

Investigation of External Electromagnetic Disturbance in HDWDM System

J. Porins, G. Ivanovs, V. Bobrovs, and A. Supe

Institute of Telecommunications, Riga Technical University
12 Azenes Street, Riga LV-1010, Latvia

Abstract— In the work, variations in the optical signal parameters in high-density wavelength division multiplexing (HDWDM) optical fiber communication system under strong external electro-magnetic (EM) field are analyzed for different modulation formats and transmission speeds. It is established that a 8-channel HDWDM system with NRZ modulation is more sensitive to the polarization state changes on exposure to external EM field as compared with a system in which the polarization state modulation (POLSK) modulation format is used. The BER analysis shows that the EM effect is one of the factors limiting the minimum for the allowed inter-channel interval. If this allowed minimum is chosen to be 0.3 nm for data transmission speed 10 Gbps, in view of the EM influence it should be raised to 0.4 nm in order to ensure the necessary BER level an HDWDM system.

1. INTRODUCTION

The increasing need to access information generates progress of wide development in the field of fiber optics communication systems by WDM. Transmission of high bitrate optical signals and dense optical channel spacing is used for increasing the capacity of the optical long-haul communication systems [1]. The influence of the external electro-magnetic field on its optical properties is rather weak, which, in turn does not cause changes of optical signals in optical fibers. At the same time, this is not so unambiguous for the WDM communication systems with closely spaced channels (HDWDM) as the data transmission speeds are increasing and the channel intervals are decreasing (down to 0.4 or even 0.2 nm). The same refers to the optical fiber cables with metal wires or metallic line armouring, especially to the optical cable lines enclosed in high-voltage ground wires and in the case when the NRZ or POLSK modulation format is used. This format is offered as an alternative to traditionally employed intensity manipulation (IM), and is the newest from the signal modulation formats to be applied just to the optical fiber transmission systems, imparting to them a very valuable property — better resistance to the self phase modulation (SPM) [2].

2. BACKGROUND

External electric, magnetic and electromagnetic (EM) fields can affect light transmission in optical fibers through Kerr effect, Faraday effect and Pockels effect. The point is that changes of state of polarization (SOP) in WDM transmission systems occur not only due to the polarization mode dispersion (PMD) but also due to non-linear effects (NOE). Therefore, the refractivity depends not only on the frequency but also on the intensity of electric field that is propagating through a dielectric medium (fiber) or interacts with it. As the number of channels increases in the core of a single-mode optical fiber, a rather high concentration of electric field is built up, this gives rise to refractivity changes and to such non-linear effects as self-phase modulation (SPM), cross-phase modulation (XPM) and four wave mixing (FWM). The Kerr effect has been found to occur not only under the internal electric field (that of optical signal) but also as being induced by external field. The external electro-magnetic field changes the SOP of the optical signal in the fiber, which, in turn, leads to changes in the process of propagation and reception of such a signal. Apart from changes in the optical signal polarization in fibers also double refraction properties can arise. The rotating angle φ of an optical signal's polarization under the electric field is expressed as [3]:

$$\varphi = 2\pi K E^2 l \quad (1)$$

where K — Kerr coefficient ($K = f(n, T)/\lambda$; E — electric field intensity; l — length; λ — wavelength.

Kerr effect is proportional to the outer square of the field and depends on the refractive index n and temperature T . Difference in the refractive indices in the optical medium due to electro-optic Kerr effect can be calculated using equation [3]:

$$\Delta n = \lambda K(\lambda) E^2, \quad (2)$$

where Δn — refractive index difference between two orthogonal optical waves in the optical medium.

The Kerr coefficient is dependent on the wavelength and assuming that the solids approximation anisotropic molecules turning in a similar way as a liquid or gaseous substance that is obtained [3]:

$$K = \frac{1}{30} \frac{(n^2 - 1) \cdot (n^2 + 2)}{n} \cdot \frac{m\varepsilon_0}{\lambda k T \rho}, \quad (3)$$

where ε_0 — electric constant, m — particle mass of mater, λ — wavelength, k — Boltzmann's constant, T — absolute temperature (Kelvin's).

Faraday effect or Faraday rotation is a magneto-optical phenomenon. It gets as an interaction between light and a magnetic field in a medium. The Faraday effect causes a rotation of the plane of optical radiation polarization. Angle β by which this rotation occurs is linearly proportional to the component of the magnetic field that is oriented to the direction of light propagation. Following equation shows relation between turn angle of polarization state and magnetic field [3]:

$$\beta = \vartheta B d, \quad (4)$$

where ϑ — Verdet constant, B — magnetic flux density, d — the length of the path where the light and magnetic field interact.

Research of author [3, 4] shows that turning the plane of polarization can occur even up to 45° to 90° if optical fiber affects strong lighting. Change in the polarization state can produce errors in data transmission especially for modulation formats where coherent detection is used. Changes of plane of polarization can cause double refraction and two mutually orthogonally wave components occurrence in optical fibers [5].

3. SIMULATION SCHEME AND PARAMETERS

This research is based on WDM system performance analysis using simulation software Opt-Sim5.2. The method of calculation implemented in this software is based on solving the non-linear Schrödinger equation [6]. The Split Step method to solve the non-linear Schrödinger equation to perform the calculation of the optical wave propagation through the OF is used.

To evaluate EM field influence to FOTS we propose to use a 8 channel WDM transmission systems working in the C band (conventional band from 1530 to 1565 nm wavelength). Whole system can be divided into three main parts: transmitter, transmission line and a receiver part (Fig. 1).

Transmitter part consists of 8 multiplexed optical channels each located at different wavelength. All the channels are located with even spacing. Interval between adjacent channels is chosen according to data transmission speed in channels. For 10 Gbps data transmission speed the adjacent channel interval is set to 0.3 nm [7]. For 12.5 and 40.0 Gbps data transmission speed this interval is set to 0.4 and 1.2 nm accordingly.

Each transmitter consists of random data generator (PPG), code driver (NRZ_driver), laser source (CW_laser) and electro-optical modulator (MZM_modulator). The laser is always switched

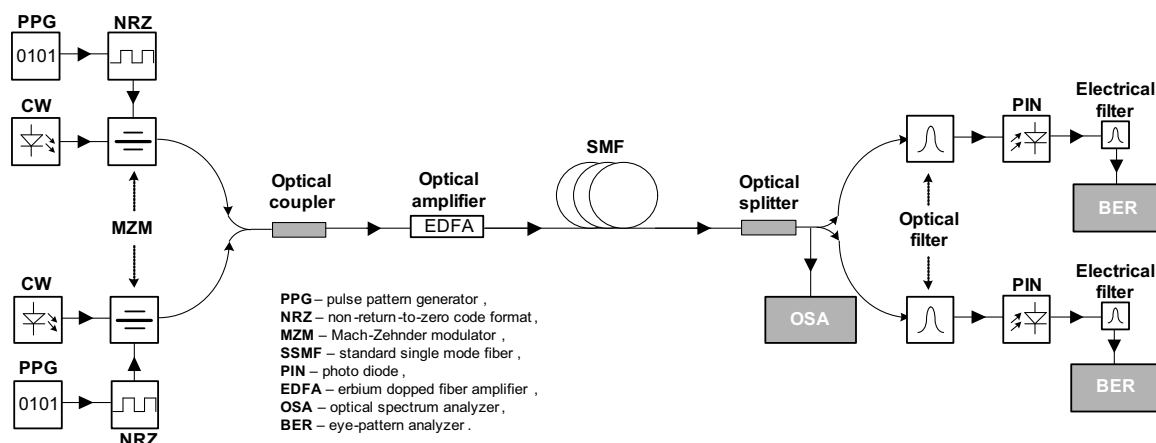


Figure 1: The setup used for investigation of HDWDM transmission system.

on and its lightwaves are modulated via external electro-optic Mach-Zender (MZ) modulator by random data pulse sequence output of a pulse pattern generator (PPG). Data signal from PPG are coded using non-return-to-zero (NRZ) pulse shapes.

Each transmitter MZ modulator output is connected to an optical coupler. Further multiplexed optical signal is sent to a standard single mode fiber (SSMF) ITU-T G.652D, where optical pulses propagate via 40 km length. In the receiver each channel is optically filtered by Bessel filter) to separate channels. Filter bandwidth is set accordingly to the transmission data rate. Optical filter output is connected to polarizer. That simulates polarization dependent losses at the receiver part. After polarizer optical signal is converted to electrical signal using photodiode (PIN) whose sensitivity is -15 dBm. To evaluate the data transmission performance eye diagram measurements of electrical signal have been taken at the output of each channel. Eye diagram gives determination of signal quality factor Q and correspondingly bit error rate (BER). System overall performance will be determined by the worst channel BER.

To determine electric and magnetic field influence we will artificially introduce changes in the proposed WDM system. Electric field influence due to electro-optic Kerr effect can be evaluated by increase in optical fiber PMD and changes of SOP. Whereas magnetic field influence due to Faraday effect will be simulated by inserting optical signal polarization rotator at the output of fiber. EM field influence to the overall WDM system performance will be evaluated by the received data signal worst BER value. For crystals the Kerr constant typically ranges from 10^{-18} to 10^{-14} m^2/V^2 [8]. Optical fiber is an optical radiation waveguide that is created from optical materials based on SiO_2 . If we assume typical electric field intensity $E = 3.2$ kV/m at ground level from 220 kV power transmission overhead line we get negligible change in refractive indices $\Delta n = 8.41 \cdot 10^{-18}$ [9]. To get more notable interaction it is worth to assume much higher electric field intensity. Faraday effect occurs when magnetic field direction match with optical radiation propagation direction. As an EM field source we chose a case of lightning induced electric flux density that can shift optical radiation polarization plane up to 90° .

4. RESULTS AND DISCUSSION

The experiment was run in two stages in order to simplify analysis of the results. In the first stage, a system was simulated with no electro-magnetic influence and with only tabulated parameters of the elements so that its efficiency is determined in the absence of such influence. In the second stage, under simulation was a system which in the middle of line is affected from outside by a strong electro-magnetic field. Simulations were performed using previously described HDWDM system. Data transmission speed for each channel is set to 10.52, 12.5 and 40 Gbps and two different modulation formats — IM and POLSK. Following two tables show the eye diagrams for 40 Gbps channel data rate as it showed the highest performance decrease determined by BER.

From the results we can see that for higher data transmission speed this influence gives greater increase in BER. So influence of external EM disturbance in optical fibers can become more common especially in long-span high density WDM (HDWDM) systems with high data transmission speed and modulation formats with coherent detection.

If we compare electrical and magnetic field influence then it shows similar results. But magnetic

Table 1: Achieved eye diagrams and BER values for 40 Gbps WDM system.

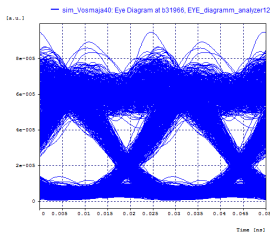
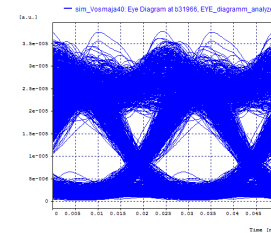
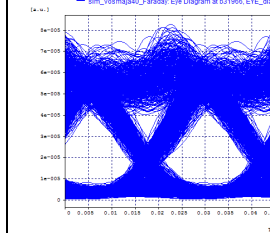
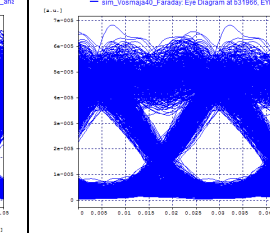
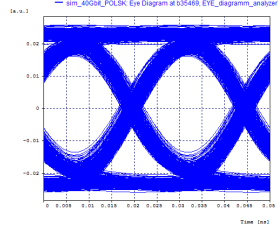
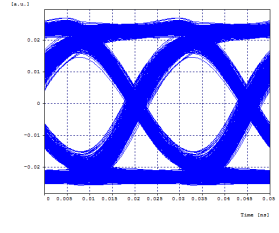
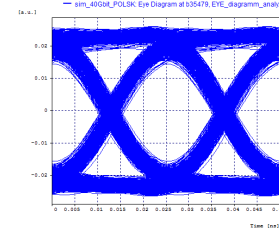
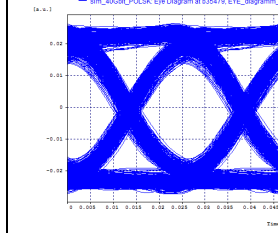
Amplitude modulation (NRZ code)			
Electro-optic Kerr effect		Faraday effect	
without EM field	with EM field	without EM field	with EM field
			
BER= $2.13 \cdot 10^{-14}$	BER= $6.66 \cdot 10^{-12}$	BER= $1.81 \cdot 10^{-16}$	BER= $1.16 \cdot 10^{-14}$

Table 2: Achieved eye diagrams and BER values for 40 Gbps WDM system.

POLSK modulation			
Electro-optic Kerr effect		Faraday effect	
without EM field	with EM field	without EM field	with EM field
			
BER= $7.58 \cdot 10^{-28}$	BER= $1.64 \cdot 10^{-24}$	BER= $3.70 \cdot 10^{-27}$	BER= $7.46 \cdot 10^{-24}$

field influence is less likely to have serious problems to FOTS, because it is most effective when magnetic field direction coincide with optical radiation propagation direction. In the case of power transmission lines this condition fulfills only in the case of optical fiber and power line being located mutually orthogonally.

5. CONCLUSION

Simulation results show that BER value increase at EM field interaction in our HDWDM system with POLSK modulation is smaller compared to IM. The obtained eye diagrams show changes pointing to those in the system's quality indices under the EM influence. For the analysis we have used the 1st, 5th, and 8th channels. This choice is explained by a comparatively wide band (1546.8–1552.8 nm) in which the WDM system's channels are arranged, whereas it is known that fiber parameters (attenuation, chromatic dispersion and PMD) are specified for 1550 nm. Therefore, it was of important to give consideration just to side channels (the 1st and 8th, respectively) where the deviations of parameters from designed values are the greatest. When analyzing the eye diagrams degraded after the EM action, it is seen that the eye narrowing occurred owing to the PMD influence, since we observed increased phase jitter and frequency chirps caused by NOE (SPM, XPM). The degradation of eye diagrams corresponds to changes in the signal BER values from $5.43 \cdot 10^{-16}$ to $6.66 \cdot 10^{-12}$. The differences could be interpreted, e.g., as consequences of NOE, since these effects are dependent also on dispersion and attenuation. A great concern as to the really placed optical lines is the influence of high-voltage transmission lines that can arise in the cases of line faults. Obviously, in practice the consequences of external EM influence (considered in the simulation) would not be significant, since the voltage that can arise due to such a fault is much lower (110 kV in the ground wire) — i.e., by 50 kV; however, since the fibers are inserted enclosed in the cables of high-voltage lines, such influence takes place all along the fiber length, which could cause definite changes.

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