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Parameter Evaluation of a Dense Optical Network

V. Bobrovs, Ģ. Ivanovs
Department of Telecommunications, Riga Technical University,
Azenes st. 12, LV-1010 Riga, Latvia, tel. +371 7089245; e-mail: ahil@inbox.lv

Introduction

A Wavelength Division Multiplexing (WDM) system is a high-speed optical transmission system that simultaneously transports optical signals of different wavelengths over a single optical fiber. WDM was developed as a next generation optical signal transport technology after traditional Time Division Multiplexed (TDM) systems offering much greater potential capacities. TDM is the most popular technology in the electrical networks, but it cannot utilize the available bandwidth, because it is limited by the speed of the time-multiplexing and demultiplexing components. That technology uses electrical components, which restrict potential resources of optical fibers. The latest version of WDM, High Density WDM (HDWDM), achieves higher capacity by dividing a wavelength-band into even more channels. Today's HDWDM systems can combine up to 128 or more wavelengths onto a single fiber [1].

Theoretically WDM technology gives indefinitely many resources in optical fibers. How much resources are dependent on many factors: channel spacing between multiplexing channels, modulation types, and optical fiber lengths (optical fiber span can be restricted by attenuation or by dispersion) [1]. This work contains the research of optical signal wastages and practical connectedness between signal transmission speed and losses. Researches are created with WDM optical link simulation contribution, where the different modulation types, signal bit rates and nonlinear effects (Self Phase Modulation SPM, Cross Phase Modulation XPM and Stimulated Raman Scattering SRS) are presented. SPM and XPM are described by Schrodinger nonlinear equations and SRS by numerical integration with the trapeze rule help [2].

Structure of a WDM system

Principal scheme of WDM system is given in Fig. 1. The main elements of the circuit are as follows: transmitter, WDM multiplexer, Single Mode Fiber (SMF), and Dispersion Compensation Fiber (DCF), amplifier, WDM demultiplexer and receiver. First of all, transmitters get the signals from different sources, for example the first optical channel is coming to transmitter with Synchronous Digital Hierarchy (SDH) stream and the second one with Asynchronous Transport Module (ATM) flow. This is the collateral benefit of WDM systems, in which many baseband-modulated channels are transmitted along a single fiber but with each channel located at a different wavelength. Each of those streams are configured by appropriate interface data unit and multiplexed with WDM multiplexer in a total optical signal. If the optical transmission system is limited by attenuation, the total optical signal can be amplified. Otherwise the DCF utilization will be useful for dispersion compensation [1].

Receiver part of the system amplifies an outgoing simultaneous signal; demultiplex them (divide the signal on λ_n wavelength), and indicate each of λ_n by detector. The band filter can be installed before the detector, to reduce transitional noises. As a result the primary digital pulse code sequence will be restored [1].

The multichannel signal which is going from WDM multiplexer to WDM demultiplexer is commonly worse, because of many factors. The work considers the main reasons of signal deterioration, and dependency between the signal transmission, bit rates, and different modulation types.

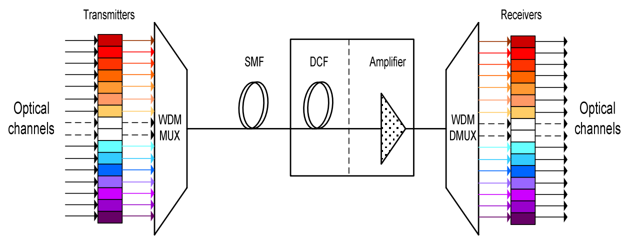


Fig. 1. Structure of WDM system (WDM MUX/DMUX – WDM multiplexer/demultiplexer, SMF – single mode fiber, DCF – dispersion compensation fiber).

The deterioration of signal in WDM system

Understanding the sources of attenuation and getting rid of them are the first steps toward the designing of networks.

Dispersion, or the spreading out of optical pulses over time, comes from several possible sources [1].

Chromatic dispersion is the wavelength dependence of the speed of light when traveling through a medium other than a vacuum, such as a glass fiber. With single-mode fibers, the group velocity changes with wavelength for two reasons. First, there is chromatic dispersion in the bulk material. This bulk dispersion results from the wavelength dependence of the fiber's refractive index. Second, there is waveguide dispersion. Waveguide dispersion results from the wavelength dependence of the fiber's mode-field diameter (MFD) [1].

However, in systems operating near the fiber's zero-dispersion point and using very narrow-line-width sources, the dominant source of pulse broadening can be differential group delay (DGD) due to birefringence in the optical fiber. After chromatic dispersion, DGD is the most likely effect limiting the transmission bandwidth of single-mode fiber, and it presents an inherent potential limitation in long-distance communications systems operating in the multi gigabit range [1].

With wavelength-division multiplexing (WDM), where many different channels at different wavelengths are present, too little chromatic dispersion can actually be a detriment because of nonlinear effects within the optical fiber [1]. One of the phenomena is Stimulated Raman Scattering (SRS). When multiple channels are present, power is transferred from shorter wavelengths to longer ones. This has resulted in additive noise at the longer wavelength and subtractive noise at the shorter one [5]. In a single-channel system the SRS (the power level at which Raman Scattering begins to take effect) is very high [1].

Another one is SPM, which creates a "chirp" (a gradual shift in frequency) over the whole duration of a pulse. This chirp is conceptually like the chirp created by chromatic dispersion in the normal dispersion regime [5].

When there are multiple signals at different wavelengths in the same fiber Kerr effect caused by one signal can result in phase modulation of the other signals. This is called Cross Phase Modulation (XPM) because it acts between multiple signals rather than within a single signal. In contrast to other nonlinear effects XPM effect involves no power transfer between signals. The result can be asymmetric spectral broadening and distortion of the pulse shape [5].

Simulation process and results

For WDM system research we have used WDM system modulation program [3, 4]. The algorithm of that program divides the Schrodinger nonlinear equation for two parts (for linear part and nonlinear part). The linear part stores an attenuation and dispersion, and nonlinear part SPM and XPM. Each of the part joins to zero, and solves with Split-Step Fourier algorithm. SRS effect is studied with the help of trapeze integration rule. At the end of the counting all that parts are summarized.

We studied the Standard Single Mode Fiber SSMF practical optical fibers for high-speed telecommunications (the main parameters are: attenuation 0,2 dB/km, dispersion 17 ps/(nm*km), dispersion slope 0,06 and nonlinear index is 2,7e-20 m^2/W), where we will change the amount of channels, frequency interval, bit rates and signal shapes to estimate systems signal characteristics, optical fiber length is 100 km. The central wavelength was 193,1 THz (International Telecommunication Union ITU standard), because of Erbium Doped Fiber Amplifier (EDFA) spectrum. That's analyzing the WDM system input/output spectrum with 16 channels and 100 GHz frequency interval Fig. 2.

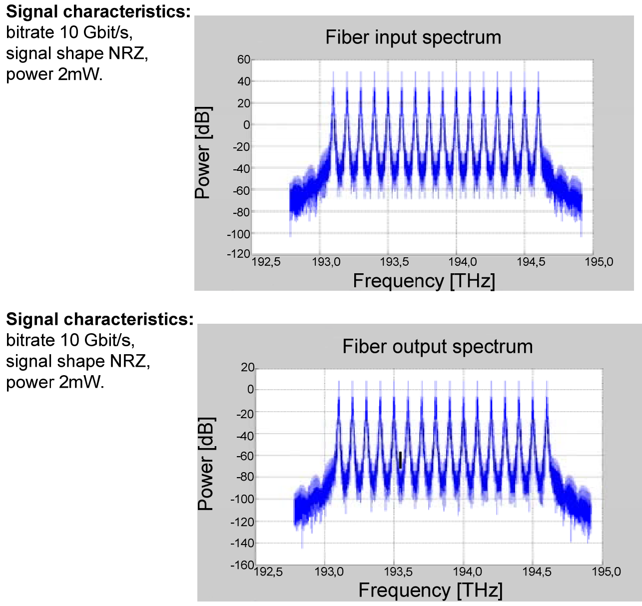


Fig. 2. WDM system with 16 channels and 100 GHz frequency interval

How we can see from figure 2. the signal-to-noise ratio is enough for WDM system operation. The maximum power level on output is -10 dB and minimum is -90 dB.

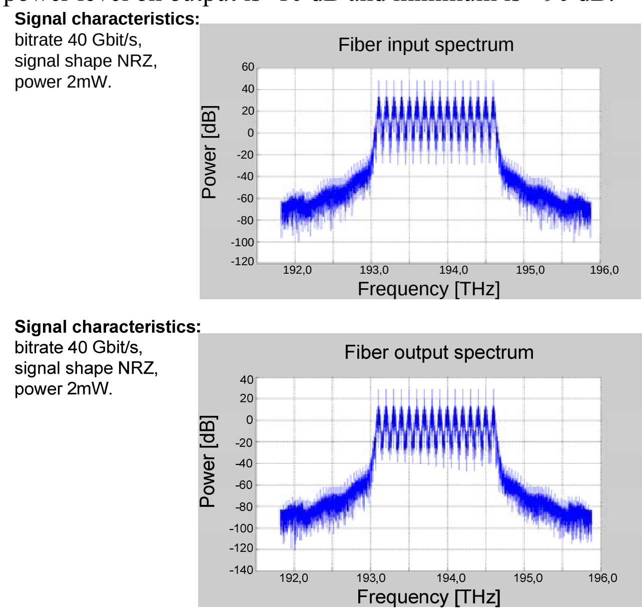


Fig. 3. WDM system with 16 channels and 40 Gbit/s bit rate

Modifying the transmission speed from 10 Gbit/s to 40 Gbit/s, the signal-to-noise ratio decrease, maximum power level on output is 10 dB and minimum is -20, Fig. 3.

To change the channel spacing from 100 GHz to 400 GHz the signal-to-noise ratio stabilizes, maximum power level on output is 10 dB and minimum is -70 dB Fig. 4.

Signal characteristics:
bitrate 40 Gbit/s,
signal shape NRZ,
power 2mW.

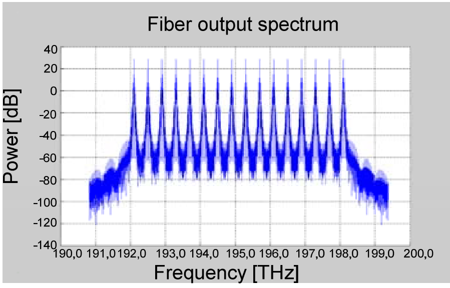


Fig. 4. WDM system with 400 GHz channels spacing and 40 Gbit/s bit rate

The RZ code is safer in synchronous transmission systems than NRZ code, because of self-synchronization [2], but that requires carrying capacity expansion. Modifying the system modulation to RZ, the signal-to-noise ratio decrease and channels spectrum overlays, the maximum power level on output is -10 dB, and minimum is -60 dB, Fig. 5.

Signal characteristics:
bitrate 10 Gbit/s,
signal shape RZ,
power 2mW.

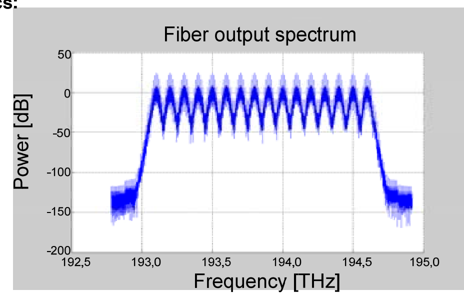
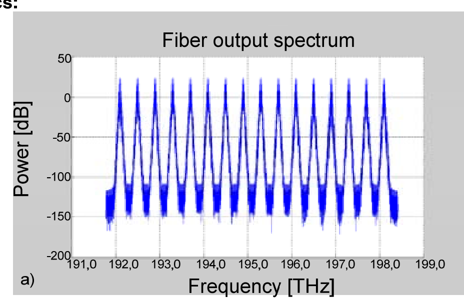


Fig. 5. WDM system with 10 Gbit/s bit rate, 100 GHz channels spacing and RZ modulation

To get the better signal-to-noise ratio and signals suspension spectrum we need to change the channel spacing at least 4 times or reduce transmission speed, Fig.6.

Eye diagrams provide a good representation of the behaviour of a transmission system, accounting for many of the factors that affect its performance. Idealized eye diagram (without any noises) for WDM system is created in Fig. 7.

Signal characteristics:
bitrate 10 Gbit/s,
signal shape RZ,
power 2mW.



Signal characteristics:
bitrate 2.5 Gbit/s,
signal shape RZ,
power 2mW.

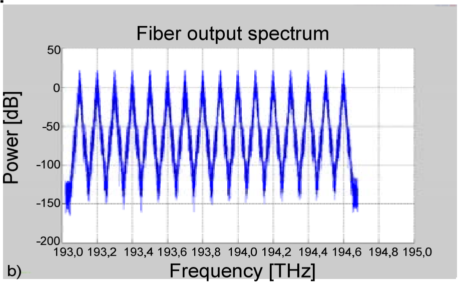


Fig. 6. WDM systems: a) 10 Gbit/s bit rate, 400 GHz channel spacing, and b) 2,5 Gbit/s bit rate, and 100 GHz channel spacing

Signal characteristics:
bitrate 10 Gbit/s,
signal shape NRZ,
power 2mW.

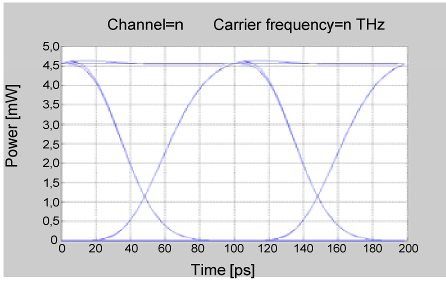
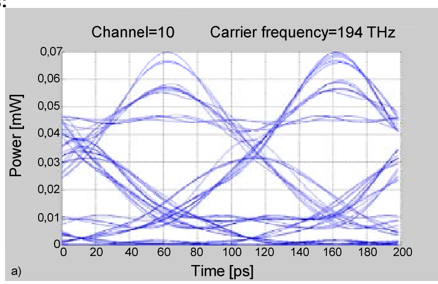


Fig. 7. Output eye diagram without any noises

Signal characteristics:
bitrate 10 Gbit/s,
signal shape NRZ,
power 2mW.



Signal characteristics:
bitrate 10 Gbit/s,
signal shape NRZ,
power 2mW.

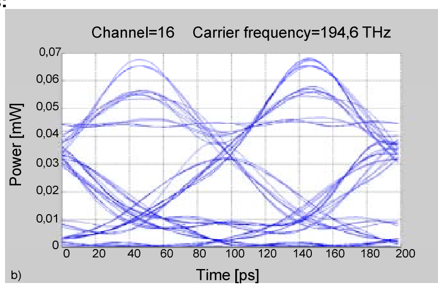
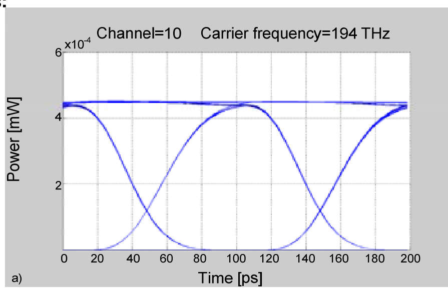


Fig. 8. Output eye diagrams: a) channel number 10, b) channel number 16

Signal characteristics:
bitrate 10 Gbit/s,
signal shape NRZ,
power 2mW.



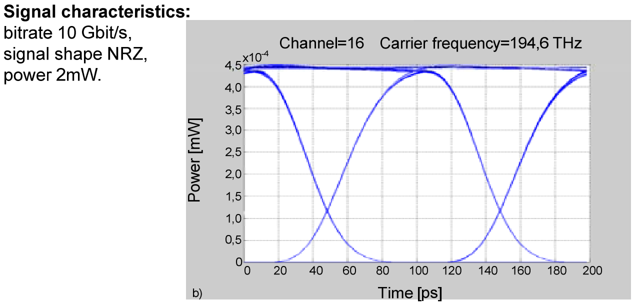


Fig. 9. Output eye diagrams after DCF connection

The impact of dispersion and nonlinear effects presented in Fig. 8. The eye height from the bottom to the top is the indicator of noise, when the lines become thicker and shaggy the signal is degraded. The signal width at the central of eye diagram is index of jitter. If the lines are thins like on Fig. 7. the level of jitter is low, otherwise increase [1]. To compensate nonlinear effects and dispersion we need to put on the DCF, Fig. 9.

Conclusions

In this work we have presented the WDM systems signal parameters dependency on the number of WDM channels, modulation types and intervals between WDM systems signals. The results show the dispersion impact on total number of channels, modulation, interval and bit rate. To enlarge one of them or change the modulation scheme, the total dispersion impact will increase.

To reduce the impact of SRS using one of the technical solution practically not feasible, but to decrease the input power level will decrease the SRS too.

When the channel interval in WDM systems is increased the effect of XPM decreases.

SPM will decrease, if the total level of dispersion will be reduced. In WDM systems where the total dispersion level is compensated the SPM will not appear.

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This paper contains the investigation of dispersion and nonlinear effects impact on WDM systems signal, depending on number of WDM channels, modulation types (Non Return-to-Zero NRZ and Return-to- Zero RZ) and intervals between WDM signals. The effect of dispersion has been examined. It has been shown that total signal characteristics directly depended on nonlinear effects (Self Phase modulation SPM and Cross Phase Modulation XPM). The spectrum and eye diagrams created for signal quality estimation, which represent the signal dependency on many factors. Ill. 9, bibl. 5 (in English; summaries in Lithuanian, English, Russian).

В. Бобровс, Г. Ивановс. Оценка параметров плотной оптической сети // Электроника и электротехника. – Каунас: Технология, 2006. - № 4(68). – С. 51–54.

Анализируется влияние дисперсии и нелинейных эффектов на сигналы систем WDM, которое зависит от количества каналов WDM и типов модуляции. Показано, что характеристики сигнала зависят от SPM и XPM. Предложены диаграммы спектра для оценки качества сигналов. Ил. 9, библ. 5 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Bobrovs, G. Ivanovs. Tankaus optinio tinklo parametrų įvertinimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2006. – Nr. 4(68). P. 51–54.

Tiriamas dispersijos ir netiesinių reiškinių poveikis WDM sistemų signalams, priklausantis nuo WDM kanalų skaičiaus, moduliacijos tipų (negrįžtant į nulį – NRZ ir grįžtant į nulį – RZ) bei intervalų tarp WDM signalų. Tirtas dispersijos poveikis. Parodyta, kad bendro signalo charakteristikos tiesiogiai priklauso nuo netiesinių veiksnių (savaiminės fazės moduliacijos – SPM ir tarpusavio fazės moduliacijos – XPM). Sukurtos spektro ir akies diagramos, skirtos signalo kokybei įvertinti. Diagramos iliustruoja signalo priklausomybę nuo daugelio veiksnių. Il. 9, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).