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Investigation of Colorless WDM-PON using a Broadband ASE-Source

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Introduction

Optical fiber access to the user, the so-called Fiber-to-the-Home (FTTH), is becoming a mature concept and a reality in many regions of the globe, with more than 4 millions homes already connected only in Europe [1]. The number of connected users is growing exponentially. It is widely accepted, FTTH is the only future proof technology that will be able to support the upcoming interactive multimedia services.

Traditional optical solutions based on point-to-point architectures are expensive for access configurations. To achieve the aim of cheap access networks the passive point-to-multipoint topology has been developed. Passive Optical Network (PON) has more advances because the number of active equipment is relatively low, that can increase cost-efficiency and decrease complicity in maintenance compared with traditional solutions [7]. Current PON systems are generally based on Time Division Multiplexing (TDM-PON) and have bandwidth limitations due to fundamentals of time division. The main way of increasing the bit rate is the use of Wavelength Division Multiplexing (WDM-PON) [6]. In WDM-PON systems, it is advantageous to deploy wavelength-agnostic (‘colorless’) Optical Network Units (ONUs) and Optical Line Terminals (OLTs), in order to avoid wavelength-specific equipment at each end user. This allows having a universal ONU at each user, and thus reduces costs by economy-of-scale and less stock diversity. Spectral slicing is an attractive approach for a colorless OLT [2, 3, 4, 5, 6].

In this paper we demonstrate 4, 8 and 16 channel WDM-PON system using broadband Amplified-Spontaneous Emission (ASE) source with optical slicing technique. The ASE source was chosen due to its power characteristics for bit rate increasing. The lack of power of LED sources doesn’t allow to use the external modulation [8].

We used two fibers for full-duplex transmission of information. The system is not symmetrical. The simulation consists of only the OLT's downlink part. The uplink part could be done using Ethernet PON or Gigabit PON for asymmetrical data transfer using another fiber or the entire fiber with the wavelength of 1310 nm. Another solution could be Spectral Sliced WDM system [8].

Spectral slicing was made with the Arrayed Waveguide Grating (AWG) and thin film filters with optical splitters.

The analytical part of our investigation was done using a software simulator. All the system components were simulated using OptSim software.

System Design and Simulation

Fig. 1 shows the schematic of proposed system with a EDFA generating broadband ASE (ASE-source). On the transmission side of the system we have the ASE-source with o power of 8.1 dBm.

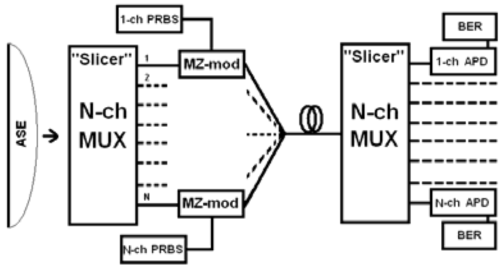


Fig. 1. A schematic diagram of N-channel system

Spectral slices are made with a help of AWG multiplexer or less complex construction which consists of splitters and thin-film filters. The spectrum of the ASE-source is shown in Fig.2.

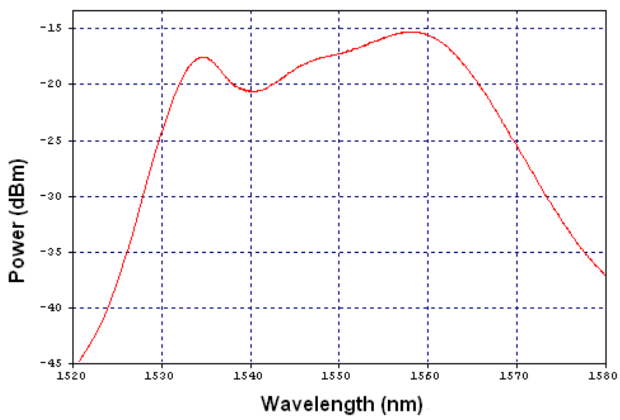
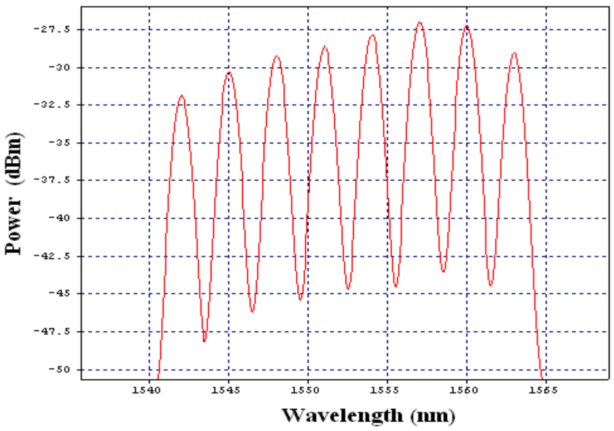
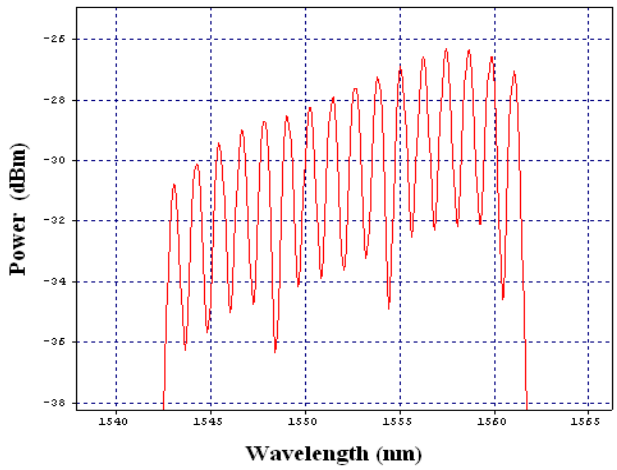


Fig. 2. Spectrum of ASE-source

All the slices are made in the region of 1540-1565 nm. 1530-1540 nm region in future can be used for broadcast video transmission. Each slice has the width of 1 nm for 4 and 8 channel systems and 0.6 nm for 16 channel system. The slice is modulated using Mazh-Zehnder modulator and pseudorandom bit sequence. NRZ (Non-Return to Zero) format was chosen for coding due to its simplicity. Due to nonflatness of the spectrum, the level of slices is different on side channels.



a)



b)

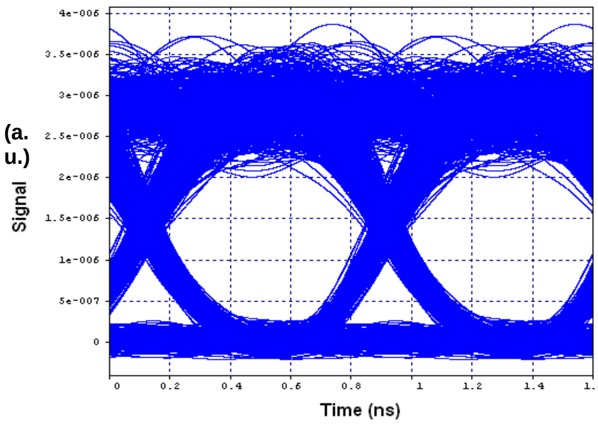
Fig. 3. Spectrum of: a – 8 channel; b – 16 channel systems

As we can see in Fig.3 the level of side channels can differ by 4 dB in 16 channel system that is why all the BER values are calculated for the worst case. The step between channels is the compromise between the slicing power penalty and SNR with dispersion. The configuration of multiplexer and demultiplexer is the same.

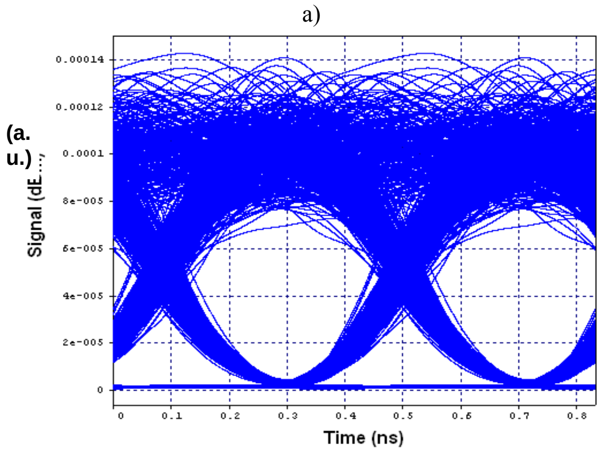
Table 1. System design

Systems capacity (channels)	Channel width (nm)	Step between channels (nm)
4	1	3.5
8	1	3
16	0.6	1.2

We used 10 km of SSMF (standard single mode fiber) for transmission because this type of fiber is the most popular among already installed infrastructure of optical distribution networks. On the receiver side of the system we have avalanche photodiodes (APDs) to detect signals with 4-order electrical Bessel filtering, 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 sensitivity of APD in this simulation is -32 dBm for 1 Gbit/s and -29 dBm for 2.4 Gbit/s. The sensitivity doesn't take into account the affect of dispersion and ASE-noise. One of the main limiting factors of the system is the noise of spontaneous emission, which can decrease the sensitivity of the receiver at least for 3 dB. There are 2 cases in Fig. 4: a) 1 Gbit/s 8 channel system b) 2.4 Gbit/s 8-channel system with excess amplifying which adds the decrease of SNR (Signal-to-Noise ratio).



a)



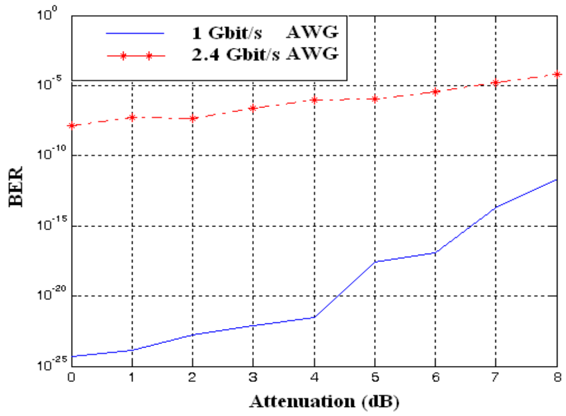
b)

Fig. 4. Eye diagram of the received signal for: a – 1 Gbit/s; b – 2.4 Gbit/s

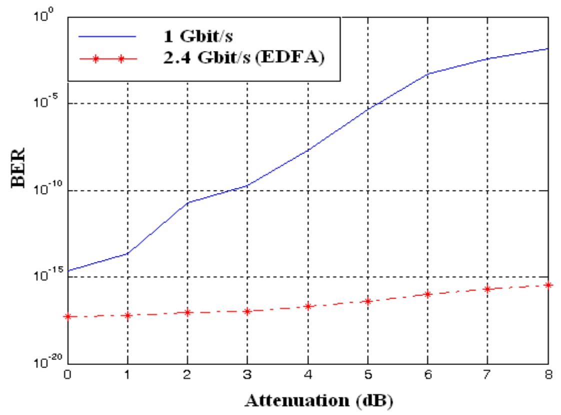
During the simulation we inserted attenuation of signal to have margin for power loss in connectors, aging of fiber and equipment, and installation induced power losses – the factors OptSim doesn't take account of. The goal was to find the maximum margin for the BER < 10^{-9} performance.

The first configuration of the system with for channels uses AWG MUX/DEMUX. It is seen that 2.4 Gbit/s modification can work only with excess amplifying. AWG MUX/DEMUX can be used for 1 Gbit/s realization with the margin reserve of 8 dB.

The configuration with splitters and thin-film filters is less complex, but the losses are higher. 1 Gbit/s realization has the reserve of only 3 dB. Losses due to incorrect installation can exceed this value. 1 and 2.4 Gbit/s systems with excess amplifying have the reserves of at least 8-10 dB. The disadvantage of the excess EDFA is the need of more bandpass and gain flattering filters to decrease the ASE noise and the channel power level differences.



a)



b)

Fig. 5. BER dependence of inserted attenuation for 4-ch system: a – AWG; b – thin-film filters

All this actions can decrease the cost-efficiency of the proposed system. The main difference between 4 and 8,16 channel system realization is the 3 dB inserted excess power margin. 16 channel realization has more powerful ASE-source with a power level of 15 dBm to compensate extra attenuation in AWG MUX and splitters. 8-ch system can "comfortably" work at a bit rate of 1 Gbit/s, but achieving 2.4 Gbit/s need extra amplifying.

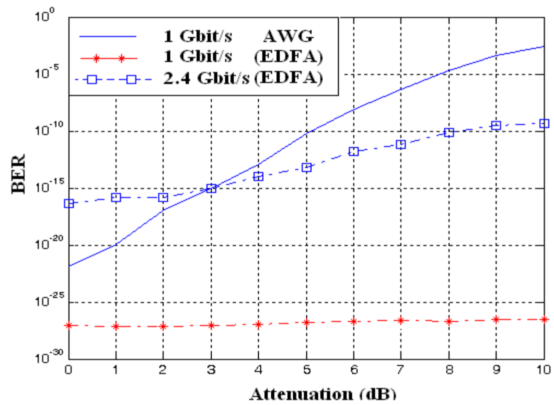


Fig. 6. BER dependence of inserted attenuation for 8-channel system

Fig.7. shows us that 16-ch system's stable work can be achieved only with AWG MUX. Splitter and thin-film filter configuration doesn't have enough margin reserve.

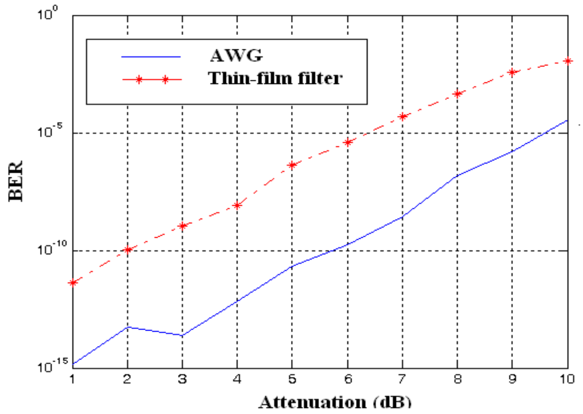


Fig. 7. BER dependence of inserted attenuation for 16-channel system

16 channel 2.4 Gbit/s system also is not reachable due to big slicing losses that is why all the BER measurements were made at a bitrate of 1 Gbit/s.

Conclusions

The main advantage of the 4 channel systems is the ability to use the configuration with cheap thin-film filters and splitters for 1 Gbit/s instead of expensive and temperature-sensitive AWG without amplifying. The use of AWG can enlarge the distance of the system by 10 km. Due to excess margin cheapest PIN photodiodes with worse sensitivity can be chosen. If there is a lack of "dark" fiber, 4 channel system is not cost-effective for optical distribution networks.

The eight channel configuration was chosen balancing between "dark" fiber utilization and bit rate. Modifications with external amplifying can also use PIN photodiodes instead of expensive APD.

Optimal utilization of the ASE-source bandwidth has the sixteen channel configuration, but it can be achieved only with AWG multiplexer that has high installation complicity and sensitivity to environment obstacles. This configuration has the bit rate limitation of 1 Gbit/s. To increase the channel number and bit rate, more powerful source must be used.

The simulation showed us the effect of the spontaneous emission noise on receiver sensitivity. The degradation can achieve the level of 5 dB using excess amplifying. Another main conclusion is the level difference between channels that can achieve 4 dB in the sixteen channel realization. The use of extra bandpass and gain flattering filters can solve this problem, but the payback is the increase of attenuation.

One of the disadvantages of the system is the inability to add new channels in the C and L-bands because of the full utilization of the ASE-source spectrum. As it was mentioned above 1530-1540 nm region can be used for extra video applications. The only way how channels can be added is the O-band using lasers or light emitting diodes, but it is impossible to use EDFA in this region. Another way of uplink realization using the same fiber is the use of Ethernet PON or Gigabit PON time division technologies.

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I. Ļašuks. Investigation of Colorless WDM-PON using a Broadband ASE-Source // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 6(94). – P. 43–46.

The use of fiber optic solutions increases every year in access networks to enlarge the bandwidth for each user. However, FTTH (fiber-to-the-home) networks and time division access that they use have technological limitations. WDM-PON technology is the best solution to satisfy future demand for the increasing of bandwidth. This paper contains an overview of investigation of 4,8 and 16-channel system based on the use of the spectrally-sliced ASE-source and an external modulation. The realizations with AWG-multiplexer and thin-film filters at different bit rates are also considered in this paper. 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. 7, bibl. 8 (in English; summaries in English, Russian and Lithuanian).

И. Ляшук. Исследование "безцветной" WDM-PON системы с использованием широкополосного источника усиленной спонтанной эмиссии // Электроника и электротехника. – Каунас: Технология, 2009. – № 6(94). – С. 43–46.

Оптоволоконные устройства с каждым годом всё более широко применяются в сетях доступа для увеличения полосы в расчете на одного абонента. Однако сети FTTH (волокно в дом) и технология временного уплотнения, используемая в них, имеют свои технологические ограничения. Для удовлетворения будущих потребностей в увеличении скорости наилучшим решением является технология WDM-PON. Работа содержит описание исследования 4,8 и 16-ти канальной системы на основе источника усиленной спонтанной эмиссии с применением внешней модуляции и техники спектрального нарезания каналов. В работе рассмотрены случаи с применением AWG-мультиплексеров и фильтров на тонких плёнках при различных скоростях. 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. 7, библ. 8 (на английском языке; рефераты на английском, русском и литовском яз.).

I. Ļašuks. Bespalvės pasyvaus optinio tinklo spektrinio multipleksavimo technologijos tyrimas taikant plačiajuostį ASE šaltinį // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 6(94). – P. 43–46.

Prieigos tinkluose naudojant optinį pluoštą, didėja galimybės kasmet kiekvienam vartotojui pasiųsti vis daugiau duomenų. Tačiau taikant optinio tinklo ir namų technologiją, iškyla tinklų ir laiko padalijimo technologinių problemų. Joms pašalinti siūloma taikyti pasyvaus optinio tinklo spektrinio multipleksavimo technologiją. Taikant spektrinį ASE šaltinį ir išorinį moduliavimą ištirta 4,8 ir 16 kanalų sistema. Taip pat ištirta AWG multiplekserio ir plonasluoksnių filtrų realizacija esant skirtingiems duomenų srautams. Sistemos charakteristikos ir jų atitiktis standartų ir realių tinklų reikalavimams ištirta naudojant modeliavimo programą „OptSim“. Nustatytos kelios potencialios problemos, galinčios pasireikšti eksploatuojant realią sistemą. Pateikta rekomendacijų, kaip spręsti šias problemas. Il. 7, bibl. 8 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).