Optically Amplified Multigigabit Links in CESNET2 network

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Keywords
Erbium-doped fibre amplifier, Raman fibre amplifier, gigabit ethernet, dispersion compensation, long-haul transmission

I. TESTING OF OPTICAL AMPLIFIERS

In our experiments, we have tested three fibre amplifiers in different configurations:

- 18 dBm EDFA booster,
- EDFA high gain low noise preamplifier and
- counter-directionally pumped distributed Raman fibre amplifier implemented using 2W, 1450 nm fibre laser.

All optical amplifiers were provided by Keopsys . The first scenario we tested is depicted in Figure 1. Two backbone Cisco routers (7500 and GSR 12008) were mutually connected through Gigabit Ethernet connection. The optical line has been tested using OTDR, the total length of it was 180 km.

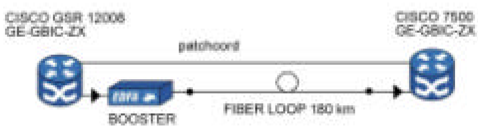

Figure 1 - Gigabit Ethernet experimental set-up, booster only

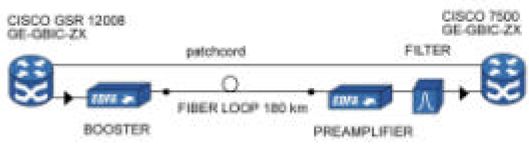

Figure 2 - Gigabit Ethernet experimental set-up, booster and preamp

The second scenario is shown in Figure 2. The preamplifier was added to the optical line to further extend the spanned distance. In this case we have tested only the Gigabit Ethernet card because its sensitivity is worse than that of POS.

The last configuration was the same as the previous one but a Raman laser was used to counter-directionally pump the transmission fiber in order to stimulate Raman amplification. The Raman pump laser wavelength was around 1450 nm so as the tested optical signal at 1550 nm could be amplified. Raman laser pump power was coupled into the fiber using WDM coupler with coupling ratio 30/70. Raman scenario was also tested with Gigabit Ethernet cards in routers.

As a practical result, two backbone lines (189 km and 188 km) are currently in use in CESNET2 network. In a booster only scenario, Gigabit Ethernet is used as transport protocol.

In the first scenario we have found that with 18 dBm output power, the BER was better than 10^{-9}. We have simulated the additional line length by adding the fixed attenuator. The preamplifier scenario is able to cover additional 10 dB of optical fiber, which is approximately 40 km of additional optical line length. Additional 14 dB gain was available from Raman effect covering extra 50 km line length.

II. DWDM SYSTEMS TESTING

In the second part of project on optical networking we have tested three DWDM platforms: Cisco 15540, Cisco 15200 (together with Cisco EDFAs 15501) and Pandatel Fomux 3000. Tests were performed on a production line Brno - Olomouc with length of 124 km and 31 dB attenuation.

One of the goals was to verify the possibility to use single channel Keopsys EDFA with DWDM systems with relatively small number of channels.

In Figure 3 you can see optical spectra at the receiver in the case of Cisco 15540 DWDM system Detailed results of spectral measurements will be given in the final paper.

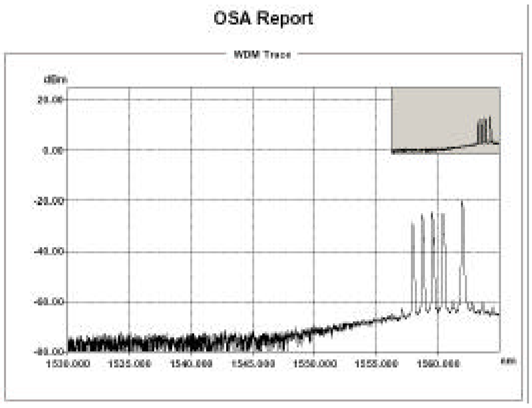

Figure 3 - Spectral diagram for 25 dBm input power, before receiver., booster only

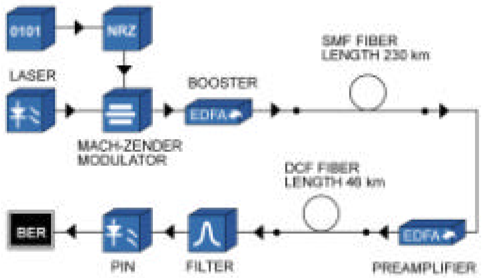

Figure 4 – Schematic diagram of the simulated post-compensation scheme

III. NUMERICAL SIMULATIONS

The aim of our numerical analysis was to estimate the maximum span length of repeater-less single-channel transmission link at bit rates of 10 Gb/s. Split-step Fourier method was used for the simulation. Schematic diagram of the simulated link is shown in Fig. 4. Chromatic dispersion of the standard single mode fibre was fully compensated by DCF. Post- and pre-compensation schemes have been considered. We have investigated the dependence of maximum Q and minimum BER on SSMF length and input power to the SSMF with the goal to keep the BER lower than 10^{-12}. It follows from the analysis that the maximum span length with GVD compensation is about 230km. The dependence of the BER on input power to the SSMF for span length of 210, 220 and 230km is shown in Fig. 5 and Fig.6 for post- and pre-compensation scheme, respectively.

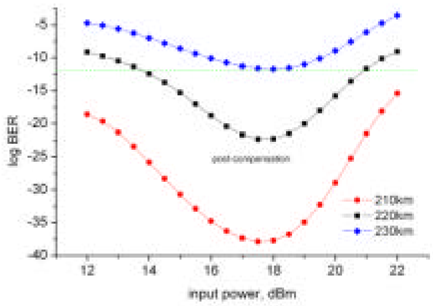

Figure 5 – BER as a function of input power: post-compensation scheme

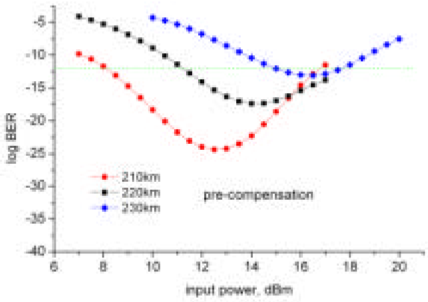

Figure 6 – BER as a function of input power: pre-compensation scheme

IV. CONCLUSIONS

Our objective in above experiments was to acquire practical experience in employing EDFA and DWDM technology in CESNET2 gigabit network in parallel with standard equipment already used. These experiments proved the applicability of Keopsys optical amplifiers in the CESNET network. For the fist quarter of 2003, we plan to perform further experiments with the aim to extend the span length over 350 km at 2.5Gb/s without using in-line amplification. For such lengths of SSMF it will be necessary to compensate the GVD either with DCF or fibre Bragg gratings (FBG). We also plan to test nothing-in-line transmission of 10 Gigabit Ethernet over as long a span as possible. We expect that the new experimental results will be included in final version of our contribution.