# Optimized Pulse Shaping for Mitigating Optical Nonlinearity

**Benoît Châtelain[1], Odile Liboiron-Ladouceur[1], François Gagnon[2], David V. Plant[1]**
[1]*McGill University, 3480 University Street, Montreal, QC, Canada, H3A 2A7*
[2]*École de technologie supérieure, 1100 rue Notre-Dame Ouest, Montreal, QC, Canada, H3C 1K3*
*Email: benoit.chatelain@mail.mcgill.ca*

**Abstract**: A new pulse shape for optical nonlinearity mitigation is proposed. Realistic simulations show that a 2.3 dB increase in launch power can be obtained, at no extra cost.

**OCIS codes:** (060.2330) Fiber optics communications; (060.4080) Modulation

## 1. Introduction

Self phase modulation (SPM) in single mode fiber optic links can be compensated by electronic pre-compensation [1], electronic post-compensation [2], or a mixture of pre- and post-compensation [3]. Backward propagation is used in [1] and in [2] to solve the inverse nonlinear Schrödinger equation, at the expense of a very high computational cost. A reduced complexity SPM compensation scheme is proposed in [3], but it requires digital signal processing both at the transmitter and receiver. To various degrees, the efficiency of these three algorithms relies on the knowledge of the fiber characteristics. This limits their practical applicability, since accurate estimation of fiber parameters is not easily achieved in a real-world wavelength division multiplexing (WDM) transmission scenario. In this paper, a SPM mitigation approach for electronically pre-compensated systems is proposed. It is based on the search of pulse shapes that are tolerant to nonlinearity and does not require information about the optical channel.

## 2. Pulse Shape Optimization

It is well known that the return to zero (RZ) pulse shape is the most robust to fiber nonlinearity. However, it has a baseband bandwidth of twice the data rate, resulting in a poor spectral efficiency and an increased sensitivity to optical add-drop multiplexer concatenation. Furthermore, following Nyquist's sampling theorem, an electronic pre-compensation system running at a 10 Gbps data rate using a RZ pulse would require a digital-to-analog converter (DAC) clock speed of at least 40 GHz. Current state of the art 6-bit DAC clock speed is limited to 22 GHz [4], which render impossible the generation of a RZ sequence. The raised cosine (RC) pulse shape, with a baseband bandwidth that is equal to the data rate, is thus usually used in electronic pre-compensation systems. For nonlinearity tolerance, the goal of the pulse optimization algorithm is set to obtain a pulse shape that resembles the most to the RZ pulse in time domain but that has similar spectral characteristics to the RC pulse. More precisely, the objective function is to maximize the energy of the pulse between -1/2$T$ and 1/2$T$, where $T$ is the symbol period. The main constraint is that the passband of the optimized filter should be inferior to the data rate. The optimization objective function is expressed as:

$$\text{maximize} \quad f(t,f) = \alpha \frac{\int_{-T/2}^{T/2} s(t)^2\,dt}{\int_{-T\cdot M/2}^{T\cdot M/2} s(t)^2\,dt} + \beta \frac{\int_0^R S(f)^2\,df}{\int_0^{1/(2T/N)} S(f)^2\,df}, \qquad (1)$$

where $M$ is the number of data symbols covered by the pulse $s(t)$, $N$ is the oversampling rate, $R$ corresponds to the data rate ($R$=1/$T$ ) and $S(f)$ is the Fourier transform of $s(t)$. The optimization problem is solved by the SQP algorithm [5]. Fig. 1 shows the impulse and frequency response of the obtained pulse shape for $M$=32, $N$=4, $\alpha$=100 and $\beta$=1.

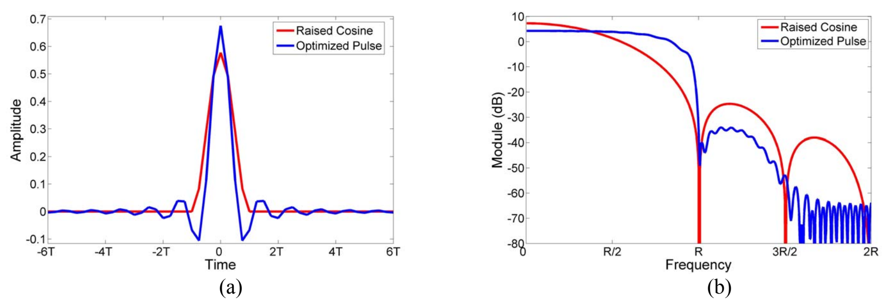


Figure 1. Impulse response (a) and frequency response (b) of the raised cosine pulse with a roll-off factor of 1 and of the optimized pulse.

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### 3. Simulation Results

Fig. 2 shows the considered optical communication system. The data rate is 10 Gbps at a wavelength of 1550 nm, with a total fiber length of 1600 km, a span length of 80 km, a fiber attenuation of 0.2 dB/km, a dispersion of 17 ps/nm/km, a dispersion slope of 0.08 ps/nm$^2$/km, an effective area of 80 μm$^2$, and a nonlinear refractive index of $2.67\times10^{-20}$ m$^2$/W. The laser linewidth is 1 MHz, the Mach-Zehnder extinction ratio is set at 20 dB and the peak amplitude of the signal at the output of the DACs corresponds to 87.5% of $V_\pi$. The EDFA gain and noise figure are adjusted to 16 dB and 6 dB, respectively. To highlight the effect of SPM, polarization mode dispersion is not considered and the DAC is modeled with a 16-bit resolution. Simulations are carried out using OptiSystem 7.0 for a binary data sequence of $2^{16}$ symbols, at an optical sampling rate of 40 GHz (4 samples per bit).

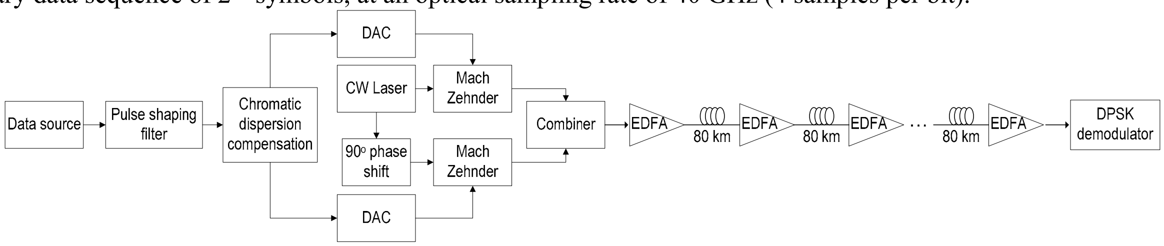


Figure 2. System functional block diagram.

Fig. 3 shows that compared to the RC pulse, the optimized pulse is both more tolerant to noise and nonlinearity. The launch power window is increased from 2.1 dB to 6.3 dB, for a forward error code (FEC) threshold of $1\times10^{-3}$. Fig. 3 also indicates that the use of the optimized pulse increases by 2.3 dB the maximal launch power. Furthermore, the required OSNR for error free transmission is reduced from 12.2 dB to 10.3 dB.

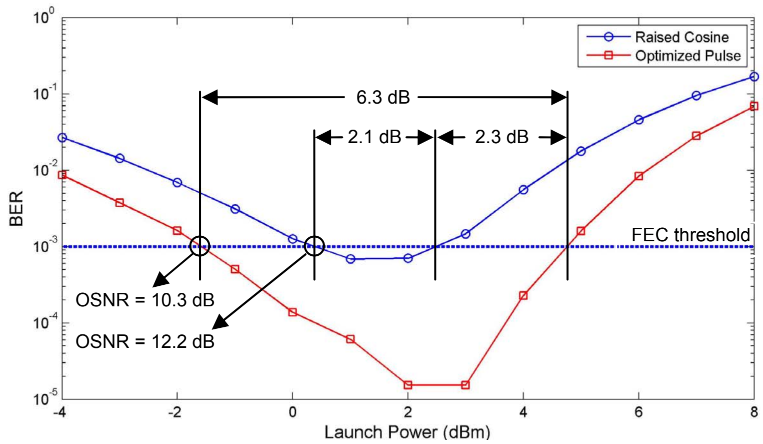


Figure 3. Bit error rate (BER) versus launch power.

### 4. Conclusion

A simple and efficient scheme for SPM compensation was proposed. The present work considers DPSK modulation at 10 Gbps but it should be noted that the optimized pulse shape can be used with any modulation type that requires pulse shaping, at any data rates. The proposed method can either provide additional margins in the system design or increase the optical reach. Moreover, since the optimized pulse shape replaces the original pulse shaping circuit, this method is implemented at no hardware or computational cost. Preliminary simulation results show that the optimized pulse shape also reduces cross-phase modulation (XPM) effects.

The authors would like to acknowledge the NSERC/Bell Canada Industrial Research Chair Program.

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