Paulo Monteiro

***Resumo* - O crescente interesse na modulação de sinais em banda lateral única para transmissão digital de informação em fibras ópticas, deve-se à melhor eficiência do espectro do sinal e à redução da distorção produzida pela dispersão cromática da fibra.**

Neste artigo é analisado o impacto da profundidade de modulação, e é estudada a implementação do filtro de Hilbert no emissor, com o intuito de optimizar o desempenho de um sistema óptico. Para o sistema óptico a 10 Gbit/s estudado, concluiu-se que o valor óptimo obtido para a profundidade de modulação é de 0.2, e que um filtro de Hilbert com 4 baixadas e um atraso temporal elementar de 37.5ps, mostra-se adequado.

***Abstract* – The interest in single sideband modulation for transmission of digital data along optical fibers is growing, since it allows an improvement on the signal spectral efficiency and a reduction on the distortion produced by the fiber chromatic dispersion.**

In the optical single sideband transmitter the influence of the Hilbert filter configuration and the modulation depth were analysed in order to optimize the performance of the optical system. For the 10 Gbit/s optical system presented, an optimum value of 0.2 is obtained for the modulation depth and a 4-tap transversal filter structure with an elementary time delay of 37.5ps is shown to be an appropriate solution to implement the Hilbert transform.

I. INTRODUCTION

In order to reduce the effects of the chromatic dispersion the transmission of optical single sideband signals has received great interest in the last few years.

The bandwidth of optical single sideband (OSSB) signals is approximately one half of the corresponding conventional double sideband signals. This bandwidth reduction improves the signal tolerance to the fiber chromatic dispersion and permits a higher channel density in wavelength division multiplexing (WDM) networks. Furthermore, if the OSSB signal is combined with the corresponding carrier, then its optical direct detection can be taken as a self-homodyne detection. This technique preserves the phase information in the detected signal and therefore permits linear dispersion equalization in the electrical domain.

The difficulty with most of SSB transmission techniques [1] is that they require filter designs, which are matched to the frequency separations of interest and are therefore limited in bandwidth [2,3,4]. A new approach is proposed by [5] in which is possible to generate optical SSB signals in digital band or in sub carrier's applications. Moreover in self-homodyne OSSB systems that make use of this technique the modulation depth of the transmitted signal is a crucial parameter. The influence of the modulation depth for a 10 Gbit/s system with different transmission lengths is investigated based in simulation experiments, and the optimum value is found.

In Section II, it's described the complete optical system link studied, in particular the optical source technique for SSB transmission. In Section III the simulation results demonstrate the influence of the modulation depth and the filter time delay on the performance of an optical system at 10 Gbit/s. The concluding remarks are given in Section IV.

II. SYSTEM MODEL

The system that was carried out through the simulation is presented in figure 1. In this system, a master optical carrier at 1550 nm is generated by a laser diode. The OSSB modulation is based on the Hartley concept [6], where combinations of the information signal and its Hilbert transform modulate two quadrature optical carriers. The modulation circuit consists in a dual arm Mach-Zehnder (MZ) modulator followed by a phase modulator. The electrical waveforms required to drive the two modulators, in order to generate a chirp-free OSSB signal, are described in [5,7]. If this optical signal is attached to a photodiode, which corresponds to square-law detection, then the electrical signal at the detector output will be given by (1), where the Taylor series has been used to expand the signal till the third order. In (1), $m(t)$ represents the binary information sequence, a pseudo-random sequence at 10 Gbit/s in our experiments, with levels of +0.5 and -0.5 for the two binary digits, and $\hat{m}(t)$ is its Hilbert transform; V_π is the modulator's switching voltage. The magnitude of the signal modulation can be strained by the parameter *x*, which hereafter will be designed by *modulation depth*.

Hilbert transform filter is used. In these spectra, the suppression of the lower side band is clear, as well as the presence of the optical carrier.

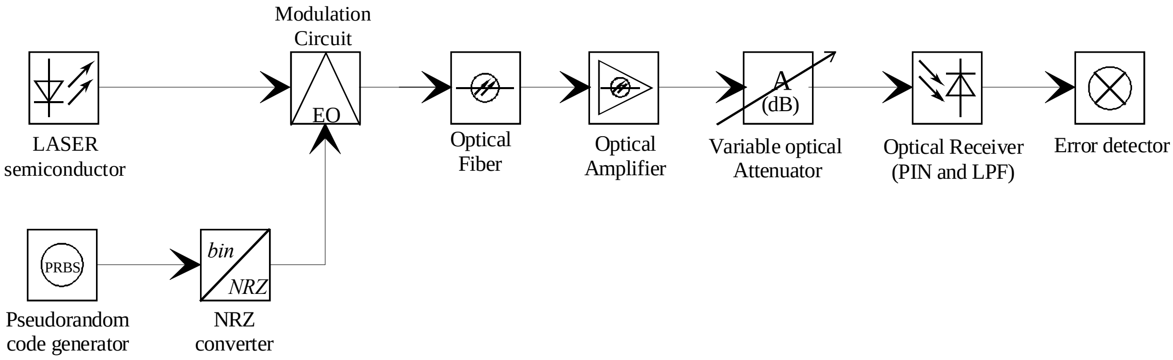

Fig.1 - Optical SSB system configuration.

$$\left|Eout(t)\right|^2 = \frac{1}{2} + xV_\pi m(t) - \frac{2}{3}\left(xV_\pi\right)^3 m^3(t) + \frac{1}{4}\left(xV_\pi\right)^3 m(t)\hat{m}^2(t) + \ldots \quad (1)$$

From (1) it can be seen that the information signal *m(t)* is present in the detected electrical signal, but there are other terms that are potential sources of interference. In the absence of fiber chromatic dispersion, the second order powers of the signal cancel out, as it can be seen in (1), but this is no more observed in the presence of chromatic dispersion. Since the magnitude of the undesirable terms in the detected signal is proportional to higher powers of the modulation depth *x*, the value for this parameter should be kept small.

An approximation of the data Hilbert transform, which is required by the phase modulator in the SSB signal generation, is obtained by filtering the original information signal with a tapped delay filter [5]. The discrete approximation of the Hilbert filter is shown in figure 2. The cell delay to produce the Hilbert transform is in fact 2T. The central tap added to the circuit allows to append the carrier to the modulated signal. To obtain only the Hilbert transform, the α parameter in figure 2 should be null.

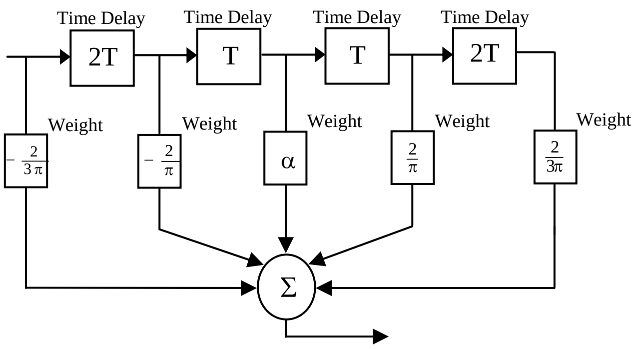

Fig. 2 – 4-tap Hilbert filter.

Figure 3 shows the power spectrum of the OSSB signal for a modulation depth of 0.2 and a filter time delay (T) of 37.5 ps, generated by our system model. In the same figure is show the spectrum obtained when an ideal

In our system model, a single mode optical fiber has been attached to the optical transmitter, followed by an optical amplifier that compensates the fiber attenuation. The transmitted signal is then detected by a photodiode and processed by a lowpass filter. A linear electrical equalizer pursues the lowpass filtering, which is based on a small–signal analysis and gives rise to a transfer function that inverts the effect of the fiber chromatic dispersion. An error rate estimator, based on a gaussian approximation for the signal distribution, completes the system. The receiver sensitivity implies a bit error rate of 10^{-9}. The simulation tests of the optical SSB transmission system where carried out through a simulator known by *Photonics Transmission Design Suite* (PTDS).

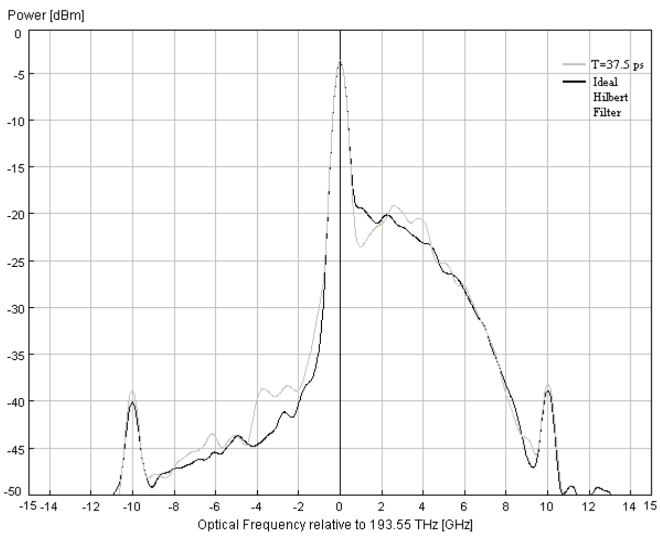

Fig. 3 – Simulated optical spectrum for SSB signals at 10 Gb/s (Gaussian Bandwidth resolution: 0.5 GHz).

III. TRANSMITTER OPTIMIZATION

The optical direct detection of the signal in the presence of the carrier results, actually, in self-homodyne detection. At the receiver, the term of interest will be the beat signal between the carrier and the SSB signal. Other components, of higher order, appear in the detected signal, which corresponds to signal distortion and thus undesirable. As discussed above, a small value for the modulation depth permits us to limit the power within these unwanted components. However, it also implies a larger fraction of the available power attributed to the carrier, in opposition to the information signal component. Nevertheless, the carrier presence is always necessary in order to obtain self-homodyne detection. Therefore, the optimum value for the modulation depth *x*, is achieved by a trade-off between distortion and effective signal power.

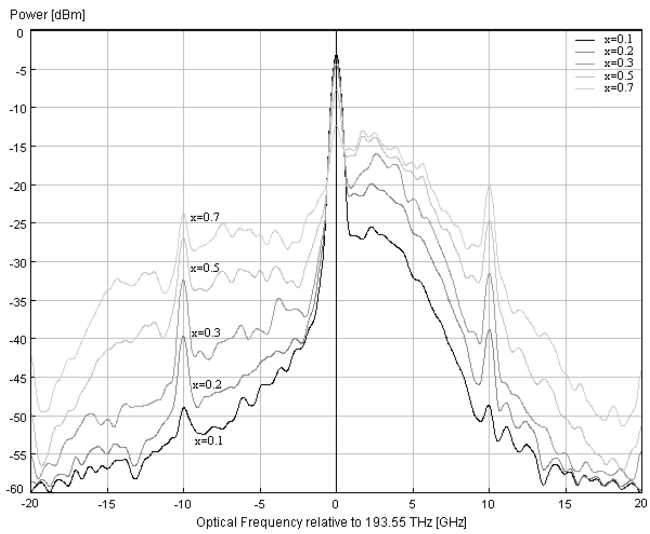

Fig. 4 – Transmitter output power spectrum for different modulation depth values (Gaussian Bandwidth resolution: 0.5 GHz).

The power spectrum at the transmitter output is plotted in figure 4, for several modulation depths. In all the curves, it can be observed the strong attenuation suffered by the frequency components below the center frequency, characteristic of an upper single sideband signal. The optical carrier presence is also evident.

The receiver sensitivity versus modulation depth for several system configurations is shown in figure 5.

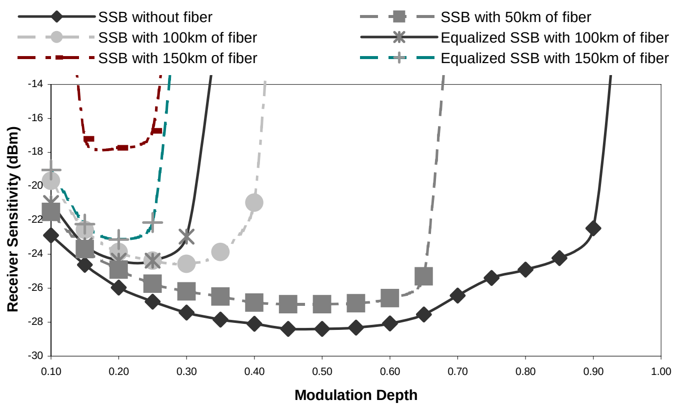

Fig. 5 – Simulated receiver sensitivity versus modulation depth in a 10 Gb/s optical system with a BER of 10^{-9}.

Without optical fiber, the optimum modulation depth is 0.5. This value corresponds to an intensity-modulated signal with an extinction ratio of 100% at the MZ modulator output. As the modulation depth deviates from that value the higher will be relative power attributed to the carrier, which does not contain any information. When 50 km of fiber are considered, without dispersion equalization, the system sensitivity is close to the preceding case for small values of the modulation depth, and the optimum value for this parameter still is 0.5. However, now the sensitivity decays abruptly when the modulation depth exceeds 0.6. The sensitivity degradation is attributed to the presence of the second order terms in the detected signal, which do not cancel out as in the case without fiber. The distortion due to chromatic dispersion and the optical amplifier noise represent other negative contributions to the receiver sensitivity.

The harmful effect of chromatic dispersion is more pronounced for larger fiber lengths. Figure 5, shows the cases of systems with 100 and 150 km of fiber without dispersion equalization. In addition to the observable degradation in the system sensitivity, the optimum value for the modulation depth is also significantly reduced, to a value of about 0.2 in both cases. Figure 5 also presents results for equalized systems with the two above fiber lengths. For these systems, the optimum modulation depth value is again in the vicinity of 0.2. As it can be seen in figure 5, the dispersion equalization is efficient for small values of the modulation depth. For higher values, other phenomena dominate the distortion and the small-signal-based equalization becomes useless. In summary, 0.2 is a suitable value for the modulation depth in OSSB systems regardless of using or not electrical equalization.

The optimization of the transversal filter that implements the Hilbert transform was also performed. A number of 4-tap shows to be a good compromise between circuit complexity and efficiency. Although additional taps do improve the filter amplitude response, the corresponding impact on the optical system performance is negligible.

The influence of the time delay used in the 4-tap Hilbert filter was as well investigated. The receiver sensitivity versus fiber length for different tap delays of the filter is plotted in figure 6. These experiments demonstrate that

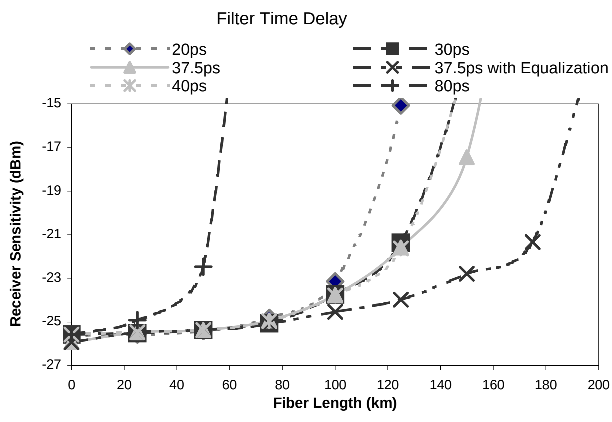

Fig. 6 – Simulated receiver sensitivity versus fiber length at a BER of 10^{-9}.

the system performance is surprisingly tolerant to the filter time delay, particularly for fiber lengths below 100 km. Nevertheless, the optimum value found for that parameter was 37.5 ps.

IV. CONCLUSIONS

Simulation experiments are used to assess the feasibility of OSSB systems using self-homodyne detection. The experiments revealed that the electrical waveforms of the drive signals, required by the transmitter modulators, play a critical role on the system performance. Particularly important is the modulation depth. The present study recommends a modulation depth of 0.2 in order to obtain the best performance. The number of cells and the tap delay used in the discrete approximation of the Hilbert filter were also optimized, resulting in a 4-tap with a time delay of 37.5 ps.

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REFERENCES

[1] Lee T. Nichols and R. D. Esman, “Single sideband modulation techniques and applications”, OFC/IOOC 1999.

[2] J. Parj, W. V. Sorin, and K.Ylau, “Elimination of the fiber chromatic dispersion penalty on 1550nm millimeter-wave optical transmission”, Electronic Letters, vol. 33, pp 512-513, 1997.

[3] Kazushige Yonenaga and Noboru Takachio, “A Fiber Chromatic Dispersion Compensation Technique with an Optical SSB Transmission in Optical Homodyne Detection Systems”, IEEE Photonics Technology Letters, vol. 5, No 8, pp 949-951, August 1993.

[4] R. Hofstetter, H. Schmuck and R. Heidemann, “Dispersion effects in optical millimeter-wave systems using self-heterodyne method for transport and generation”, IEEE Trans. Microwave Theory Tech., vol.43, pp 2262-2269, 1995.

[5] Mike Seiben, Jan Conradi and David E. Dodds, “Optical Single Sideband Transmission at 10Gb/s using Only Electrical Dispersion Compensation”, J. of Lightwave Technology, vol. 17, No 10, pp 1742-1749, October 1999.

[6] Bob Davies, Jan Conradi “Hybrid Modulator Structures for Subcarrier and Harmonic Subcarrier Optical Single Sideband”, IEEE Photonics Technology Letters, vol. 10, No 4, pp 600-602, April 1998.

[7] Edgardo Costa, Antonio Pinho, Paulo Monteiro, Rui Ribeiro, J. Fereira da Rocha and Tiago Maia, “Transmissão de sinais ópticos em banda lateral única, com igualação no domínio eléctrico utilizando o crtério dos zeros forçados, para sistemas a 10 Gbit/s”, submitted to the present issue in this journal.