Enabling technology for UDWDM access networks

Jan Lamperski*

Faculty of Electronics and Telecommunications, Poznan University of Technology, Polanka 3, 60-965 Poznan

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Abstract— In the presented paper we show an original concept of technology for access networks with ultra dense channel multiplexing using a multifrequency translator with an acousto-optic frequency shifter as a key module. As an example of functional capabilities of this module, original experimental results of a multifrequency optical source based on an erbium-doped fiber ring configuration are presented. Optical frequency comb generation with a very stable 1,5 GHz and 2.5 GHz frequency separation was obtained. We also proposed original configurations which allow the realization of network devices for gigahertz spacing channel multiplexing such as optical multiplexers, demultiplexers and optical add/drop multiplexers.

In fiber optic communication, high capacity transmission is one of the main challenges. Wavelength division multiplexing (WDM) allows a large fiber band to be efficiently exploited by spreading transmitted information over a number of optical channels. In all optical networks the WDM technology can be also used for packed switching, wavelength routing and as means of the multiple access technique.

The number of channels and channel separation depends on the progress of the optical source technology and the lowest channel spacing implemented currently in systems is 25 GHz. The ultra dense wavelength division multiplexing (UDWDM) technology required sources with an extreme wavelength stability [1-6].

For UDWDM applications, multifrequency sources can be implemented to synthesise optical carrier frequencies. Optical comb generation can be obtained by implementing glass-doped sources. Broad homogenous gain of erbium-doped fiber (EDF) is the main problem to overcome in EDF based multiwavelength lasers [7-9].

In the present work, we describe a technological concept for UDWDM access networks utilising a multifrequency acousto-optic frequency translation block as a key functional module.

This module can operate as a multifrequency signal translator, an optical source for a discretely tunable transmitter or an optical carrier frequency comb generator, to replace an array of discrete lasers.

As an example we demonstrate here experimental results of the features of a non-resonant ring optical carrier frequency comb generator [10,11] with exceptionally stable 1.5 and 2.5 GHz channel separation.

The idea of an optical multifrequency translator is presented in Fig. 1.

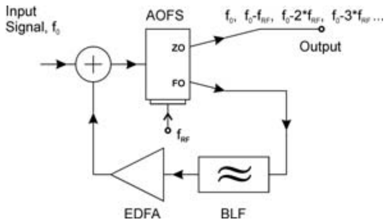


Fig. 1. The schematics of a multifrequency translator

The multifrequency translation module consists of a ring containing an acousto-optic frequency shifter (AOFS), an erbium-doped fiber amplifier (EDFA) and a band limiting filter (BLF). The operation is based on a multiple frequency shift in the optical loop. Every loop round-trip an AOFS splits an optical beam into two and after amplification and filtration a frequency shifted ray is fedback to the AOFS input. The AOFS controlled by a RF generator determines a frequency comb interval and a BLF limits the number of frequency lines.

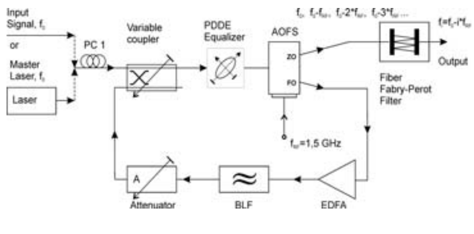
As the bulk acoustic wave AOFS operating frequency is limited to the value of 1.5 GHz, to obtain higher channel distances it is necessary to use a double frequency shifter configuration. We built two variants of experimental setups: a single and a double shifter configuration (Fig. 2). As an example of functional capabilities we focused on the results corresponding to the optical comb generator configuration.

In the experimental setups (Fig. 2) we used a narrow linewidth tunable laser as a master laser (ML) and double stage erbium-doped fiber amplifiers (EDFA), band limiting filters (BLF) with 1.2 nm transmission width acoustooptic frequency shifters (AOFS) of 1.5 and 1.0 GHz.

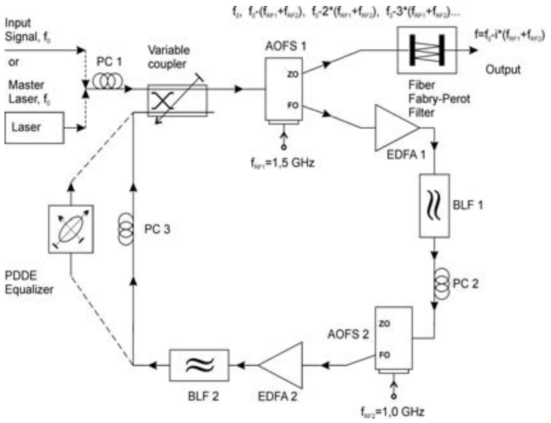
The acousto-optic frequency shifters had fairly different parameters: AOFS1 operating at 1.5 GHz had the insertion loss (IL) of 10.4 dB and the polarization sensitivity (polarization dependent loss PDL) of 4.2 dB, AOFS2 operating at 1.0 GHz had a higher IL (12.8 dB) and a considerably higher PDL value (15.1 dB).

* E-mail: jlamper@et.put.poznan.pl

The polarization controller PC1 allowed to adjust the state of polarization (SOP) of a master laser for the maximum diffraction efficiency, and PC2/3 were used to control the feedback loop polarization.



(A)



(B)

Fig. 2. Block diagrams of experimental setups: single shifter (A) and double shifter configuration (B)

The acousto-optic frequency shifters had quite different parameters: AOFS1 operating at 1.5 GHz had the insertion loss (IL) of 10.4 dB and the polarization sensitivity (polarization dependent difrection efficiency loss PDDE) of 4.2 dB, AOFS2 operating at 1.0 GHz had higher IL (12.8 dB) and a considerably higher PDDE value (15.1 dB).

The polarization controller PC1 allowed to adjust the state of polarization (SOP) of a master laser for the maximum diffraction efficiency, and PC2/3 were used to control the feedback loop polarization. Further experiments show that for a larger number of spectral lines the generation adjustment of polarization state in the loop turned out to be ineffective. In the final version of the experimental setup to compensate for PDDE of AOFS1 (with lower PDDE) we proposed and implemented an equalizer of the diffraction efficiency. In the case of AOFS2 (PDDE=15.1 dB) this approach was not useful because of a very high power penalty.

In both configurations a variable coupler was used to balance ML and loop beam powers.

A measured output spectrum of optimized comb generators operating at 1.5 GHz channel spacing is shown in Fig. 3.

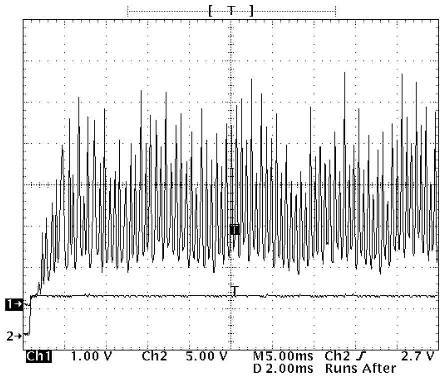


Fig. 3. Generated comb spectrum consisting of 84 spectral lines, channel separation: 1.5 GHz

A measured output spectrum of optimized optical carrier frequency comb generator operating at 2.5 GHz is shown in figure 4.

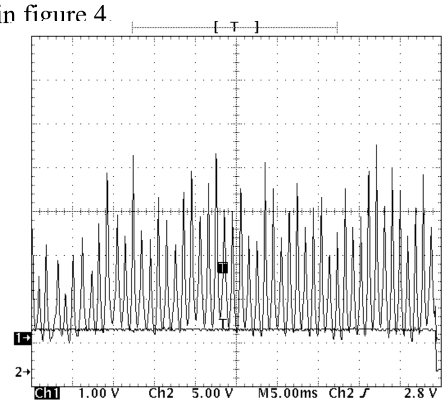


Fig. 4. Generated comb spectrum output spectrum with 60 optical carrier frequencies, channel separation: 2.5 GHz

We obtain 84 optical carrier frequencies with the separation of 1.5 GHz and 60 spectral lines with the distance of 2.5 GHz.

The construction of an access network with wavelength division multiplexing requires devices such as: optical couplers, optical filters, multiplexers (Mux) and demultiplexers (DeMux), optical add/drop multiplexers (OADM) and optical switches. Here we focused only on some wavelength dependent devices with a selectivity necessary for gigahertz optical channel separation.

As a basic building block we chose all fiber Fabry-Perot fixed or tunable filters. This type of FF-PF filters has a periodic transfer function with a free spectral range (FSR) value from 100 to 54,000 GHz and the finesse up to 16,000. These optical properties are excellent for UDWDM applications considered in this paper. The FF-PF filter can be used to select a desired channel in a tunable receiver or to select an optical carrier frequency in a discretely tunable transmitter with a multifrequency comb generator. A discretely tunable fiber Fabry-Perot filter adjusted to a UDWDM frequency grid can also be obtained [11, 12].

The FF-PF filter type can also be used for the realization of the UDWDM multiplexing and demultiplexing or optical add/drop multiplexers. In all cases the FF-PF transmission and reflection type of work is utilized. As an example the configuration of demultiplexer and modulation module for a transmitter with a multifrequency optical comb generator is shown in Fig. 5.

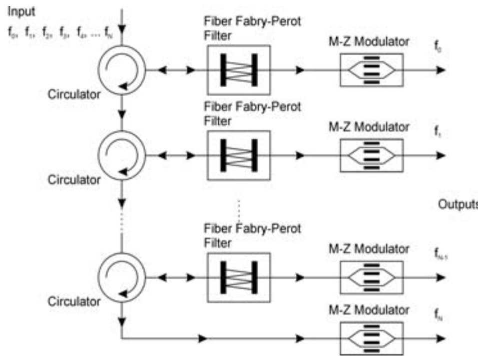


Fig. 5. Demultiplexer and modulation module, configuration with all fiber Fabry-Perot filter

Figure 6 shows a possible arrangement of FF-PF based OADM.

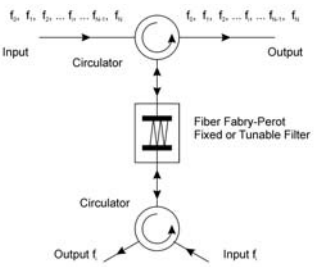


Fig. 6. Optical add/drop multiplexer, configuration with all fiber Fabry-Perot filter

Reconfigurable multiplexers (R-Mux, R-DeMux and R-OADM) can be obtained by implementing tunable FF-PF.

In the presented paper we show an original concept of the enabling technology for access networks with ultra dense channel multiplexing using a multifrequency translator with an acousto-optic frequency shifter as a key module.

This module can operate as a multifrequency signal translator, an optical source for a discretely tunable transmitter (using a tunable output filter) or an optical carrier frequency comb generator, to replace an array of discrete lasers.

As an example of functional capabilities of this module the original experimental results of a multifrequency optical source based on an erbium-doped fiber ring configuration are presented.

We obtained 84 optical carrier frequencies with the separation of 1.5 GHz and 60 spectral lines with the distance of 2.5 GHz. The experimental results are in agreement with the previously reported simulations [13-15]. The separation values allow for a signal transmission rate at 622 Mbps and 1063 Mbps, respectively. These results assure us that using proper acousto-optic frequency shifters would make it possible to adjust optical channel distances to the values of 1.5625 GHz and 3.125 GHz, which correspond to 1/64 and 1/32 part of a standard 100 GHz frequency grid [16]. Considering the results presented above, we believe that an optical comb generator with AOFSs utilising the surface acoustic wave technology would make it possible to obtain the channel separation of 6.25 GHz, which is 1/16 part of the standard 100 GHz separation value.

We also proposed novel configurations which allow the realization of network devices for channel multiplexing with gigahertz spacing such as optical multiplexers, demultiplexers and optical add/drop multiplexers.

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