TELECOMMUNICATIONS ENGINEERING

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TELEKOMUNIKACIJŲ INŽINERIJA

Investigation of Spectrum-sliced WDM System

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Introduction

The enormous potential of WDM technology is widely used in today's telecommunication networks. However, the economical factor makes WDM systems available only for application in long-haul systems with demand for high capacity (the order of Tbit/s) [1]. In case there was an affordable WDM system providing moderate data rates (the order of Gbit/s) it could be used for application in MANs (Metropolitan Area Networks) with fiber spans of up to 10 km. Using such a system telecom operators would be able to multiplex various technologies/services via one fiber, for example Ethernet for data services and STM-4 for telephony applications, or multiplex several physical (e.g. Ethernet) links for the purpose of greater capacity and/or reliability.

In this paper we demonstrate a theoretical 4-channel spectrum-sliced WDM telecommunication system, utilizing LED sources with internal modulation and optical filtering (slicing) for channel separation. A LED source was used for each channel to avoid the need for external modulators, therefore making the system more cost-effective. Similar configurations can be found in [2,3]. Alternative configurations utilizing external modulation can be found in [4– 7].

We used two fibers for full-duplex transmission of information, so the system is symmetrical, i.e. both sides of the system are fully identical. The main reason for not using WDM for direction separation was to avoid SNR degradation due to noise from signal reflections and Rayleigh scattering. This configuration also makes the system less complex, though such a system is also less flexible and needs two fibers instead of one. Another reason for two-fiber configuration is that both ends are identical, making it possible to use the same components at both ends, therefore lowering the price and complexity of system maintenance.

The analytical part of our investigation was done using a software simulator. All the system components were simulated using OptSim software. OptSim is an advanced optical communication system simulation package designed for professional engineering and cutting-edge research of WDM, DWDM, TDM, CATV, optical LAN and other emerging optical systems in telecom applications. OptSim represents an optical communication system as an interconnected set of blocks. Each block is simulated independently using the parameters specified by the user for that block and the signal information passed into it from other blocks [8].

System Design and Simulation

Fig. 1 shows a schematic diagram of the proposed 4-channel SSWDM system. On the transmission side of the system we have 4 LEDs with internal modulation operating in the 1540 nm region. This region was chosen to minimize influence of fiber loss and to have a potential opportunity to use EDFAs (Erbium Doped Fiber Amplifiers) for spans longer than 10 km. The output power and 3-dB bandwidth of each LED were – 5 dBm and 60 nm respectively [4].
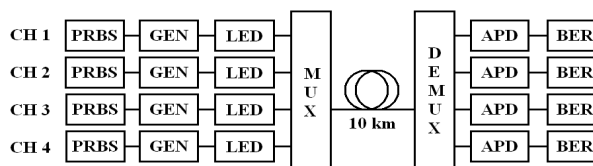

Fig. 1. A schematic diagram of 4-channel SSWDM system

We modulated each LED with two different modulation rates to achieve data transfer rates of 622 Mbit/s and 1 Gbit/s. A pseudorandom bit sequence was used for this purpose (pattern length is 2^{15}). The type of modulation used was on-off keying (OOK) and NRZ (Non-Return to Zero) format was used for signal coding. The spectrum of modulated LED signal is shown in Fig. 2.
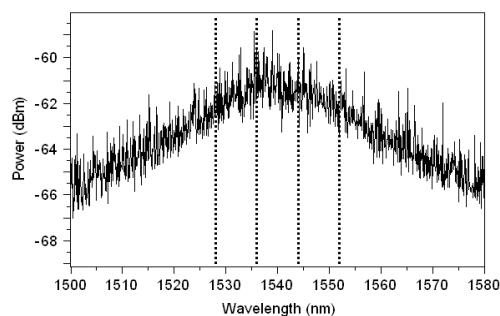

Fig. 2. Spectrum of modulated LED (central wavelengths of channels are shown with dashed lines)

For multiplexing four channels into a single fiber we used optical multiplexer with 3 nm channel bandwidth and 8 nm channel spacing. Due to the filtering process in multiplexer we could use LEDs of the same kind for all the four channels. The system was designed so that to minimize noise from the adjacent channels, resulting signal-to-noise ratio is greater than 20 dB for each channel. The spectrum of the four channel multiplexed signal is shown in Fig. 3.
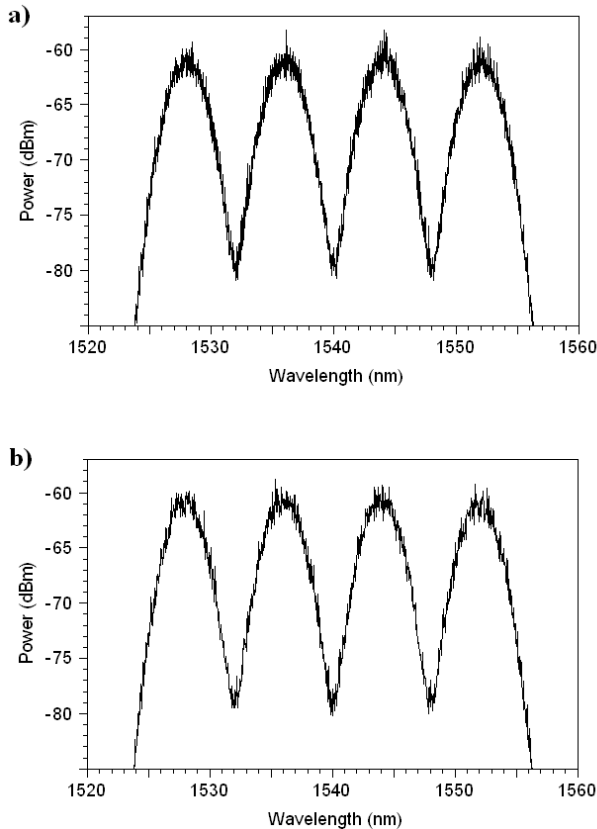

Fig. 3. Spectrum of four spectrum-sliced channels multiplexed signal for a) 622 Mbit/s; b) 1 Gbit/s

Fig. 3 shows SNR of approximately 21 dB for 622 Mbit/s, and 1-2 dB lower SNR for 1 Gbit/s. The reason for this decrease in SNR for 1 Gbit/s is higher modulation ratio and thus broader spectrum of modulated LED signal.

The multiplexed signal is transmitted over 10 km of standard single mode fiber [1]. Single mode fiber was chosen to minimize the influence of dispersion, the main limitation of the system as it is seen from the simulation. The demultiplexer has the same parameters as the multiplexer in terms of channel bandwidth and channel spacing.

On the receiver side of the system we have four avalanche photodiodes (APDs) to detect signals and four BER (Bit Error Rate) meters and eye-diagram analyzers to evaluate performance of each channel. Avalanche photodiodes were chosen because they have higher sensitivity than PIN photodiodes which is essential, because of high slicing losses.

The simulation of 622 Mbit/s and 1 Gbit/s configurations of the optical system gave us consequent results in terms of optical link power budget (the worst channel case is shown in the Table 1):

Table 1. Power budget

Transfer rate, Mbit/s	622	1000
Distance, km	10	5
LED output, dBm	-5,00	-5,00
Modulation loss, dB	3,30	3,30
Multiplexer loss, dB	14,30	15,40
Fiber Loss (0,25 dB/km), dB	2,50	1,25
Demultiplexer loss, dB	1,20	1,20
Attenuation, dB	7,00	4,00
APD input, dBm	-33,30	-30,15
BER	$4,25 \cdot 10^{-10}$	$8,68 \cdot 10^{-10}$
With FEC		
Attenuation, dB	11,00	9,00
APD input, dBm	-37,30	-35,15
BER	$1,4 \cdot 10^{-17}$	$1,3 \cdot 10^{-16}$

Multiplexer loss is very high for both transfer rates because this is where the filtering takes place. For 1 Gbit/s this loss is approximately 1 dB higher also for the reason of broader spectrum of modulated signal.

During the simulation we inserted attenuation of signal to have margin for power loss in connectors, aging of fiber and equipment, and installation induced power losses – the factors OptSim doesn't take account of. The goal was to find the maximum margin for the BER $< 10^{-9}$ performance. Table 1 shows these margin values for both transfer rates with and without FEC. Forward error correction gives an increase in power margin of 4 and 5 dB for 622 Mbit/s and 1 Gbit/s respectively. Reed Solomon (255,239) encoding was used as the FEC algorithm.
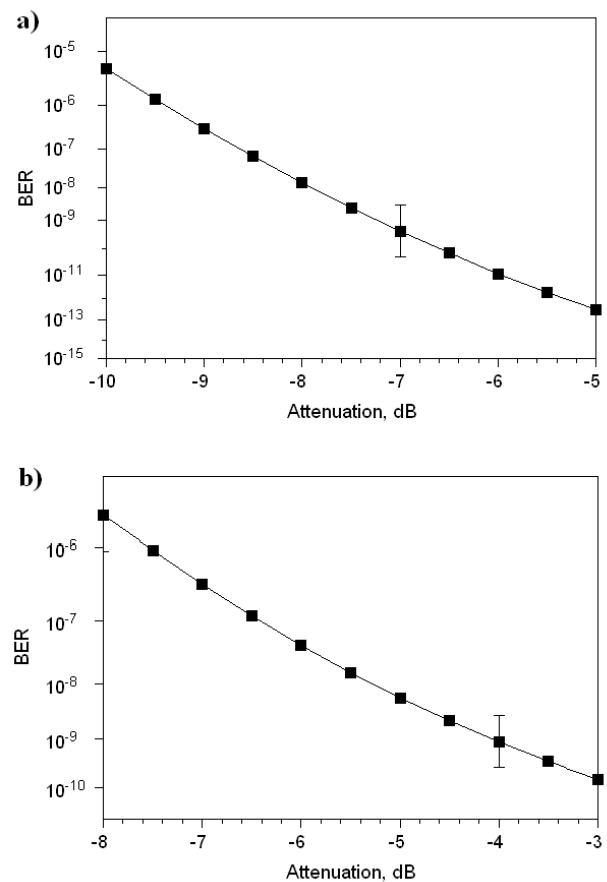

Fig. 4. BER dependence of inserted attenuation for a) 622 Mbit/s; b) 1 Gbit/s

The major influence of dispersion on 1 Gbit/s signal made us change the fiber span from 10 to 5 km in order to achieve BER $< 10^{-9}$ performance. Fig. 4 shows BER dependence of inserted attenuation for 10 km 622 Mbit/s and 5 km 1 Gbit/s links without FEC, Fig. 5 shows the influence of dispersion on BER for 1 Gbit/s link.
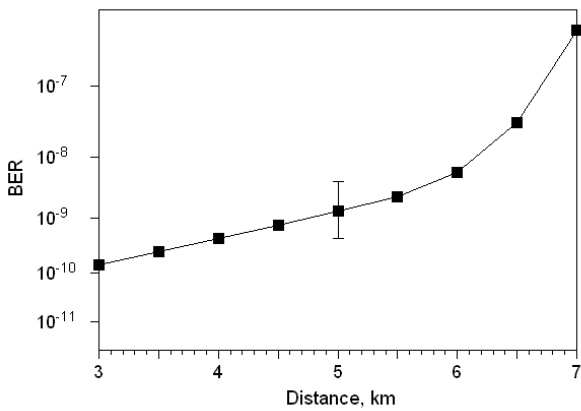

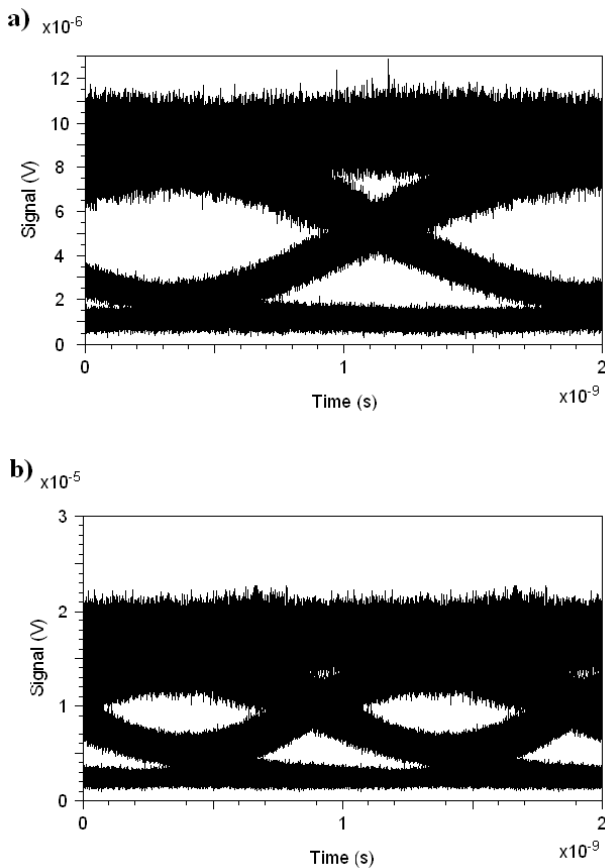**Fig. 5.** BER dependence of distance for 1 Gbit/s link

Fig. 6. Eye diagram of the received signal for a) 622 Mbit/s; b) 1 Gbit/s

Fig. 6 demonstrates that the amplitude of the received signal at 622 Mbit/s is approximately two times lower than the amplitude of 1 Gbit/s signal. This is primarily due to the difference in distance between the two configurations. Also we can see that the eye diagram of 1 Gbit/s signal is worse, the main reason for this being the influence of dispersion, which is greater in 1 Gbit/s case even though the link is two times shorter.

Conclusion

The four channel configuration of the system was chosen balancing between capacity and performance on one hand and physical limitations on the other. The distance limitation of 10 km is usually sufficient for most intracity optical spans, therefore system can be found useful in new and existing MAN networks. In some special cases the proposed 4-channel SSWDM system can be used as an alternative to devices like IPMUXes (IP multiplexers multiplex IP and TDM traffic onto the Ethernet transport) without the need for complex and expensive electronics and avoiding IP protocol induced latency and jitter problems for TDM traffic. In other cases the system can be used to aggregate Ethernet links to increase several times the transmission rate of trunk lines in metropolitan networks through the same fibers.

The proposed system can also be modified for use in FTTH (Fiber to the Home) applications, although the need for greater channel number in FTTH may not be feasible to satisfy with this approach, because of major multiplexer losses, which grow together with the number of channels.

Another reason for FTTH incompatibility is major difference in channel performance. The simulation showed that the worst channels are those on both sides of the sliced portion of the LED spectrum. Physical interpretation of this result is clear when looking at Fig. 2. Side channels have a 2-3 dB lower level of emitted power than central channels which corresponds to 10^2-10^3 BER increase according to Fig. 4.

Simulation approved the need for FEC: the results showed that forward error correction gives a 4-5 dB margin for the signal attenuation. This is equivalent to an increase in distance of about 16-20 km, though dispersion will definitely limit this to a much smaller distance increase in a real system.

Some of the disadvantages are also to be mentioned, the first one being inability to extend an already working system adding new channels, due to the fact the LED spectrum is fully utilized for initial 4-channel configuration. The second disadvantage is the need for two fibers for each bidirectional installation of the system. The reasons for this were described in the introduction part of this paper.

References

1. **Agrawal G.** Fiber-Optic Communications Systems. Third Edition. – Academic Press. – 2002.
2. **Han K. H., Son E. S., Choi H. Y., Lim K. W., and Chung Y. C. //** Bidirectional WDM PON Using Light-Emitting Diodes Spectrum-Sliced With Cyclic Arrayed-Waveguide Grating // IEEE Photonics Technology Letters. – 2004. – Vol. 16, No. 10. – P. 2380–2382.
3. **Han K. H., Son E. S., Lim K.W., Choi H. Y., Jung S. P., and Chung Y. C.** Bi-directional WDM passive optical network using spectrum-sliced light-emitting diodes //

Optical Fiber Communication. – 2004. – Paper MF98.

4. **Jung D. K., Youn C. J., Woo H. G. and Chung Y. C.** Spectrum-Sliced Bidirectional WDM PON // Optical Fiber Communication Conference. – 2000. – Vol. 2, No. 9. – P. 160– 162.

5. **Jung D. K., Shin S. K., Lee C.-H. and Chung Y. C.** Wavelength-Division-Multiplexed Passive Optical Network Based on Spectrum-Slicing Techniques // IEEE Photonics Technology Letters. –1998. – Vol. 10, No. 9. – P. 1334–1336.

6. **Jang Y. S., Lee C.-H. and Chung Y. C.** Effects of Crosstalk in WDM Systems Using Spectrum-Sliced Light Sources //

IEEE Photonics Technology Letters. – 1999. – Vol. 11, No. 6. – P. 715–717.

7. **Leeson M. S., Luo B. and Robinson A. J.** Spectral Slicing for Data Communications // Proceedings Symposium IEEE/LEOS Benelux Chapter Eindhoven. – 2006. – P. 165–168.

8. **RSoft Design Group, Inc.** OptSim 4.5 User Guide. – Physical Layer Division, 200 Executive Boulevard Ossining, NY 10562. – 2005.

I. Ļašuks, A. Ščemeļevs, O. Ozoliņš. Investigation of Spectrum-sliced WDM System // Electronics and Electrical Engineering. – Kaunas: Tehnologija, 2008. – No. 5(85). – P. 45–48.

Wavelength division multiplexing technology is widely used in modern long-haul systems to increase bandwidth of communication channels. However there is also a clear demand for higher capacity in metropolitan area networks, where CWDM and DWDM technologies are rarely used due to economical factors. This paper contains an overview of investigation of four channel SSWDM system. The main advantage of such a system is its relatively cheap components: light-emitting diodes with internal modulation are utilized on the transmission side. The investigation of the system characteristics and their conformance to the requirements of standards and real networks is executed using OptSim simulation software. As a result of the investigation several potential physical issues that can arise during maintenance of a real system are defined, recommendations are given to solve these issues. Ill. 6, bibl 8 (in English; summaries in English, Russian and Lithuanian).

И. Ляшук, А. Щемелев, О. Озолиньш. Исследование системы со спектральным нарезанием каналов // Электроника и электротехника – Каунас: Технология, 2008. – № 5(85). – С. 45–48.

Технология спектрального уплотнения (WDM) широко используется в современных магистральных системах связи для увеличения пропускной способности каналов. Однако потребность в увеличении пропускной способности существует и в городских сетях (MAN), в которых применение CWDM и DWDM технологий в большинстве случаев является экономически не целесообразным. Работа содержит описание исследования четырехканальной системы, основанной на технологии спектрального нарезания каналов (SSWDM). Главное приемущество данной системы заключается в сравнительной дешевизне ее компонентов, при достаточно высокой производительности: в системе применяются светодиоды с внутренней модуляцией. Соответствие характеристик системы требованиям стандартов и потребностям реальных сетей передачи данных исследуется при помощи программного симулятора OptSim. В результате исследования определены проблемы физического характера, которые могут возникнуть в процессе эксплуатации данной системы, даны рекомендации по их решению. Ил. 6, библ. 8 (на английском языке, рефераты на английском, русском и литовском яз.).

I. Ļašuks, A. Ščemeļevs, O. Ozoliņš. Spektre padalytų kanalų WDM sistemos tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 5(85). – P. 37–40.

Spektrinio multipleksavimo technologija (WDM) plačiai taikoma šiuolaikinėse ryšio magistralių sistemose, siekiant padidinti komunikacijų kanalų pralaidumą. Tačiau aiškiai reikia didinti ir miestų tinklų (MAN), kuriuose naudoti CWDM ir DWDM ekonomiškai netikslinga, pralaidumą. Pateikiamas keturių kanalų SSWDM sistemos tyrimas. Esminis tokios sistemos pranašumas yra palyginti pigūs komponentai: siųstuve naudojami šviesos diodai su vidine moduliacija. Sistemos charakteristikų bei jų atitikties standartų ir realių tinklų reikalavimams tyrimas atliktas naudojant modeliavimo programą „OptSim". Tyrimo metu nustatytos kelios potencialios problemos, galinčios pasireikšti eksploatuojant realią sistemą. Pateiktos rekomendacijos, kaip spręsti šias problemas. Il. 6, bibl. 8 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).