CHANCES OF WRONG INFORMATION RECEPTION DURING ELECTROMAGNETIC INFLUENCE UPON OPTICAL CABLE

Stanislav Sokolov [1],

[1] Institute of Radio and Information Systems (IRIS), Vienna, Austria; sokolov@media-publisher.eu

ABSTRACT

Long-distance communication lines are optical fiber lines in most cases now. This moment PM QPSK system (polarization-division multiplex with quadrature phase shift keying) appear. Polarization-division multiplex uses a fact that the optical signal can propagate as two orthogonal polarized modes that allows to use the modes independently and makes it possible to double carrier capacity (together with already other used multiplex system). Two orthogonal waves using in the same fiber can cause problems during lightning discharges close by cable line. Under influence of external cross electrical field (or longitudinal magnetic) the polarizations plane of lights wave can turns on angle, which depends on field value, light path length upon field action and fiber sensitivity. During the influence of external electromagnetic field issue a part of one polarization signal can pass to other orthogonal plane and it will perceive wrongly. The Wavelength Division Multiplexing (WDM) systems development with increasing number of carriers brought to transmission in the same transparency window some tens or hundreds waves. They are shifted relative to each other for some parts of nanometers during the lightning stroke. Therefore the polarization plane rotation will be different for each wave (other conditions being equal): the short waves rotated greater than the long waves. On input of optical amplifier there will be packet of waves with different polarizations, and it can produce problems to filters, optical insulators and amplifiers, to Raman amplifiers specially, which are sensitive to polarization. It is known that short and long waves are moving with different velocity as refraction index depends upon wave length. Usually the rotation angle quantity is small if resistivity of earth near cable is not heavy and if equipment does not contain sensitive to PMD (Polarization Modes Dispersion). This phenomenon passes usually unnoticed. But sometimes with strong thunderstorm and lightning stroke at a short distance the polarization plane rotation can exceed 45º or even 90º. Hereby, it is possible the complex electrical and magnetic fields influence during thunderstorm on orthogonal polarization using, that can lead to additional component appearance in orthogonal axes and to signal reception error. Error level for year is estimated.

KEYWORDS: *Optical Cable, Wavelength Division Multiplexing, Polarization.*

DOI: 10.36724/2664-066X-2023-9-2-26-29

Received: 10.12.2022
Accepted: 15.02.2023

Citation: Stanislav Sokolov, "Chances of wrong information reception during electromagnetic influence upon optical cable," *Synchroinfo Journal* **2023**, vol. 9, no. 2, pp. 26-29.

1 Introduction

The phenomena of plane light polarization rotation in transverse electric (Kerr effect) and longitudinal magnetic (Faraday effect) fields were discovered back in the 19th century. When light passes through a fiber under the influence of an external electromagnetic field, the plane of oscillation (polarization) of the light wave rotates. Differently polarized waves of light when incident on a flat surface have different values of Fresnel coefficients. A change in the polarization plane of light in an optical fiber can also lead to so-called birefringence and the appearance of two orthogonal wave components between which the original signal energy is distributed. Each of the components will be distributed independently of each other. Since the fiber parameters along different planes passing through the axis may differ slightly, the consequence may be an increase in signal dispersion and attenuation, similar to polarization mode dispersion with geometrical inhomogeneities of the fiber.

2 Exposure to external electromagnetic fields on optical cable

The rotation of light polarization plane in the fiber under the action of a transverse external electric field is determined by the expression:

$$\varphi = 2\pi\, K(\lambda)\cdot E^2 \cdot L \qquad (1)$$

where E – electric field intensity;

L – section length where the cable is exposed to the field;

K – Kerr constant, which depends on the refractive index n, temperature T and wavelength λ:

$$K = F(n,T,\lambda) = \frac{f(n,T)}{\lambda} \qquad (2)$$

$K \approx 0.402\cdot 10^{-13}$ m/V^2 at $\lambda = 1.55$ µm; $n = 1.5$; $T = 293^{\circ}$ Kelvin. K has a small value, and for a noticeable Kerr effect to occur, the electric field must be quite large. Large field values are possible near the point of a lightning strike and when exposed to a high-altitude nuclear explosion. There is no immediate damage to the cable, but when the plane of light polarization is rotated, field components appear along the main axes of the fiber cross-section, and if there is a slight ellipticity of the fiber, additional polarization mode dispersion (PMD) subsequently appears.

The magnitude of the rotation angle and the probability of occurrence of one or another value of it were considered earlier [1,2]. Usually, when laying a cable in soils with low resistivity, the angle of rotation of the polarization plane is small, and if the equipment does not contain elements sensitive to polarization, this phenomenon goes unnoticed. However, during a close lightning strike with a large current amplitude, the rotation of the plane of polarization can exceed 45° and even 90°.

Table 1 shows the calculated values of the number of cases of rotation of the plane of polarization of light in the fiber at a given angle φ_0 for a wave $\lambda = 1.55$ µm and at average lightning activity.

Table 1. The number of cases where the value of φ_0 is exceeded during a thunderstorm season at $q = 0.1$; $L = 100$ km; $N = 25$ and various earth resistivities

ρ, Ohm·m	φ_0, deg.					
	5	10	30	45	90	180
100	0.37	0.29	0.20	0.18	0.14	0.11
200	0.58	0.46	0.32	0.28	0.22	0.18
400	0.92	0.73	0.51	0.44	0.35	0.28
1000	1.7	1.35	0.94	0.82	0.65	0.52
2000	2.7	2.15	1.49	1.3	1.03	0.82
5000	4.97	3.96	2.74	2.4	1.9	1.51

The calculations assumed the density of lightning strikes into the ground q = 0.1 strikes / km^2 per day, the number of days with thunderstorms per year N = 25 (conditions of the central zone of the European part of Russia), the line length L = 100 km.

For other values of q, L and N, Table 1 can easily be redone using linear recalculation by multiplying the table values by the coefficients q/0.1; L/100; N/25 respectively.

As can be seen from Table 1, the rotation of the plane of polarization, for example, by 45 degrees over a length of 100 km with a resistivity of 100 Ohm·m, occurs approximately once every 5 years, and at ρ = 400 Ohm·m already once every two years. At ρ = 2000 Ohm·m this happens more often than once a year, and at ρ = 5000 Ohm·m – two and a half times a year. Soil with a resistivity of 50 to 500 Ohm·m is found in the presence of stones and rocks, as well as in areas with permafrost. When calculating Table 1, a lightning strike was assumed to be a single strike; multiple strikes were not taken into account. However, real lightning strikes have an average number of strokes of about three, so the total rotation is likely to be much greater.

Under the influence of the longitudinal magnetic field of lightning, that is, in the case when light propagates along the magnetic field lines, the plane of polarization also rotates by an angle

$$\psi=VLB, \qquad (3)$$

B – magnetic induction in the propagation medium; L – the length of the light path along magnetic field lines; V – Verdet constant.

However, the value of ψ during lightning strikes is significantly less than φ.

3 Impact with wave and orthogonal multiplexing

The development of wave multiplexing systems with an ever-increasing number of carriers has led to the fact that several tens, or even hundreds of waves, shifted relative to each other by fractions of nm, can be transmitted in one transparency window. Therefore, the rotation of the polarization plane will be different for all waves, and, other things being equal, short waves will shift by a larger angle compared to long waves.

If initially all the waves had the same (for example, vertical) polarization and propagated along one of the main axes (since the fiber has some ellipticity), then after the rotation of the planes of polarization under the influence of an external field, short waves will have a large component along the horizontal axis, and long waves will have relatively large vertical components. It is also known that short and long waves travel at different speeds due to the dependence of the refractive index on the wavelength. Consequently, the determined wave packets with different polarization will also have different propagation speeds, which will cause additional dispersion. If orthogonal multiplexing is used with simultaneous transmission of waves with horizontal and vertical polarization along the fiber, then components that were originally vertically polarized after rotation of the plane of polarization under the influence of an external field may be superimposed on the main waves with horizontal polarization, which will further increase the risk of errors.

Unfortunately, there is some uncertainty in the accuracy of determining the value of K, the value of which may depend on the fiber manufacturing technology. However, the impact of lightning on an optical cable, even without metal elements, can be quite dangerous when transmitting high-capacity channels at speeds of several terabits/sec, since the cost of errors when receiving such signals is very high.

4 X-ray and gamma radiation during thunderstorms in the mountains and near high-rise buildings

Previous studies [3-9] have shown that during the leader stage of a lightning discharge, especially with positive leaders, which most often occurs in the mountains and near high-rise buildings, radiation occurs in the form of X-rays and γ-quanta with energy exceeding 10 MeV. The effect of radiation on fiber is divided into three main categories: the formation of so-called color centers, changes in fiber density, and changes in the properties of polymer materials. When exposed to radiation, displacement processes and the formation of lattice defects occur in the fiber material. Conduction electrons and holes appear on these defects, the combination of which with vacancies creates color centers that absorb light in some parts of the spectrum, which leads to additional attenuation. In the case of polymers, ionizing radiation significantly changes the macroscopic properties of polymers, disrupting the bonds of polymer chains. As we can see, the impact of lightning discharges in mountainous areas can be accompanied not only by the flow of high amplitude current and the influence of a strong electromagnetic field, but also by exposure to X-ray and gamma radiation, which are dangerous for optical cable.

5 Estimation of the number of errors encountered

Lightning activity is usually assessed by the total duration of thunderstorms *T* in hours per year in each area. It depends on a number of reasons, including climate, terrain, distance from the sea, etc. Based on the total duration of thunderstorms, we can make a preliminary estimate of the proportion of time during which the cable may be exposed to lightning:

$$\alpha_1 = T/8760. \quad (4)$$

8760 is the total number of hours in a year. The value of *T* can vary greatly, for example, for Moscow it is approximately 37 hours per year and α_1 = 0.00422. During a thunderstorm, the cable is not necessarily exposed to lightning. The probability of such an impact is determined by the resistivity of the soil along the cable route, the location and length of the route, the type of cable, and the duration of lightning activity. Typically this event can be estimated at 0.05-0.3 per 100 km of route per year. For a cable without metal elements in the design, the duration of rotation of the plane of polarization, which can lead to a failure in information reception and the appearance of additional dispersion, can be on the order of 0.1 to 0.5 seconds. This is the time of the total duration of a lightning discharge, including repeated discharges developing along the old channel. If conditions along the line length are approximately constant, then with a transmission line length L km, the total time of disruption due to thunderstorms per year can be t = 0.1·0.3· L /100 sec = 3·10-4 L sec. The level of errors over the measurement period of one year will be

$$\alpha_2 = 3\cdot 10^{-4}\, L \,/\, (8760\cdot 60\cdot 60) \cong 10^{-11}\, L \quad (5)$$

where *L* is the line length in km, 8760 is the number of hours per year.

If time and wave multiplexing systems operate along the cable fibers, then an error occurs in all systems, and if orthogonal multiplexing is also used, the number of errors doubles. Lost or incorrectly received information per year for this reason is equal to the total transmission speed of the cable multiplied by the operating time and K_{er}.

REFERENCES

[1] S.A. Sokolov, “Kerr and Faraday effects in an optical cable,” *Telecommunications*. No. 4, 1996.

[2] S.A. Sokolov, “The emergence of polarization mode dispersion under the influence of lightning discharges,” *Telecommunications*. No. 11, 2004

[3] J.R. Dwyer et al., “X-ray bursts associated with leader steps in cloud-to-ground lightning,” *Geophysical Research Letters*. Vol.32, L01803, 2005.

[4] J.R. Dwyer et al., “A ground level gamma-ray burst observed with rocket-triggered lightning,” *Geophysical Research Letters*. Vol.31, L05119, 2004.

[5] S.A. Sokolov, “The impact of lightning discharges on optical cables in mountainous areas and near high-rise buildings,” *First Mile.* No. 2, 2013.

[6] S.A. Sokolov, “Electromagnetic fields inside and near a building,” *Science-intensive technologies in space research of the Earth*,” 2014. Vol. 6. No. 5, pp. 28-32.

[7] S.A. Sokolov, “Possible risk of incorrect reception of information via an optical cable during lightning discharges,*” Science-intensive technologies in space research of the Earth*,” 2014. Vol. 6. No. 3, pp. 22-25.

[8] S. A. Sokolov, A. L. Zubilevich and B. N. Morozov, "Communication Disturbances In Moving Objects," *2019 Systems of Signals Generating and Processing in the Field of on Board Communications*, Moscow, Russia, 2019, pp. 1-6, doi: 10.1109/ SOSG.2019.8706767.

[9] K. Ivanov and P. Uzunov, "Coupled Finite Element Analysis of Optical Ground Wire for Overhead Power Lines," *2022 8th International Conference on Energy Efficiency and Agricultural Engineering (EE&AE)*, Ruse, Bulgaria, 2022, pp. 1-4, doi: 10.1109/ EEAE53789.2022.9831238.