Optical Communication Routes Planning

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Summary
Contemporary demand for data services is not a realistic demand anymore because of capabilities of currently existing optical routes. Services like Video on Demand, videoconference, real-time audio and video streams, large-file transmissions and other multimedia services lead to an increasing demand for transmission capacity. The quick transport layer is not established only on high-quality end-point equipment with sufficiency throughput, but it is necessary to ensure an equivalent physical layer by optical fiber routes.

Optical fiber is an ideal medium for high-speed backbone routes - as the development in communications has shown. Due to its advantages (unlimited bandwidth usage, interference and wiretapping resistance or low price) optical fiber is also the most used medium. Continuous traffic increase has shown that even optical fibers have their limits. Tests carried out on optical fibers have shown the presence of physical effects, which have impact on transmitted signal, degrade its power and cause numerous types of light dispersion.

Key words:
OPTICAL FIBRE, DESIGN, APLICATION, PMD, POLARIZATION MODE DISPERSION.

1. Introduction

Contemporary optical fibers can deal with almost all of the unfavorable effects which are known these days. They have sufficiently low specific attenuation, they can handle the attenuation caused by OH- ions, they can restrain the multimode effect and finally they can compensate a chromatic dispersion. But there is one problem, which the present science can't solve and this problem is the Polarization Mode Dispersion (PMD). This effect is a restricting factor of high-speed long-distance optical routes.

2. Fiber Impact on signal

Attenuation and dispersion limit optical fibers transmission capabilities in communication systems. While attenuation decreases the power of transmitted optical signal, dispersion causes data rate decrease due to time spread and deformation of transmitted impulses.

Attenuation

The Grecian letter α stands for an attenuation and it is given in [dB/km] units. The power of transmitted optical radiation decreases exponentially due to absorption and dispersion along the fiber.

Absorption

Attenuation coefficient significantly depends on wavelength. Silicon fiber has two noticeable absorption bands - the first one in infra-red region and the second one in ultra-violet region. Absorption caused by OH- ions has been recently removed by specially designed fibers according to ITU G.652d recommendation [11].

Rayleigh's dispersion is typical for silicon fiber - it decreases optical power. This causes random refraction index, which happens due to molecule distribution along the fiber, which is not homogeneous. These molecules create so called "dispersion centers". Intensity of dispersed radiation increases with wavelength - blue light is being more dispersed than red. This effect is called Rayleigh's principle.

Silicon fiber transmission capacity is therefore limited by Rayleigh's dispersion on one side and by infra-red absorption band on the other side [2].

Dispersion

Dispersion is scattering of light energy in time. Its influence is equal to fiber length. We can find three types of dispersion in optical fibers. One of them further splits in other types according to its source.

DMOD (λ) - Mode Dispersion.
Individual modes go through the fiber at different speeds. By their mutual interference, widened signal appears at the

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end of the fiber. This signal exceeds decision levels. Mode dispersion can be seen in multi-mode optical fibers only. Its impact on optical fiber is the most important.

DCH (λ) - Chromatic Dispersion
It's a sum of material, waveguide (geometric) and profile dispersions.

$$DCH(\lambda) = DMAT(\lambda) + DWG(\lambda) + DP(\lambda) \quad (1)$$

Its impact is significantly smaller than mode dispersion. Zero chromatic dispersion condition is:

$$DMAT(\lambda) + DP(\lambda) = DWG(\lambda) \quad (2)$$

DMAT (λ) - Material Dispersion
Individual wavelengths go through the fiber at different speeds because of imperfect fiber material.

DWG (λ) - Waveguide Dispersion
Individual wavelengths go through the fiber at different speeds because of different speeds through core and coat. It depends mainly on geometric construction of the fiber. Its value is comparable to material dispersion.

DP (λ) - Profile Dispersion
Individual wavelengths go through the fiber at different speeds, which is caused by refraction index wavelength dependency. Mutual compensation with material dispersion is possible. Dependency can be observed beginning from high-data-rate speeds.

DPMD (λ) - Polarization Mode Dispersion
It is caused by a physical principle of light - the light polarization. Light propagation in two components - planes (horizontal and vertical) - in two "modes" does not have the same speed. Circularly polarized wave can be seen in optical fiber most of the times. To some degree it is an accidental effect due to optical route parameters that can't be always estimated.

3. Optical Fiber Types

Single-mode fibers are nowadays defined by ITU-T and categorized to following types: G.652a, b, c, d; G.653a, b; G.654a, b, c; G.655c, d, e; G.656 [11][12][13].

G.652a fiber type is standard single-mode fiber 9/125. Sometimes denominated as USF (UnShifted Fiber), or as MC (Matched Cladding) fiber - because of typical step refraction index change at the core/coat interface. It has been designed for 1.310 nm wavelength usage on which it also has zero dispersion. It can also work at 1.550 nm wavelength but for this band it has not been optimized. Typical value of chromatic dispersion at 1.550 nm is 17 ps/nm-km, attenuation approx. 0,2 dB/km and polarization dispersion is less than 0,1 ps/km.

G.652b fiber is known as DC (Depressed Cladding) or fiber with buried(nested) refraction index. Coat refraction index in core area is lower than in coat.

G.652c/d fibers are quite new, which can be used for the whole range of wavelengths. This is possible due to no attenuation caused by absorbed OH- ions resonances. Useful especially for systems with wavelengths from 1.285 nm to 1.625 nm, hence it is useful for wavelength multiplexes. Typical attenuation values at 1.550 nm are 0,2 dB/km.

G.653 fibers are conventional fibers with chromatic dispersion suppressed at 1.550 nm. They are denominated as DSF (Dispersion Shift Fiber) or fibers with shifted dispersion characteristics. It is used for higher long-distance data rate speeds but only for transmission with one wavelength. It is not suitable for wavelength multiplex systems - cross talks occur. Maximum polarization dispersion value is lowered to 0,2 ps/^/km.

G.654 fibers - also known as CSF (Cut-off Shifted Fiber) - Fiber with shifted boundary wavelength. It is being used at 1.550 nm because here it has the lowest attenuation value. This has been achieved by using clear silicon glass in core fabrication. The main field of use is for long-distance transmissions without amplifiers (e.g. under-sea routes).

G.655 fibers are denominated as NZ-DSF (Non Zero - Dispersion Shifted Fiber). It means fiber with shifted non zero dispersion. As the name suggests - these fibers have their dispersion shifted out of 1.550 nm window. There are two types of these fibers: NZ-DSF(+) and NZ-DSF(-). In case of (+) the dispersion is shifted before 1.550nm wavelength and in case of (-) after 1.550nm wavelength. Typical value of chromatic dispersion at 1.550 nm is 4,5 ps/nm-km, attenuation is 0,2 dB/km and polarization dispersion is 0,1 ps/km. Field of use typically for dense wavelength multiplex, long-distance routes and very high-speed data rates.

G.656 fibers are actually upgraded G.655 fibers. Typically used in S, C and L bands, for WDM system - in S band, we will get another, at least 40, channels (when using dense wavelength multiplex). These fibers have non zero chromatic dispersion value in the band 1.460 nm - 1.625 nm.

4. Light Polarization

Light polarization is a physical effect given by a direction of electric field intensity vector ε(r,t) and its dependency on time. In case of monochromatic light all three components of vector ε(r,t) are sinusoidal changing in time. Fiber optics can be considered paraxial; hence the waves can be considered transversal electromagnetic waves (TEM). Electric field intensity vector lies in the plane which is perpendicular to z axis (in x-y plane) and the end point of the vector inscribes circle. Therefore, the wave is circularly polarized. Everything mentioned above is shown in Figure 1 [6].

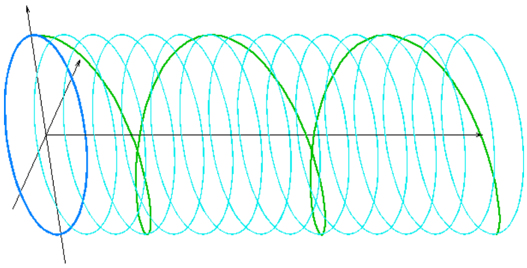

Fig. 1 - Rotation of electric field end point in x-y plane in given position and snapshot of electric field vector end point trajectory in given time

Matrix description of polarization theory is too much extensive to be mentioned in this work. It can be found in literature [2] a [1]. Mathematical definition by Jones and Stokes's space and Pointing's vector will be used for mentioned application development.

5. Present Optical Routes Planning Techniques

Progress in optical communication has made attenuation and chromatic dispersion insignificant for high-speed optical routes planning [8]. The only problem remaining is polarization mode dispersion (PMD). It doesn't have the biggest impact on signal but it is the most significant because we do not know how to remove it, yet. International telecommunication union has specified the maximum allowed values for PMD [11]. However, established practice is 1/10 of a signal element period.

Present software possibilities for designers are great. But dealing with PMD issues is not that easy. There are many tools for creating project documentation and for detailed calculations of unwanted effects on signal. Some of them have user-friendly environment allowing you to plan transparently and some of them are focused more on optical route experiments and tests. In following paragraph you can find all available design programs.

OptSim - is intuitive modeling and simulation environment developed by RSoft Company. You can design and determine the performance of physical layer in optical communication systems. This program is the only one that allows user to choose the value of PMD. However, it is not possible to observe only this parameter or to create any parametric simulations. The application only takes PMD into account for simulation, draws an eye diagram and exports values to MatLab environment.

EXFO Optical Software - application especially designed for processing the values of EXFO measuring devices outputs. There is no possibility to somehow configure the route or to change input parameters.

FIBERCORE - Polarization Mode Dispersion Emulators - these are emulators for measuring. It is a HW solution designed for imaginary optical route simulations. There is no possibility to somehow configure the route or to change input parameters.

OpTaliX - geometric optics simulator. It is possible to simulate optical transmissions, to observe parametric changes of refraction index, environment attenuation and to depict the results in dependency on parameters. However, dispersion impact simulation is available for chromatic dispersion only.

Set of simulation programs OptiWave - it is Japanese software; unfortunately no English version is present. The set includes OptiSystem (for optical route design with attenuation and chromatic dispersion calculation option), OptiBMP (VB script for comfort mapping), OptiGratings (suitable only as a school aid tool), OptiFiber (allows you to simulate changing fiber parametres except PMD) and OptiAmplifier (optical amplifier simulator).

None of the applications mentioned above can simulate PMD impact or depict final value of PMD based on route parameters.

6. Conclusion

The article contains basic impacts of optical fiber environment on a transmitted signal and analysis of present mediums for optical transmissions as well as the analysis of polarization impact on high-speed transmissions. It also deals with present route design possibilities. Part of this work is also the description of the biggest problem in optical routes - polarization mode dispersion. The aim of this article was to show the incapability of present design software for sufficient optical route design including polarization mode dispersion calculations.

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