Optically Amplified Multigigabit Links in CESNET2 network

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Outline

- Motivation for extending the span length
- Numerical simulations @10 G
- Practical results (single channel, DWDM)
- Conclusions

Motivations

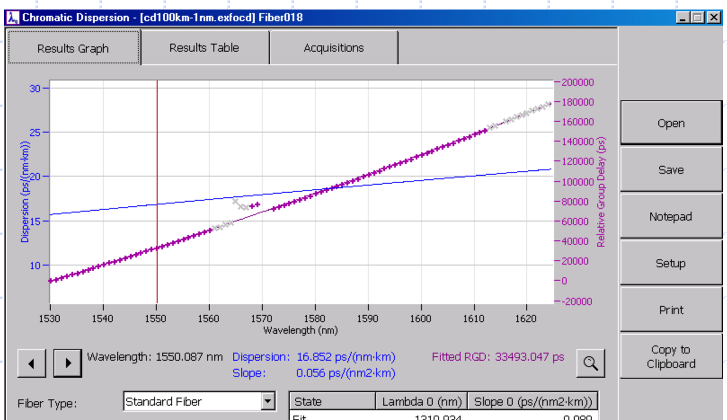
- Experimental and theoretical results on extending the span length
- Repeaters for 1 GE, 10 GE or 10 G POS ?
- Repeater-less or nothing-in-line transmissions at 1 Gbit/s, 2.5 Gbit/s and 10 Gbit/s over standard G.652 SMF
- Fibre on the top of high-voltage poles, coast-island links, power supplies, maintenance ?
- Using optical amplifiers (EDFA, Raman)

Numerical simulations

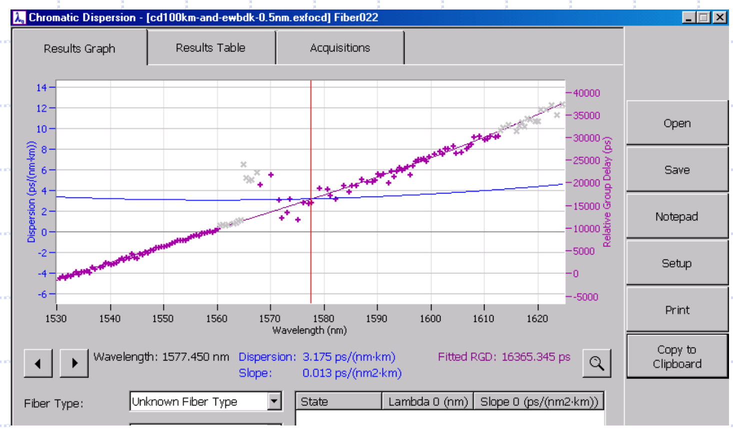
- To estimate the maximum span length @10Gb/s for single channel transmissions
- Compensation of chromatic dispersion - DCF
- Post- and pre-compensation schemes
- Effect of self-phase modulation (SPM)
- For 1 G and 2.5 G - these effects negligible
- To keep the BER better than 10^{-12} (or Q > 7)

Chromatic dispersion

- Different wavelengths propagate at different speeds
- Increases as the square of the bit rate



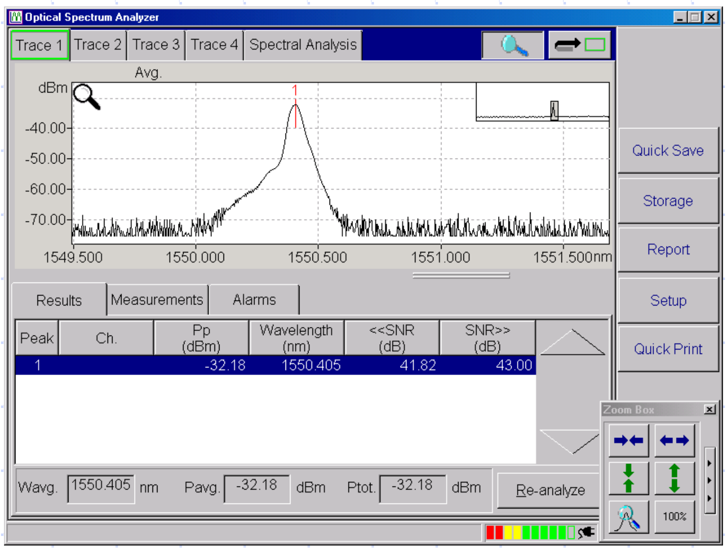
100 km of SMF G.652,
without compensation

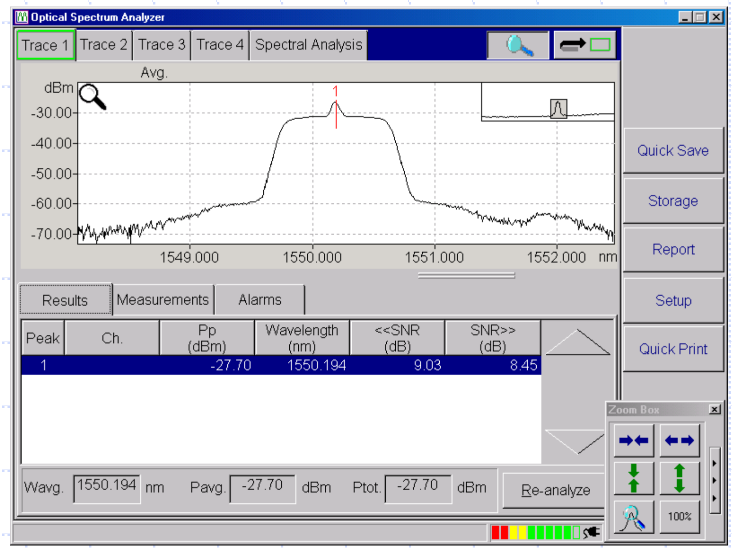


100 km of SMF G.652,
with compensation

Self-phase modulation

- Signal modulates its own phase (Kerr effect)
- The effect increases with spectral density and the bit rate





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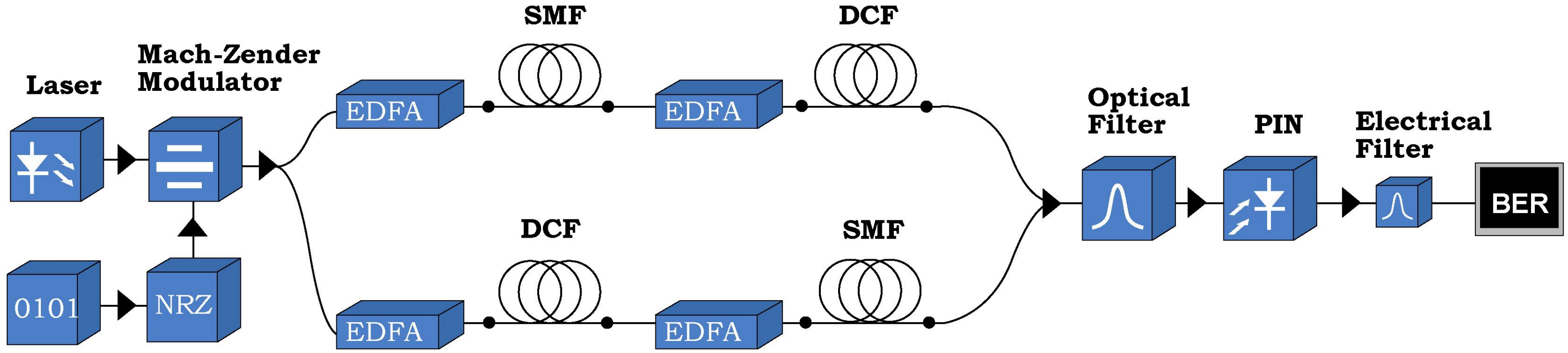
Post and pre-compensation schemes, SMF 0,22 dB/km, DCF 0,55 dB/km

Post-compensation scheme



Pre-compensation scheme

- High quality parameters for fibres and lasers
- Possible problems with „real" components
- Better - post-compensation

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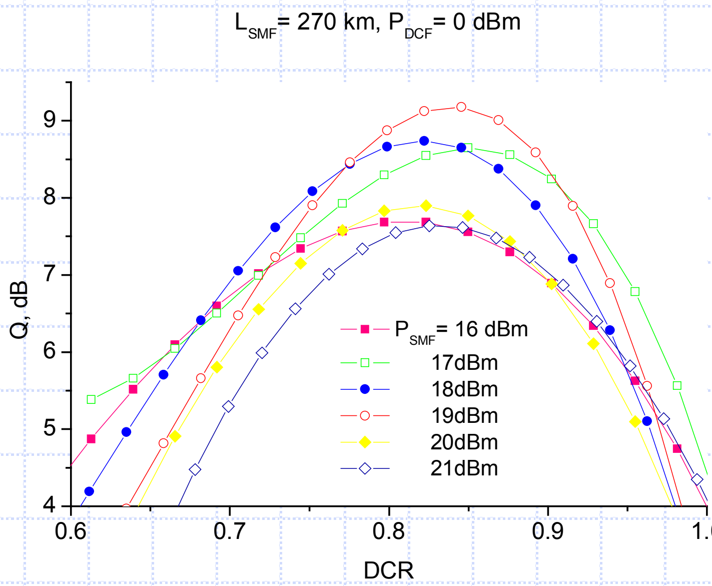
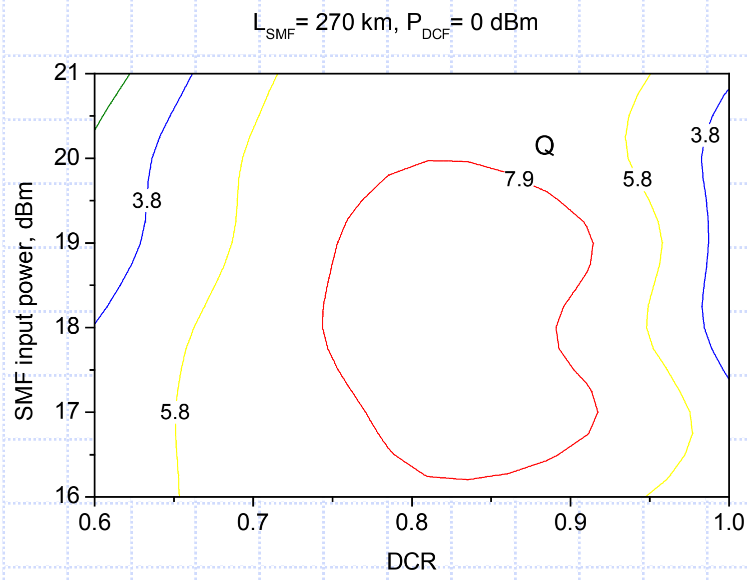
Post-compensation, optimalization of the degree of compensation

- $DCR = |L_{DCF} * D_{DCF}| / (L_{SMF} * D_{SMF})$, $L_{SMF} = 270$ km, $P_{DCF} = 0$ dBm





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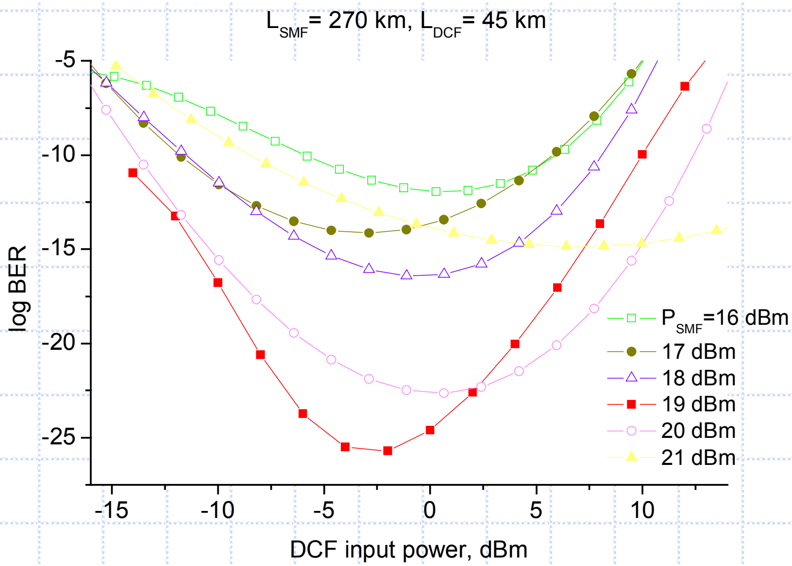
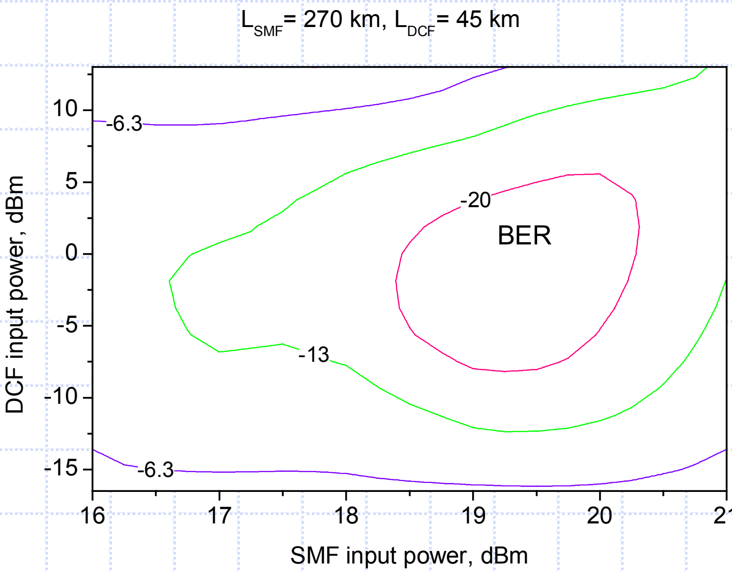
Post-compensation, optimalization of input powers P_{SMF} and P_{DCF}

- DCR = 0.83, L_{SMF}= 270 km, L_{DCF}= 45 km





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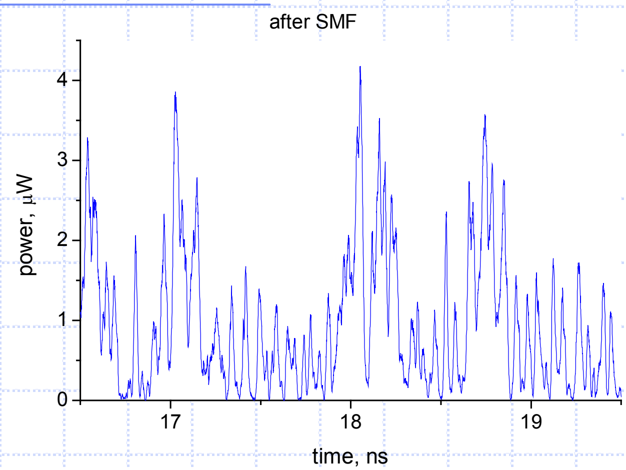
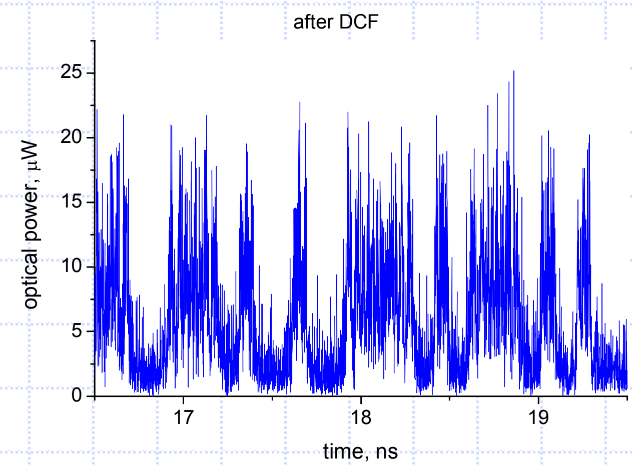
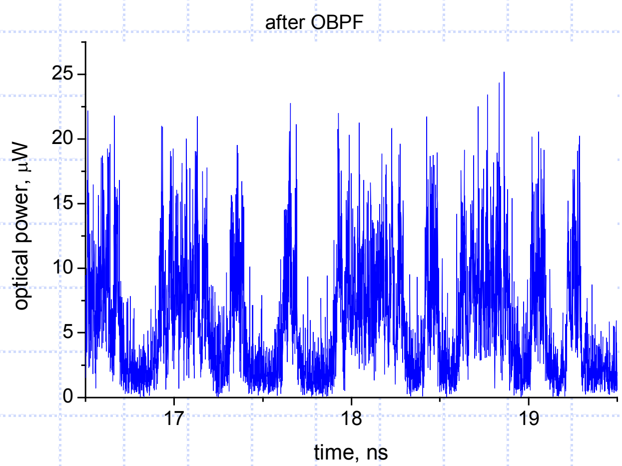
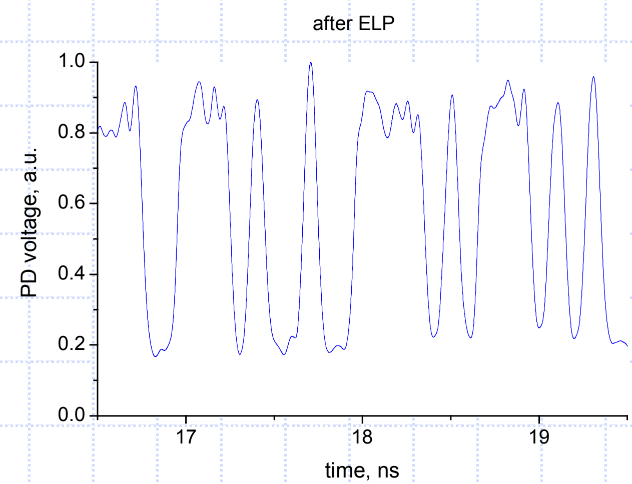
Post-compensation, 270 km SMF +45 km DCF, P_{SMF}=19 dBm, P_{DCF}=0 dBm









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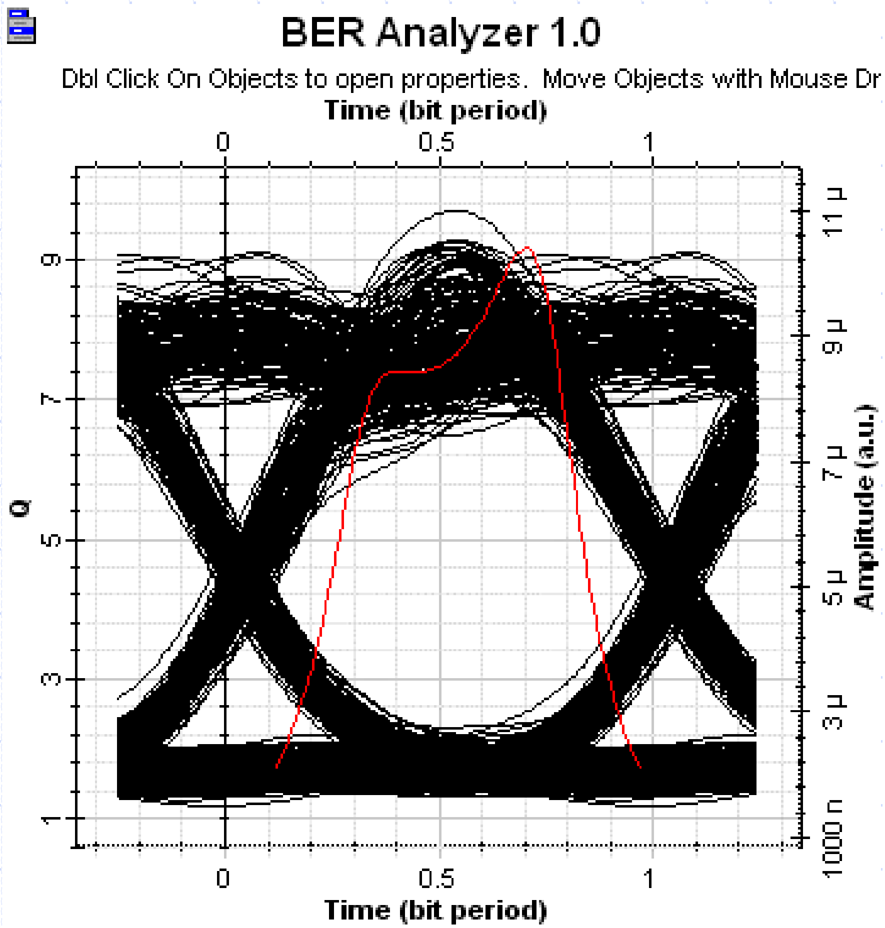


Eye diagram
post-compensation
270 km SMF + 45 km DCF
P_{SMF}= 19 dBm, P_{DCF} = 0dBm

Practical results

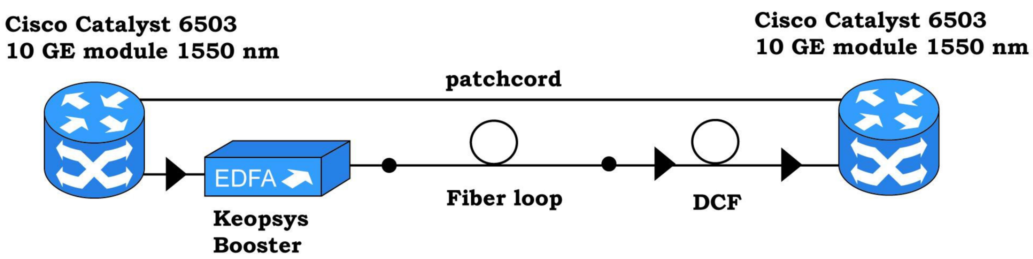
- 1 GE, 2.5 G POS and **10 GE** with NIL
- Three different configurations
- Booster, + preamp, + Raman
- Fiber field test-beds 25, 50, 100, 200 km
- Two GE backbone lines (189 km and 170 km) are currently in use in CESNET2 network [1]

Practical results – equipment used

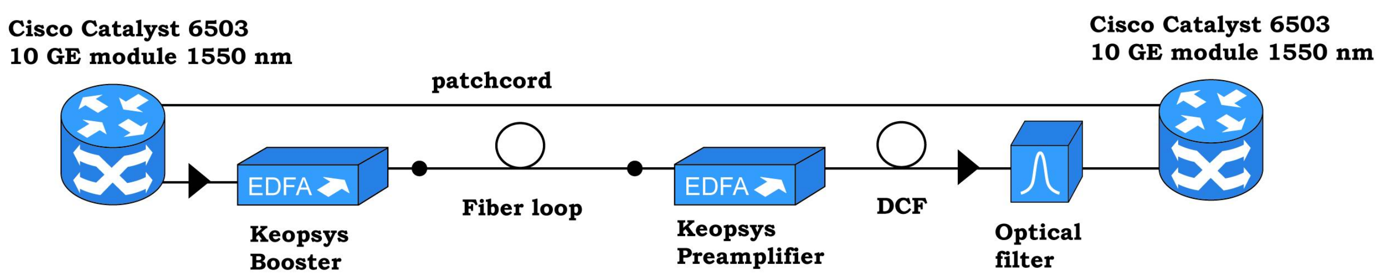
- Cisco Catalyst 6503 with 1 port 10 GE 1550 nm linecards, GSR 12008 for POS
- Keopsys High power booster 30 dBm, low noise preamplifier 13 dBm
- Raman pump 24 dBm, provided by IREE
- Santec & JDS optical filters
- OFS DCF

Practical results – tested scenarios

Scenario 1 – booster only

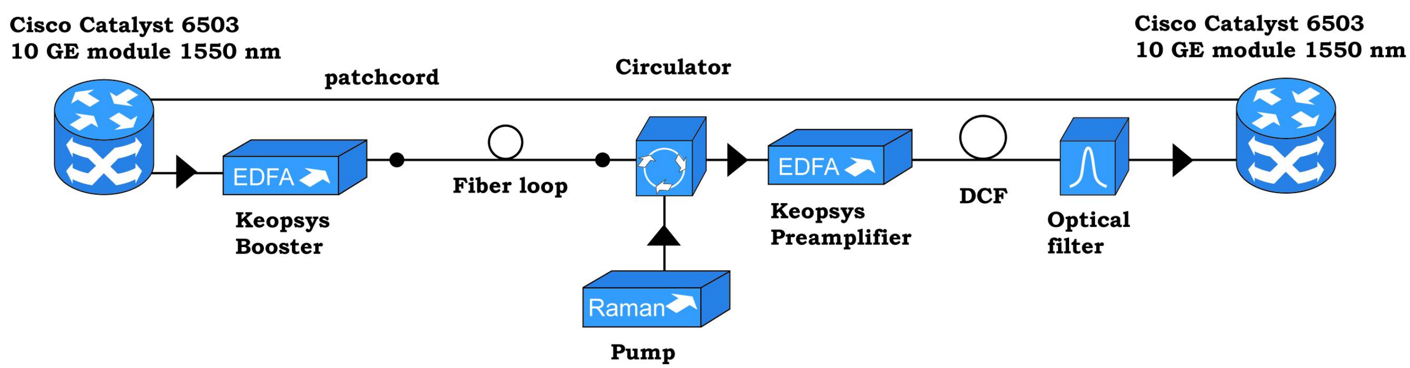


Scenario 2 – booster and preamplifier

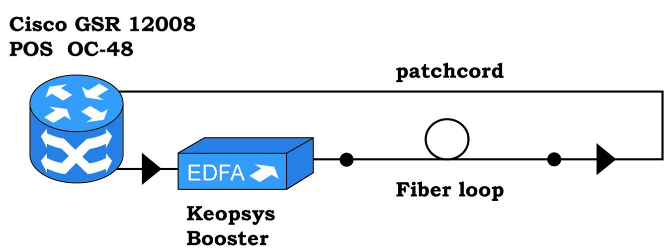


Practical results – tested scenarios

Scenario 3 – booster, preamplifier and Raman pump



Scenario 1 – booster only for POS



Practical results – problems pt.1

- Not DWDM lasers (chirp, linewidth, modulators)
- Fibre field test-beds – cables with patchcords
- A lot of patchcords between lab and ODF
- Recalculating of length to more realistic figures…with attenuation 0,27 dB/km

Practical results – 1 GE and 2.5 G POS

Speed	Loops Length	Scenario	DCF	OF	Estimated Length	Results
GE	200 km	Booster Preamp	No	No	220 km	OK!
GE	200 km + 25 km	Booster Preamp	No	Yes	270 km	Short packets
2.5 G	200 km	Booster Preamp	No	No	220 km	OK!
2.5 G	200 km + 25 km	Booster Preamp	No	Yes	270 km	Failed

Practical results – 10 GE

Loops Length	Scenario	DCF	OF	Estimated Length	Results
100 km	Booster	No	No	125 km	OK!
100 km + 50 km	Booster Preamp	Yes	Yes	180 km	OK!
200 km	Booster Preamp Raman	Yes	Yes	220 km	Failed

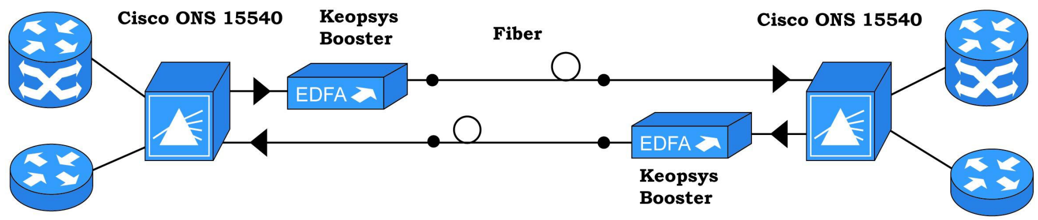
Practical results – problems pt.2

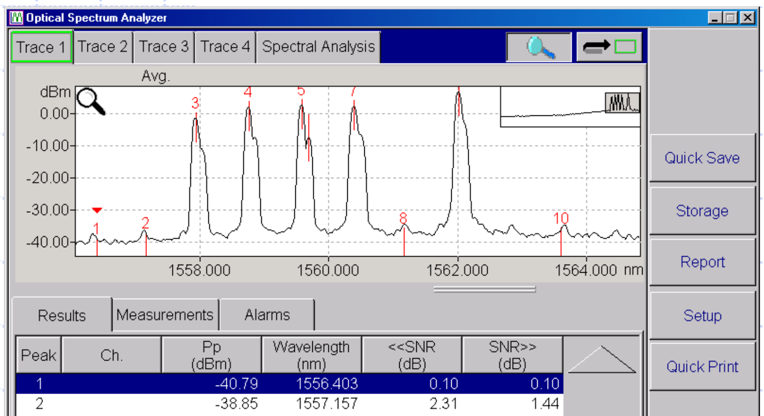
- BER measurement ?
- No BERT equipment – we rely on PING
- POS line cards with BIP counters
- For 1 GE even better situation
- Difficult for 10 GE, we still believe in our simulations and PING testing
- Billions of long packets with 0% drop-outs

DWDM systems testing

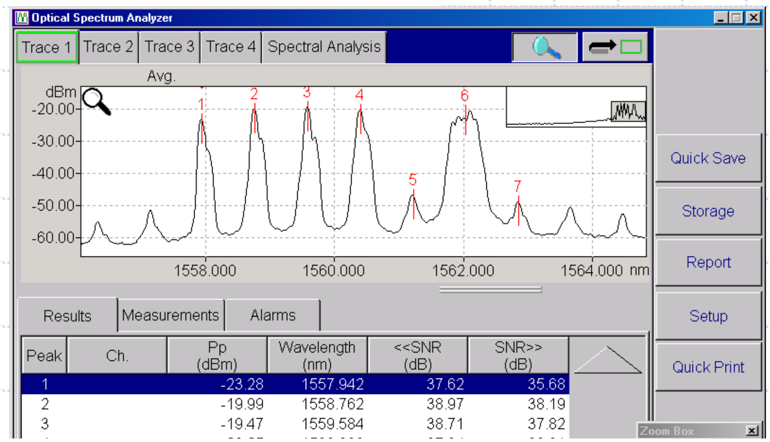
- Verify the possibility to use single channel EDFA with DWDM system (up to 8 lambdas)
- Three DWDM platforms: Cisco 15540, Cisco 15200 (together with Cisco EDFA 15501) and Pandatel Fomux 3000
- Keopsys optical amplifiers

DWDM systems testing





Spectral diagram for 30 dBm input power, after EDFA.



Spectral diagram for 30 dBm input power, before receiver.

DWDM systems testing

- Strong effects of SPM, CPM and FWM
- OSC mostly affected
- Single-channel EDFAs are OK for 5 channels
- For 16/32 channels you need really powerful booster (17 dBm for 1 channel corresponds to 2 dBm for 32 channels)

Conclusions

- We presented NIL solutions for multigigabit links
- „Better" fibers
- Better equipment (low noise amps, DWDM lasers)
- More precise compensation: DCF and/or FBG
- BER measurement, eye-mask testing

Acknowledgements

- Thanks to Lada Altmanová, Stanislav Šíma and Martin Míchal from CESNET

References

- [1] Šíma S., Altmanová L., „Development of the CESNET2 Optical Network“, TNC 2002
- [2] Agrawal G.P., „Fiber-optic Communication systems“, J.Wiley, 2002
- [3] Agrawal G.P., „Nonlinear Fiber Optics“, Academic Press, 2001
- [4] Kartalopoulos S.V., „DWDM Networks, Devices and Technology“, J.Wiley, 2003

Thank you for your attention!