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Influence of current pulse shape on directly modulated system performance in metro area optical networks

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ABSTRACT

Due to the fact that a metro network market is very cost sensitive, direct modulated schemes appear attractive. In this paper a CWDM (Coarse Wavelength Division Multiplexing) system is studied in detail by means of an Optical Communication System Design Software; a detailed study of the modulated current shape (exponential, sine and gaussian) for 2.5 Gb/s CWDM Metropolitan Area Networks is performed to evaluate its tolerance to linear impairments such as signal-to-noise-ratio degradation and dispersion. Point-to-point links are investigated and optimum design parameters are obtained. Through extensive sets of simulation results, it is shown that some of these shape pulses are more tolerant to dispersion when compared with conventional gaussian shape pulses. In order to achieve a low Bit Error Rate (BER), different types of optical transmitters are considered including strongly adiabatic and transient chirp dominated Directly Modulated Lasers (DMLs). We have used fibers with different dispersion characteristics, showing that the system performance depends, strongly, on the chosen DML–fiber couple.

1. Introduction

The proliferation of high-bandwidth applications has motivated a growing interest, between network providers, on upgrading networks to deliver broadband services to homes and small businesses. There has to be a great efficiency between the total cost of the infrastructures and the services that can be offered to the end users, very sensitive to equipment costs, requiring the use of low-cost optical components. Coarse Wavelength Division Multiplexing (CWDM) is an ideal solution to the tradeoff between cost and capacity. This technology uses all or part of the 1270 to 1610 nm wavelength fiber range with an optical channel separation of about 20 nm. This channel separation allows the use of low-cost, not cooled, Directly Modulated Lasers (DMLs). The broadening of the transmitted pulse due to the propagation in a dispersive media, as the optical fiber is, produces one of the main limitations for the length or the transmission bit rate of an optical communication link. The pulse broadening, after being propagated by a distance through the fiber, is a function of different factors, like the initial shape of the pulse, the chirp associated with and the dispersive characteristics of the optical fiber [1].

In directly modulated systems, the shape of the pulse propagated through the fiber depends, mainly, on the electric pulse applied to the optical source (modulation current) and the dynamic response of the laser for large-signal inputs. The Non Return to Zero (NRZ) format is most often used in practice for the modulation current of the resulting optical bit stream. Ideally, the NZR electrical pulses are rectangular with abrupt rise and fall edges; in practice, these pulses are nonideal and which rise and fall edges are mathematically modeled with sine, exponential, gaussian, etc expressions.

The frequency chirp for large-signal modulation can be determined from the shape of the modulated signal. If we are interested in minimizing the frequency chirp, it is mandatory to perform a study that involves the output waveforms in order to predict which of them produces the lowest chirp. We can then tailor the current input signal accordingly.

On the other hand, the best part of the theoretical studies related to the transmission of pulses across an optical fiber suppose, for analytical simplicity, is that the generator of electrical pulses provides a gaussian shape in time.

In this work, by software simulations, the consequences of non-ideal pulse generator are analyzed. Also, we present results about how to optimize the transmission performance of an optical communication system depending on the modulation current used for the laser. To do this, the shape of the current input signal is modeled according to different mathematical expressions (sine, exponential, gaussian, etc).

Since already it has been mentioned, there are other system elements and parameters affecting the shape of the transmitted optical pulse, mainly the DML output optical power and the dispersive characteristics of the optical fiber. Due to this fact, in this work, we

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have used two types of optical fiber; the already laid and widely deployed, single-mode ITU-T G.652 fiber (SMF) and the ITUT-T G.655 fiber with a negative dispersion sign around the C band (NZ-DSF); in all simulated cases, a peak power for the "1" bit between 0.1 and 10 mW has been considered.

This paper is organized as follows: Section 2 is dealing with the theoretical background where the subject of this paper is based; Section 3 represents the system model where the different types of fibers, DMLs and modulation current are simulated. In Section 4, we analyze the results obtained with the simulations. Finally, the conclusions are summarized in Section 5.

2. Simulation methodology

To analyze a directly modulated WDM system, in order to optimize its transmission performance, a basic link is considered (see Fig. 1). A block diagram of the directly modulated transmitter to be considered is illustrated in Fig. 2.

The injected laser current is given by the expression:

$$I(t) = I_b + \sum_{k=-\infty}^{\infty} a_k I_p(t-kT) \quad (1)$$

where I_b is the bias current, T is the period of the modulation pulse, the sequence of bits transmitted ($a_k = 1$ (0) if a binary one (zero) is transmitted during the k_{th} time), and $I_p(t)$ is the applied current pulse.

In a free-chirp source, the optical power output pulse of the laser, $P(t)$, is given by

$$P(t) = \eta_0 \cdot \frac{h\nu}{q} \cdot \sum_{k=-\infty}^{+\infty} a_k I_p(t-kT) \quad (2)$$

where η_0 is the differential quantum efficiency of the laser, $h\nu$ is the photon energy at the optical frequency ν, and $I_p(t)$ is the applied current pulse.

However, expression (2) is not applicable in the case of directly modulated sources where the injected current that modulates the laser, introduces a shift in the emission frequency (chirp frequency). As a consequence, the optical power output pulse is not a linear transformation of the applied current pulse.

The optical power and the chirping response of the semiconductor laser to the current waveform $I(t)$ are determined by means of the large-signal rate equations [2], which describe the interrelationship of the photon density, carrier density, and optical phase within the laser cavity.

Thus, the chirp associated with the output of the laser can be formulated by

$$\Delta\nu(t) = \frac{1}{2\pi}\frac{d\phi}{dt} \quad (3)$$

where ϕ is the optical phase, which variation with the time depends on the line-width factor or Henry's factor, α [3]:

$$\frac{d\phi}{dt} = \frac{1}{2}\alpha\left[\Gamma\nu_g a_0(n-n_t) - \frac{1}{\tau_p}\right] \quad (4)$$

n_t represents the carrier density at transparency, Γ is the confinement factor, ν_g is the group velocity, a_0 is the gain coefficient, and τ_p is the photon lifetime. Under this conditions and taking into account that $n_t \propto P$, the frequency chirp associated with DML depends on the value taken by the optical power weighted by the parameters α and κ according to the equation:

$$\Delta\nu(t) = \frac{\alpha}{4\pi}\left(\frac{1}{P(t)}\frac{dP(t)}{dt} + \kappa P(t)\right) \quad (5)$$

where k is the adiabatic coefficient determined from the parameters: gain compression factor (ε), differential quantum efficiency (η), active layer volume (V), and the mode confinement factor (Γ) according to the following equation:

$$\kappa = \frac{2\Gamma\varepsilon}{\eta h\nu V} \quad (6)$$

The first term of Eq. (5), transient chirp, produces variations in the pulse width, while the second term, adiabatic chirp, produces a different frequency variation between the "1" and "0" bits causing a shift in time between the levels corresponding to "1" and "0" bits when the pulses go through a dispersive media, as the optical fiber.

With Eq. (5), the frequency chirp for large-signal modulation can be determined directly from the shape of the modulated signal. This equation can be used to predict which output waveforms produce the lowest chirp and we can tailor the current input signal accordingly.

Nevertheless, when an optical pulse is transmitted through a dispersive media, like an optical fiber, the intensity and the shape of the optical signal at the output of the optical fiber, due to the waveform $I(t)$, are related with the dispersive characteristics of the optical fiber.

Summarizing, the pulse shape is a function of different factors: the initial pulse shape, the chirp associated with this pulse from the DML and the dispersive characteristics of the optical fiber. If we suppose an initial pulse with a gaussian form and considering no-linear effects in the fiber to be negligible, the shape of the pulse, after a distance z, is given by the equation governing the evolution of the complex amplitude of the field envelope along the fiber, $A(z, t)$ [1]:

$$A(\xi, t) = \frac{A_0}{\sqrt{b_f}}\exp\left[-\frac{(1+iC_1)t^2}{2T_0 b_f^2} + \frac{i}{2}\tan^{-1}\left(\frac{\xi}{1+C\xi}\right)\right] \quad (7)$$

where A_0 is the peak amplitude, T_0 represents the half-width of the pulse at 1/e power point and b_f is the pulse broadening factor. The parameter C in Eq. (7) takes into account the frequency chirp of the pulse at $z=0$ (DML chirp) and C_1 represents the value of the chirp associated with the pulse after a distance z. Expression (7) is depending on the normalized distance ($\xi = z/L_D$), where L_D is the dispersion length, defined as $L_D = (T_0)^2/|\beta_2|$ where β_2 is the Group Velocity Dispersion (GVD) and it is related to the dispersion parameter, D, of the fiber.

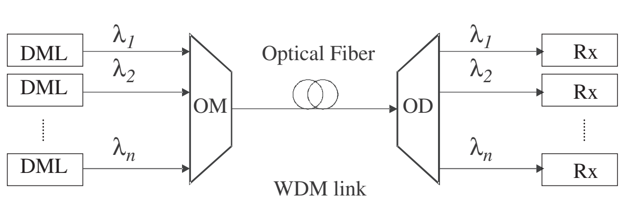

Fig. 1. Block diagram of a CWDM system.

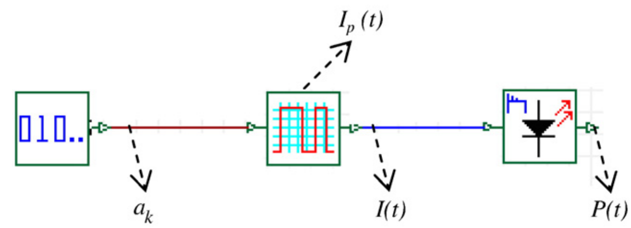

Fig. 2. Directly modulated laser scheme.