Impact Analysis of modulation formats in 40 Gbit/s DWDM systems

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Abstract—*The development of digital optical communications systems at high flow rates (NX40Gbit/s) and wavelength division multiplexed (WDM) reveals new issues such as the need to compensate the chromatic dispersion at higher levels, the onset of effects the polarization dispersion (PMD), the greater relative importance of intra-channel nonlinearities, weakening the clearing. Conventional modulation of the optical power of all or nothing (On-Off Keying) cannot handle all these challenges and specific modulation formats (duobinary, DPSK ...) are envisaged to overcome the vagaries of broadband transmission. In this paper we study some aspects of modulation formats that meet these requirements transmission.*

Keywords— *Modulation formats, On-Off Keying, Differential Phase-Shift Keying (DPSK), Quadruple Differential Shift Keying (DQPSK), Phase Shaped Binary Transmission (PSBT), PMD, CD.*

I. Introduction

Today, optical transmission links usually use a 10 Gb/s speed, but with the arrival of new technologies on the market requiring more bandwidth (broadband access, high-definition digital TV, peer-to-peer file exchanges, Tele-working, Video-conferencing ...) demand flow rate is increasing. To improve existing systems and provide optimal performance, research laboratories are moving increasingly towards improving links carrying data over large distances [13]. This involves improving the physical layer in terms of improving the OSNR, the chromatic dispersion, polarization mode dispersion (PMD), but also by optimizing modulation formats to increase the bit rate, because the conventional modulation of the optical power of On-Off Keying cannot handle all these challenges and specific modulation formats (duobinary, DPSK ...) are already planned for , as appropriate , to overcome or to benefit from the dispersion. It is very appropriate to shape the 40Gb/s optical signals in order that they can be passed on WDM/DWDM grids operating at 10 Gb/s.

II. Constraints related to a gradual increase in capacity of a WDM system [11].

The aim is to study the effects of an optical signal propagation when modulated at 40Gb/s, especially when the signal propagates through a system originally designed to carry 10Gb/s.

Propagation effects experienced by a signal depend on its optical flow rate, or more accurately the frequency of optical information, because the transition time between symbols and the width of the spectrum are directly related. We give here the main constraints for consecutive optical signal to increase its flow rate, by a factor "4" (10 Gb/s to 40 Gb/s) [9].

A .The decrease of noise tolerance:

When the bit rate increases, the spectrum of a modulated signal widens homothetically. In order to detect this signal, the bandwidth of the optical and electrical filters needed at the receiver must also increase accordingly [1].

However, the consequence is to recover as much of ASE noise in the receiver, and thus have a much higher integrated noise power at the receiver, "4 times higher for example", if the flow rate was multiplied by 4. Therefore, the OSNR (Optical Signal -to- Noise Ratio) at the receiver must be 4 times higher (or increased by 6 dB) in order that the detection quality will not be affected by the increase in flow.

Noise tolerance of an optical signal is inversely proportional to its optical information frequency [10].

B. Chromatic dispersion

The delay group, i.e the time taken for a signal to travel a length unit, depends on the wavelength λ. In the case of a signal from a source emitting a stripe width δλ, these propagation times will be spread over a certain period. The chromatic dispersion parameter (D) is defined as the derivative of the group delay relative to the wavelength for a fiber length of 1 km. It is usually given in ps/(nm.km), Picoseconds correspond to the temporal broadening, Nanometers to the spectral width and Kilometers to the fiber length [2]

In fact, the chromatic dispersion is the sum of a term of pure material (material dispersion) and a term due to the wave guiding (modal dispersion). Fig.1 shows the evolution of the material term for silica with λ.

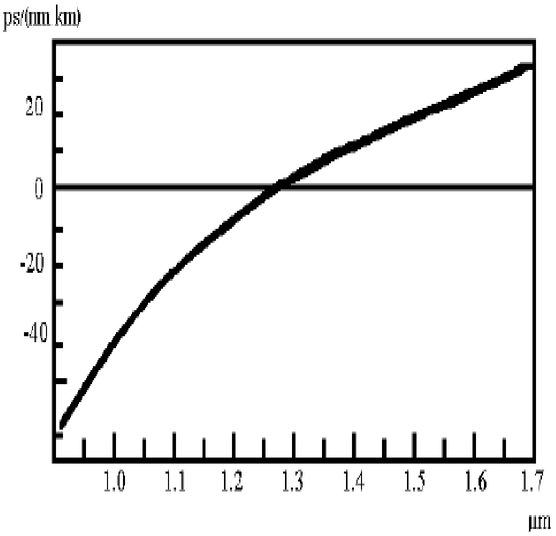


Fig.1: Dispersion in the pure silica material according to the wavelength.

In this curve, the G.652 standard monomode fiber has a maximum dispersion of 20 ps/ (nm.km) at 1550 nm. Traditionally, it is considered 17 ps/ (nm.km). In the 1288 nm to 1359 nm band, it is 3.5 ps/ (nm.km). Thus, the transmission capacity is the highest possible for a wavelength of about 1.3 microns. It is therefore ideal for this spectral window and can carry very high flow rates. Unfortunately, this is not where the attenuation is lowest (Fig. 2).

We therefore sought to move the point of zero dispersion to 1.55 µm, this type of fiber, G.653, is a called dispersion-shifted fiber (Fig.3). There is also a dispersion flattened fiber in which the total dispersion is very low, around few ps/(nm.km) in more than one hundred nanometers (Fig. 3).

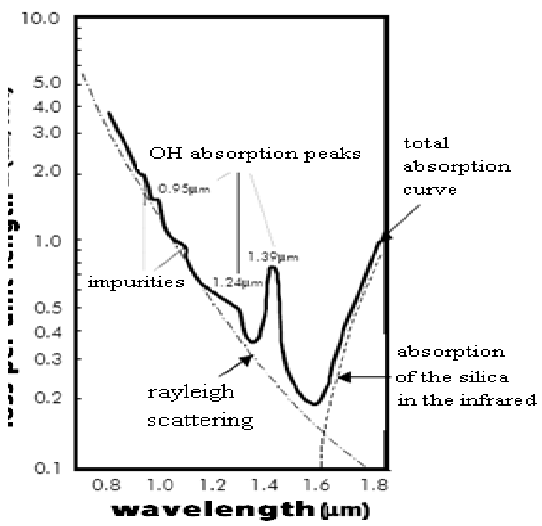


Fig.2 linear loss (dB / km in terms of the wavelength for a standard fiber (SMF)

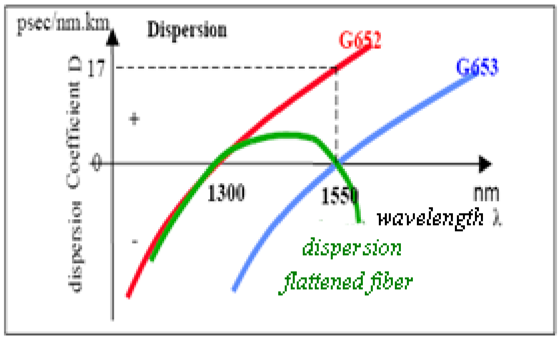


Fig.3: Dispersion curves of some optical fibers.

'e can also produce a fiber that would have an posite dispersion to the first fiber. All these special ıers are obtained by modifying the index profile [12]. ıe chromatic dispersion of a fiber thus leads to different propagation time and temporal broadening of pulses if they are not perfectly monochromatic. After a certain distance, if the spreading becomes relatively large, a generator covering intersymbol interference is possible. This broadening τ is calculated as:

$$\tau = D\ (ps\ /\ nm.km)\ *\ L\ (km)\ *\ \Delta\lambda\ (nm) \quad (1)$$

with D the chromatic dispersion coefficient of the fiber, L the fiber length and Δλ the spectral width of the source.

Thus, Chromatic dispersion is a major factor limiting the performance of transmission systems on high-speed fiber. Also, more flows to be transmitted, the higher the recovery can occur quickly, and more developed compensation techniques must be implemented.

C. The decrease of PMD tolerance:

PMD (as DGD) is consecutive to a temporal roadening of symbols due to the birefringence of the iber. As in the case of the chromatic dispersion, if the low rate increases, symbols come closer to each other. 'herefore more the flow increases, more the signal is ffected by the broadening of its symbols. But unlike ispersion, PMD is not a function of the spectral width f the signal, although it is directly dependent on the low rate.

'he tolerance of an optical signal to the PMD or DGD ; inversely proportional to its optical information requency.

$$GD = Biréfringence\ .\sqrt{Coupling\ length}.\sqrt{Fiber\ length} \quad (2)$$

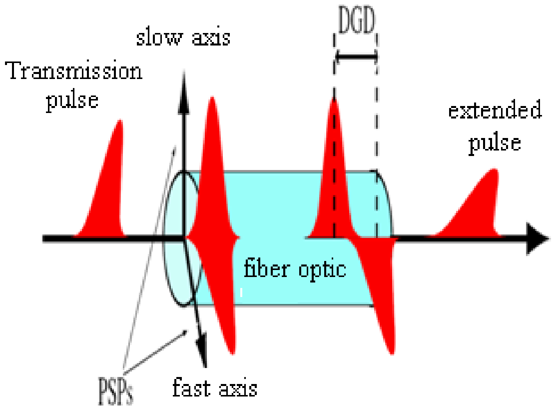


Fig.4: the effect of PMD on optical pulses through a real fib

Fig.4: Effect of PMD on optical pulses through a real fiber

D. Evolution of tolerance to nonlinear effects

Telecommunication systems on optical fiber are designed under the assumption of a linear transmission; nonlinear effects are then parasitic effects that degrade performance when the powers conveyed become high. Today transmission systems of long-distance & high-speed rate use power amplifiers at the transmitter side, which led to a very high power injected into the fiber and significant non-linear effects.

III. INTEREST CHOICE OF THE MODULATION FORMAT

Each modulation format is characterized by its temporal behavior in amplitude, for example viewable on a diagram of the eye, its phase behavior, which can be viewed on a constellation.

A light signal propagating in an optical fiber undergoes propagation effects (attenuation, dispersion, nonlinear effects, accumulation of ASE noise) [14]. However, these effects depend on the temporal and spectral nature of the signal, and thus the way in which it is modulated. Each modulation format will therefore responds to these effects in its own manner. Some formats are naturally more tolerant than others to an effect or to another; they will be penalized less than others by an accumulation of these effects.

We will now review the various modulation formats that exist and meet the requirements of propagation in an optical fiber.

A. NRZ Format (Non-Return-to-Zero)

This is the simplest format and the most intuitive out there. A modulated NRZ optical signal is an exact copy of the binary electrical signal: "0" is encoded by a low-power signal (ideally zero), and a "1" at high power signal [1], [2].

Fig.5 shows an example of time trace, eye diagram and a NRZ spectrum.

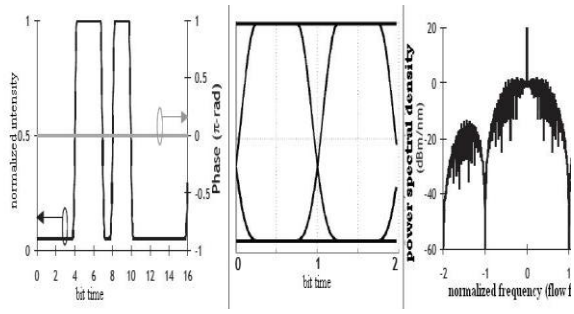


Fig.5: time trace, eye diagram and the spectrum of the NRZ format.

The choice of NRZ for transmitting 40Gb/s has a number of disadvantages:

- low-noise tolerance
- low-spectral efficiency
- tolerance to mid-level dispersion

B. Format PSBT (or Duo-binary)

The PSBT (Fig.6) also called duo-binary modulation, changes the phase and amplitude of the optical signal in a manner that reduces the bandwidth of the optical signal. Accordingly, the dispersion tolerance increases. [3], [4]. This is its main advantage. Due to the reduced width of the optical band, some PSBT models can also function in a DWDM network with a channel spacing of 50 GHz. However, the OSNR tolerance of the PSBT is comparable or even worse than that of NRZ. The PSBT can be used effectively in metropolitan area networks with requirements of limited scope.

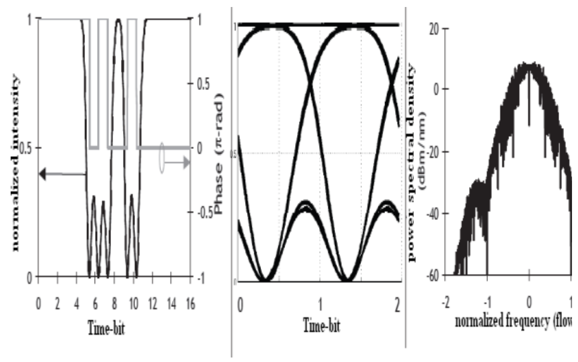


Fig.6: time trace, eye diagram and spectrum format PSBT

C. Format differential phase (DPSK)

The DPSK modulation uses the phase to encode the bit information directly to the optical transmission [8]. Receiving side has a differential receiver. It provides a tolerance of 3 dB of OSNR and provides better resistance against system deficiencies. The OSNR for the DPSK is superior to all the other modulation schemes. However, DPSK cannot operate with a channel spacing of 50 GHz. the DPSK is a good choice for long-distance networks, but with a limited number of channels : 40 in C-band. [7]. The scheme is illustrated in Fig.7.

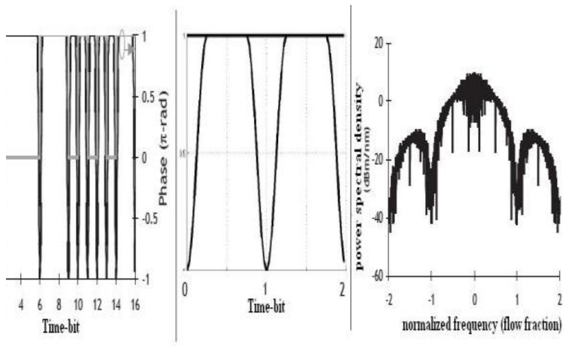


Fig.7: DPSK format characteristics

D. Format DQPSK (Differential Phase Shift Keying Quadruple)

The DQPSK format uses the phase to encode the bit information directly to the optical transmission. Receiving side has a quadrature receiver. In addition to the advantages of DPSK, it uses a lower bandwidth and therefore benefits from: [5], [6].

- Ability to work in a channel spacing of 50 GHz
- Increased dispersion tolerance
- Better tolerance to PMD

The spectrum of a DQPSK signal is illustrated in Fig.8

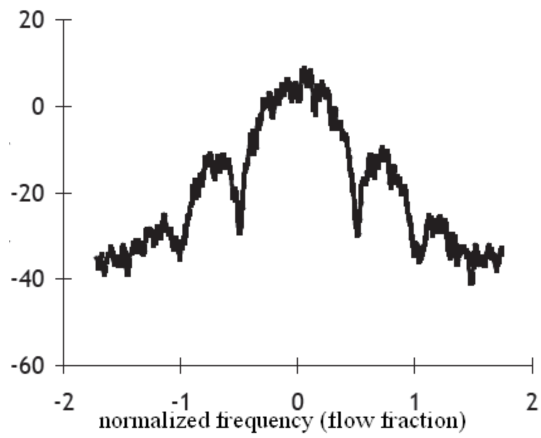
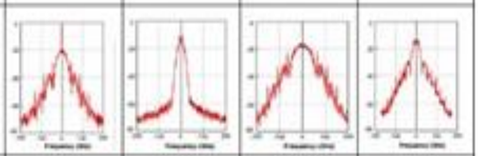


Fig.8: spectrum of a DQPSK signal

The principal pertinent parameters of different modulation format are presented in the table I.

Table I. Performance comparison of modulation formats

	NRZ	Duo-Binary	DPSK	DQPSK
Optical Spectra				
Optical Noise Tolerance	poor	very poor	very good	good
Chromatic Dispersion (CD) Tolerance	medium	good	medium	good
Polarization Mode Dispersion (PMD) Tolerance	poor	medium	medium	good
Optical non-linearity Tolerance	medium	poor	good	good

IV. Conclusion

It is necessary, for the modulated 40Gb/s channels, to employ a suitable format, with one hand, a relatively narrow range as compared to more conventional formats, and at the other hand, an increased tolerance to propagation effects especially penalizing generated in these systems. For hybrid systems using a mix of both rates “10Gb/s and 40Gb/s” in a single multiplex, we can conclude that the most suitable format is phase shaped binary transmission controlled (PSBT) [9]. The DQPSK is suitable for some hybrid systems lower information spectral density, when the distances that must be achieved are higher.

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