MULTI-PURPOSE INFRASTRUCTURE FOR DISSEMINATION OF PRECISE STABLE OPTICAL FREQUENCY

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August 20th 2018
San Diego, CA

cesnet

CzechLight

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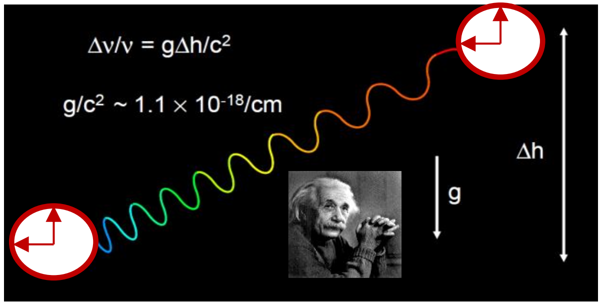
OUTLINE

- Motivation: Accurate clocks and frequency transfer
- CESNET Time and frequency infrastructure
- Optical Frequency Transfer Line Under Development
- Single Path Bidirectional Optical Amplification
- Bidirectional EDFA Gain Maximization
- Summary & Acknowledgement

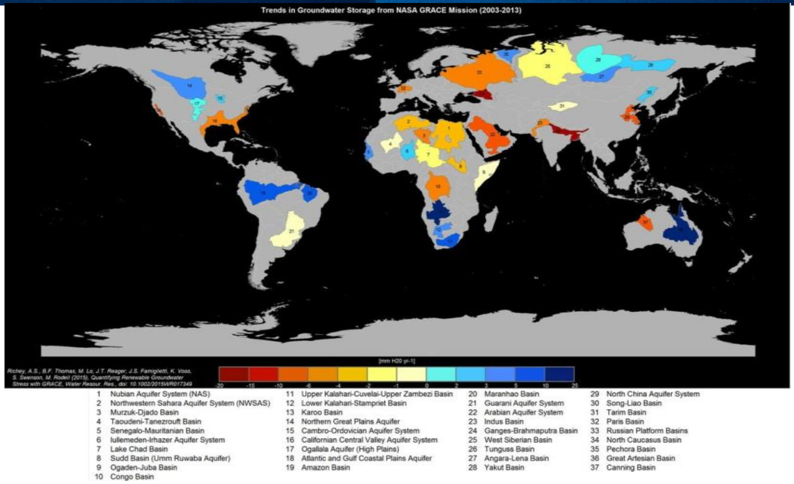
Why More Accurate Clocks?

- **Time and frequency** = quantities we are able to measure with the highest accuracy
- Represent ideal way how to measure tiny effects
- (Radio)astronomy, VLBI, SKA
- Precise tests of fundamental physics:
  - Constancy of fundamental constants
  - Detection of gravitational wave
  - Tests of special & general relativity



Credits: Newbury14, Barr10

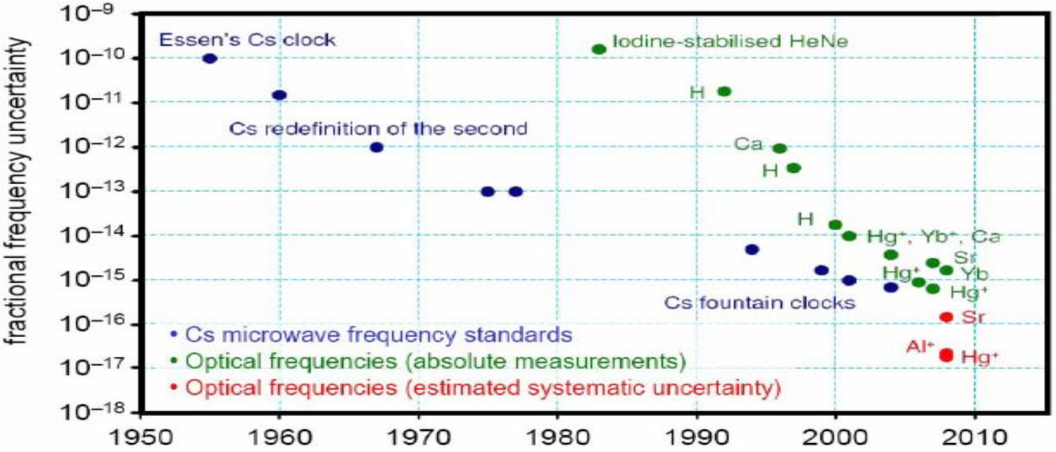
Why More Accurate Clocks?

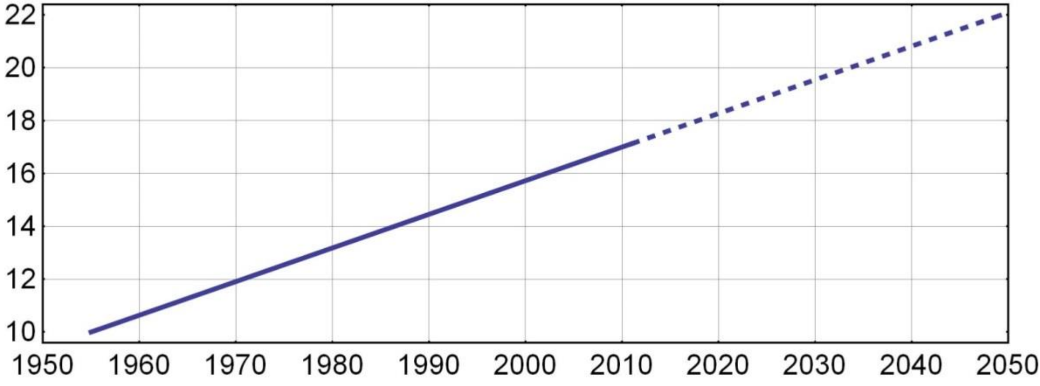


Earth sciences, remote sensing

- Land – geodesy, seismology, water resource and other natural resources inventory, etc.
- Atmosphere – climate modelling and changes monitoring, etc.
- Oceans – circulation, geoid monitoring etc.

Clocks Are Improving





'microwave' atomic clocks 'optical' atomic clocks

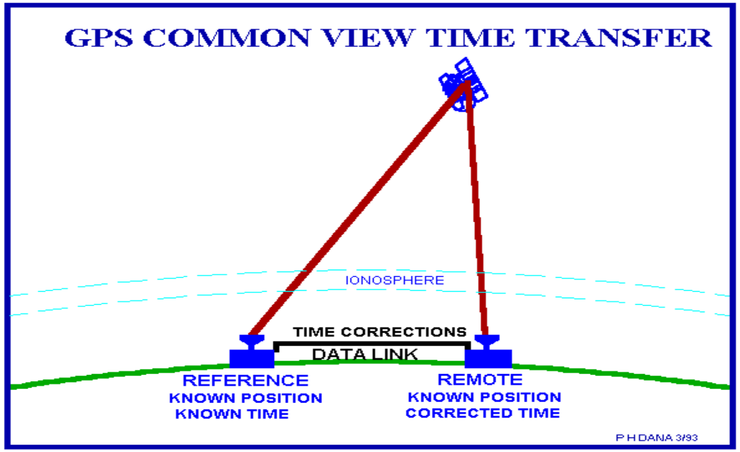
Time and Frequency Transfer

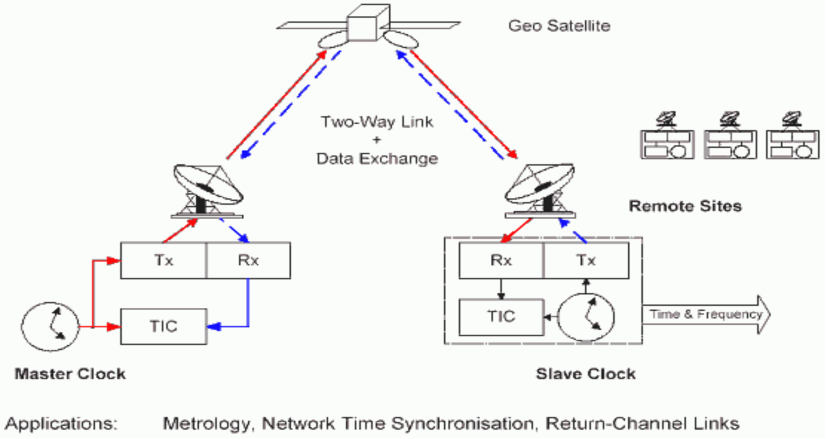
- Hard to transfer some clocks (sensitive + not a small ones)
- Cost of ownership
- More interconnected clocks (Cs primary standards and H masers) improve accuracy and stability of the time scale
- “Interconnection” means time transfer

Acetylene stabilized laser

Caesium fountain clock at NPL UK, height of 2.5 m

Satellite RF Based Transfer

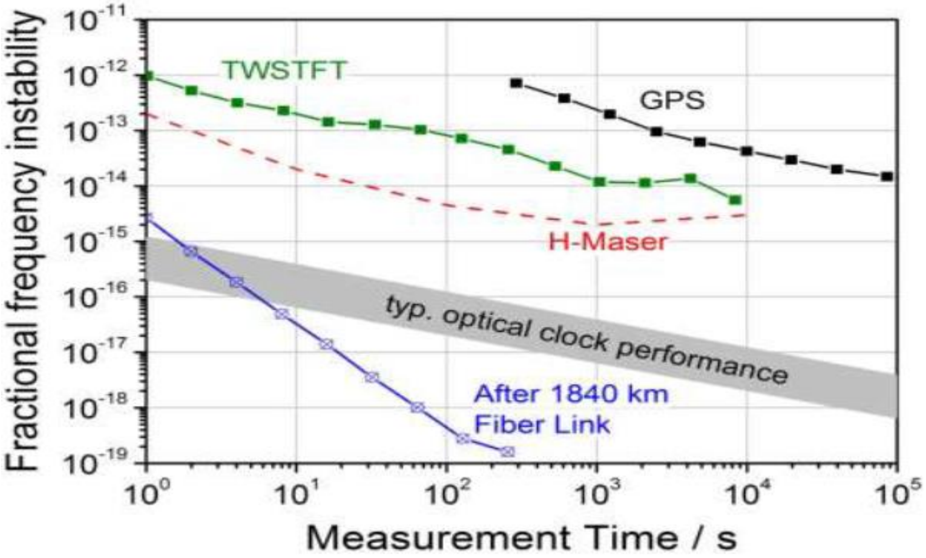




- CV GNSS (GPS, GALILEO, GLONASS, …) accuracy 3 – 50 ns
- GNSS PPP (Precise Point Positioning) 0.1 ns
- TWSTF 0.1 ns

Credits: Colorado, Timetech

Stabilities Comparison

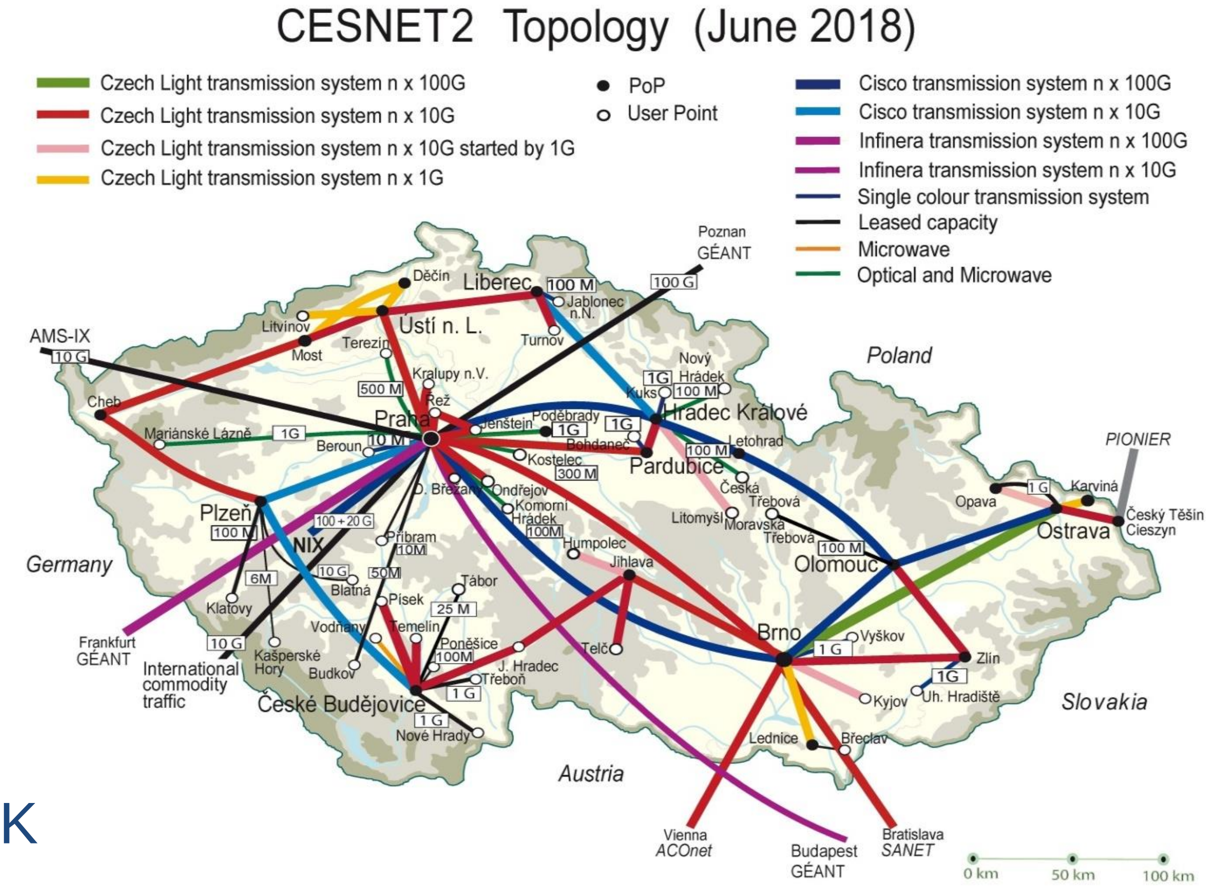


Credit: Droste13

CESNET2 Network

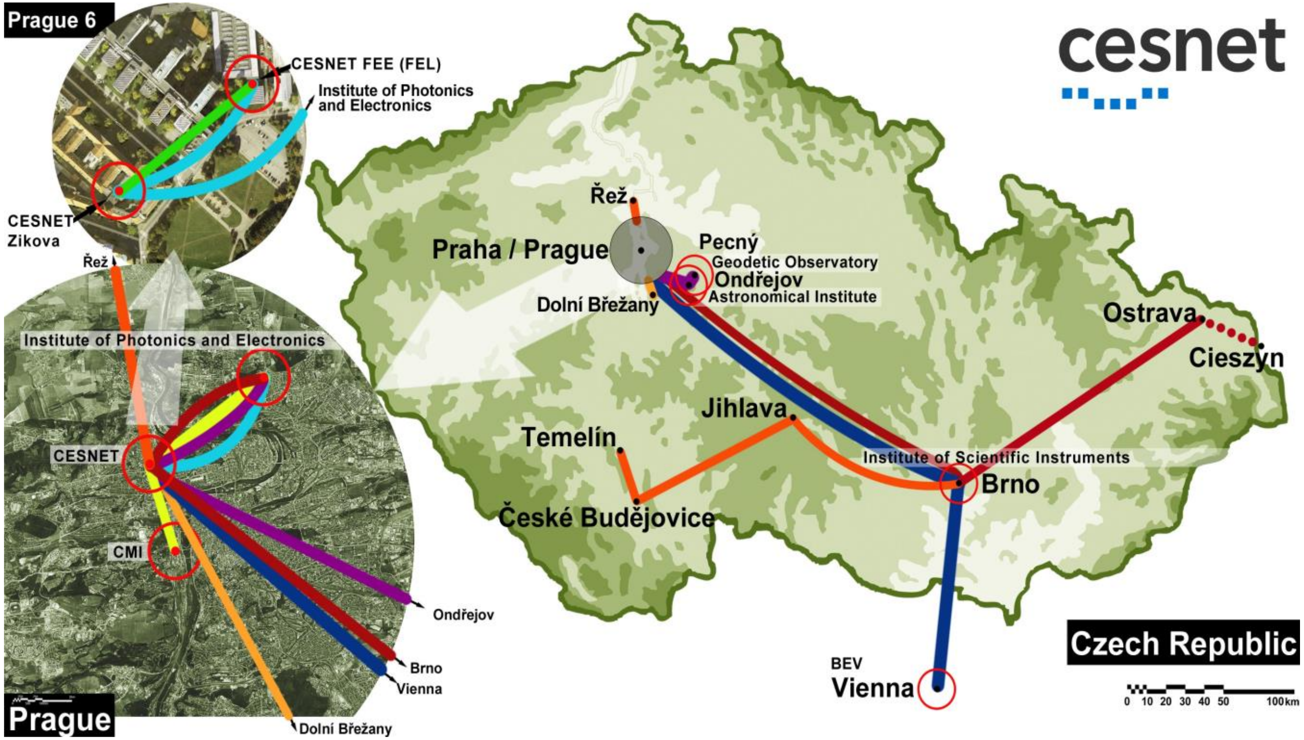
- **Research and Education Network CESNET2**
- > 5800 km of dark fiber lines
- Over 1390 km of single fiber lines
- Two DWDM systems
  - Proprietary 1510 km
  - Open 3760 km
- Hybrid transmission:

  IM-DD, coherent DP-QPSK



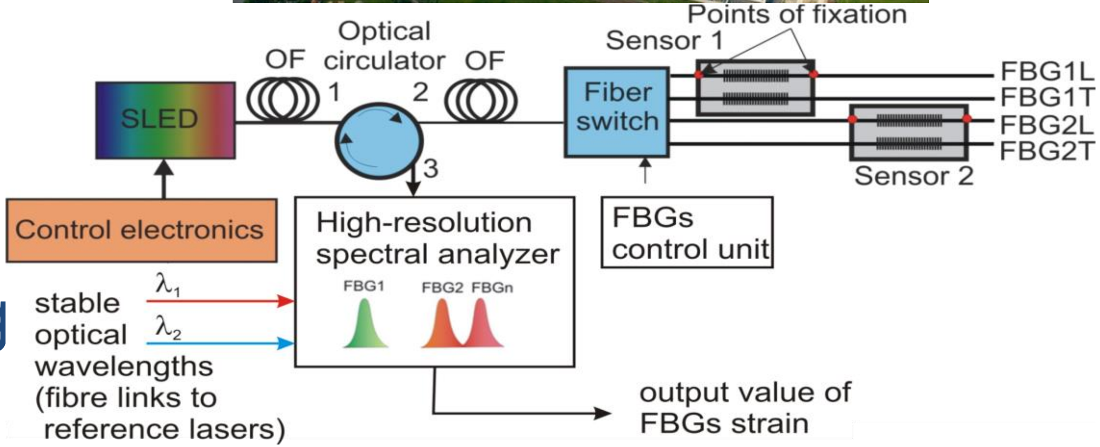
Time and Frequency Infrastructure

- T/F transfer + distribution
- Fibers shared with data
- Projected length 2476 km, transmission 1183 km
- Connection between two countries 550km (340 mil) over cross-border fiber
- Dedicated all-optical channel



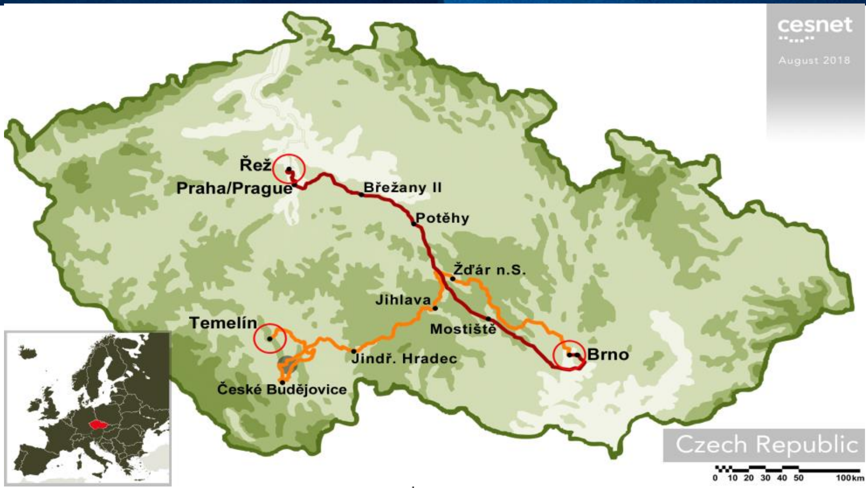
Stable Optical Frequency Transfer over 401 km

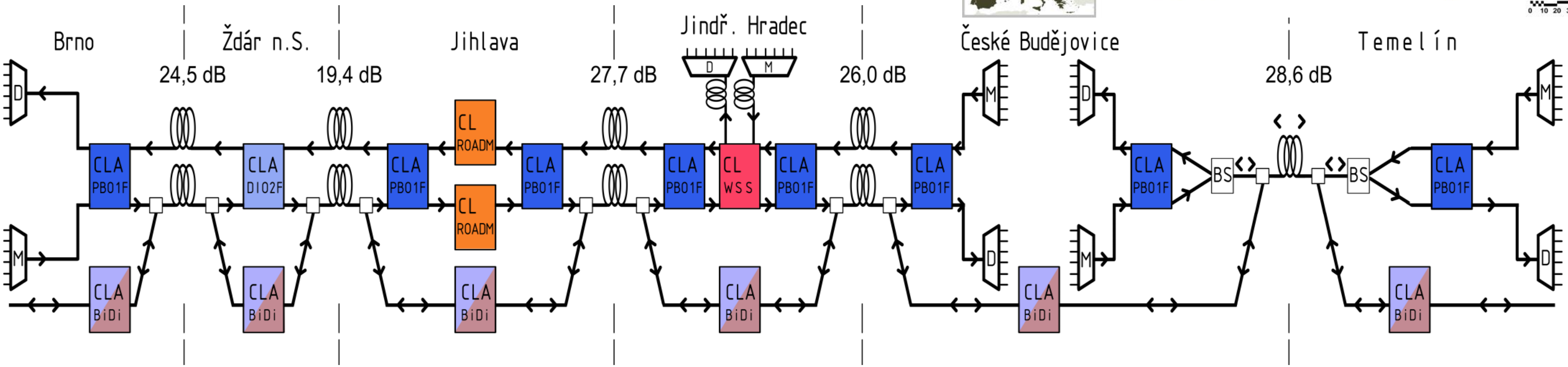
- Long-term measurement of the stability and shape deviation of the containment buildings
- 2 000 MWe of total installed capacity two PWR reactors, each protected by the containment building
- Precise measuring methods based on Fiber Bragg Grating strain gauges



Stable Optical Frequency Transfer over 401 km

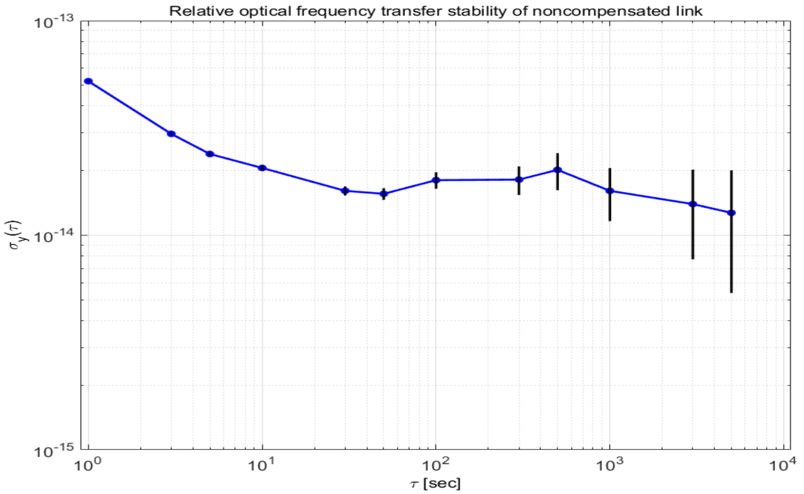
- Dark channel 400 GHz
- 6 bidi EDFA amplifiers

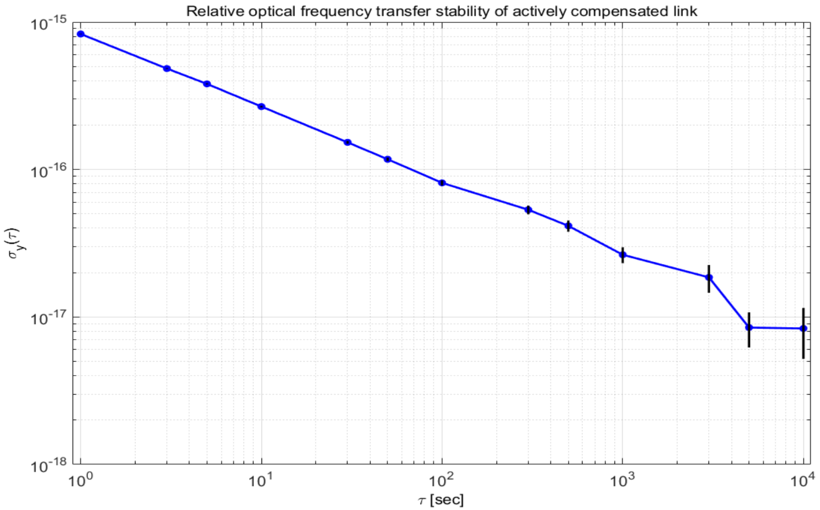




Stable Optical Frequency Transfer over 401 km

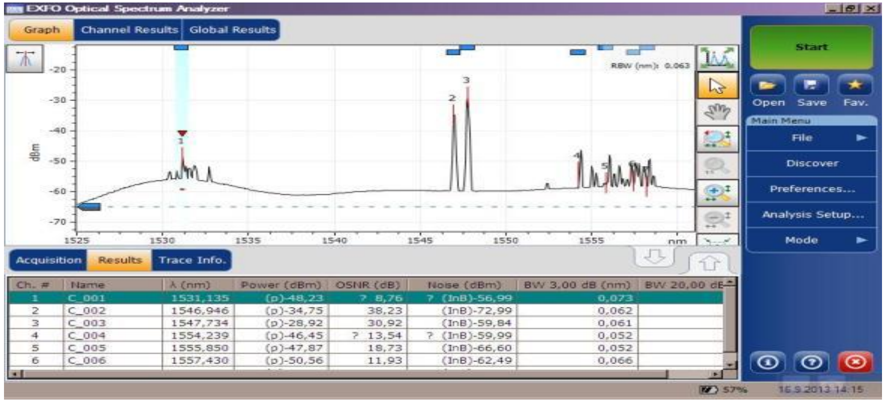
- Active stabilisation of frequecy transfer brings improvement three orders of magnitude





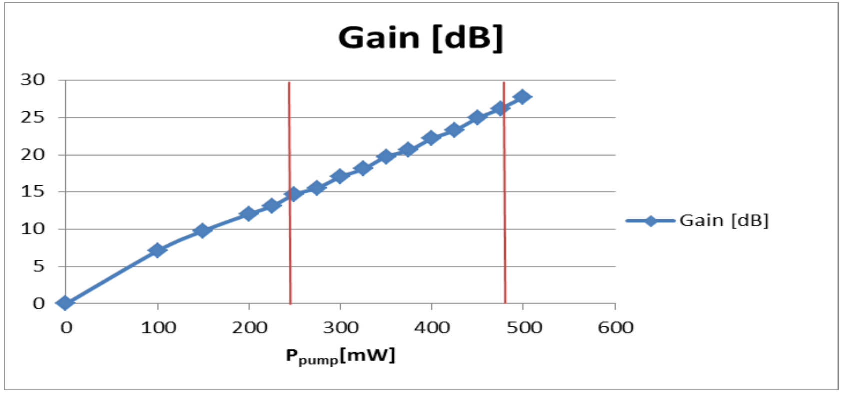
Challenge – All Optical Amplification

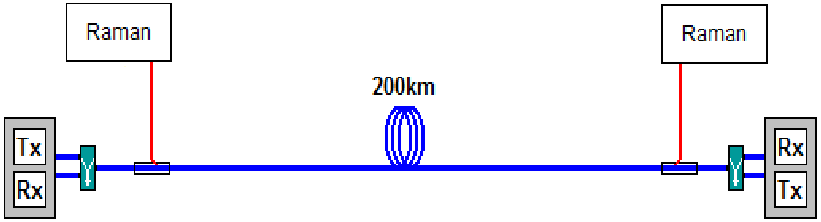
- Need reciprocal/bidirectional path to cancel slow changes $\tau AB = \tau BA$
- Bidirectional amplification?
- Hi gain medium + feedback - We are trying to avoid it!!
- $G^2 R_1 R_2 < 1$
- R composes from Rayleigh backscattering and reflections from splices, connectors etc.
- Only with limited gain up to 20-21 dB
- But we have lossy spans:
- 24, 27.7, 26 and 28.6 dB?

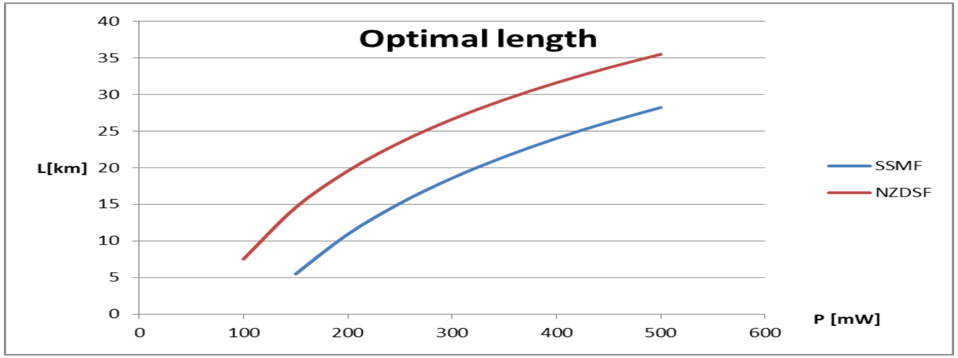


Challenge – All Optical Amplification

- Solutions:
- Try to splice fibers every where instead of connectors
- Distributed (Raman) gain – relatively week in standard G.652 fibre requires high pump powers

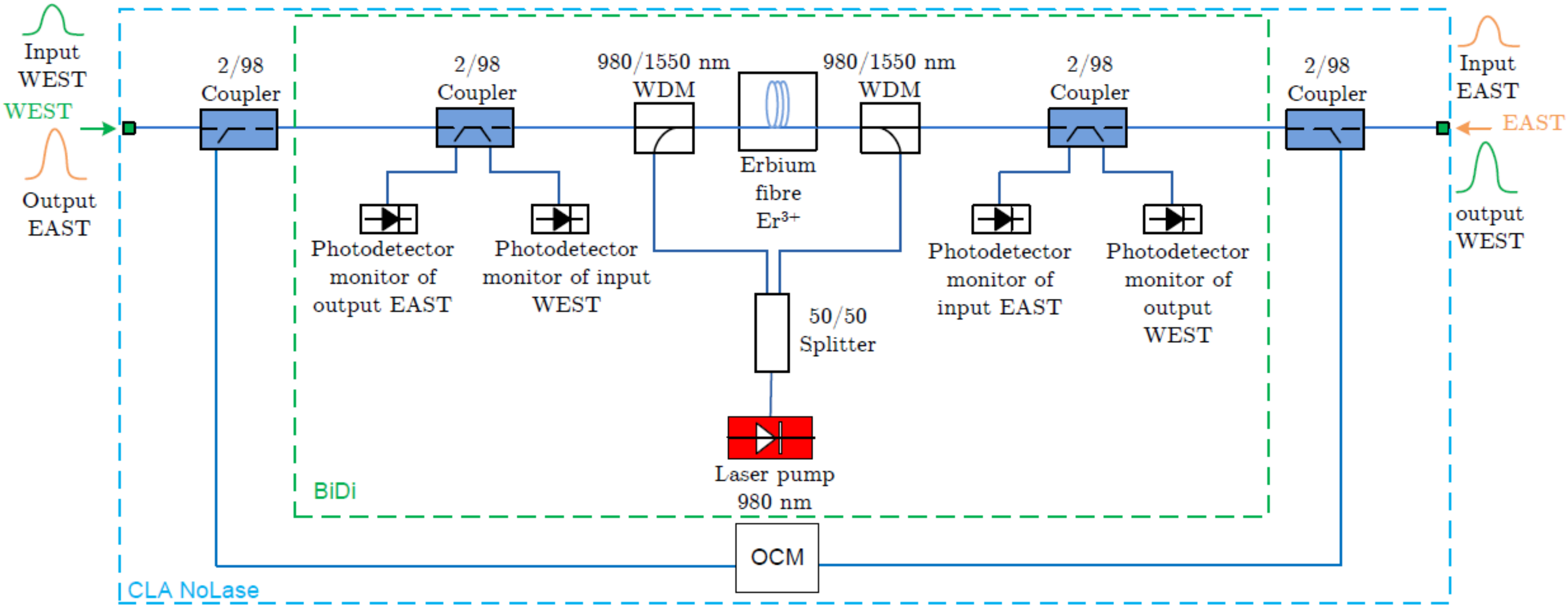






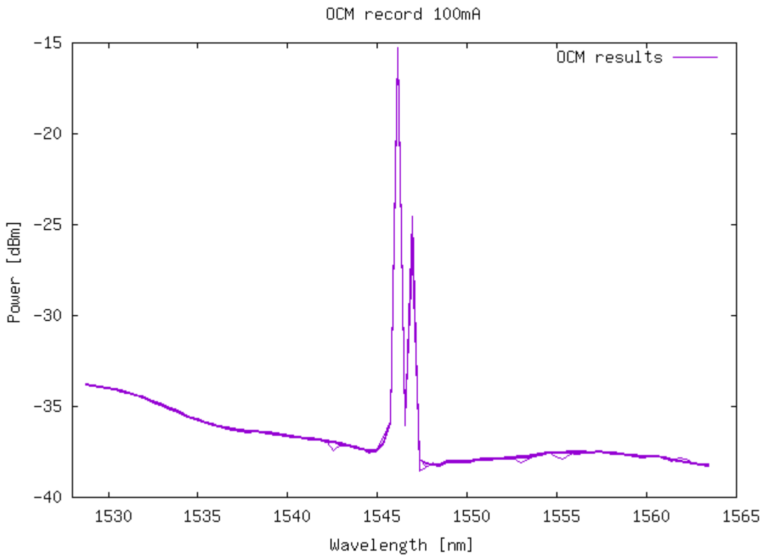
Challenge – All Optical Amplification

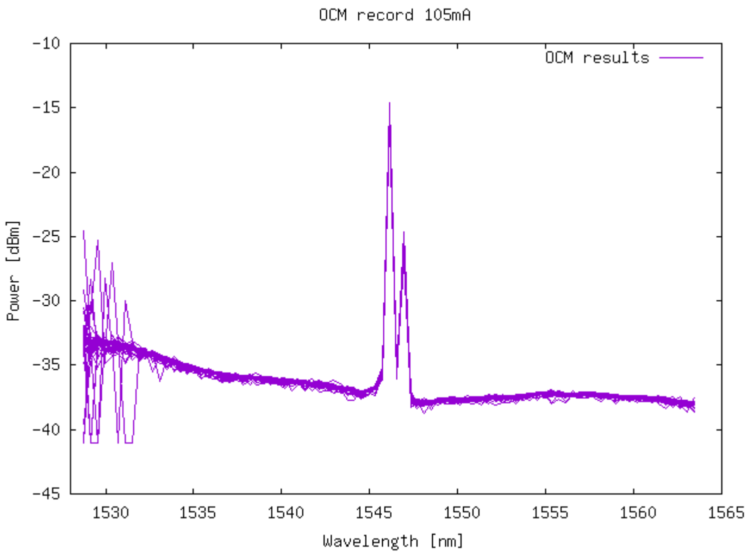
- Solutions:
- Maximize gain of bidi EDFAs + monitor and avoid unwanted oscilations



Challenge – All Optical Amplification

- Output spectrum without and with the undesirable oscillation/lasering (the record of 50 measurements with a period of 1s)

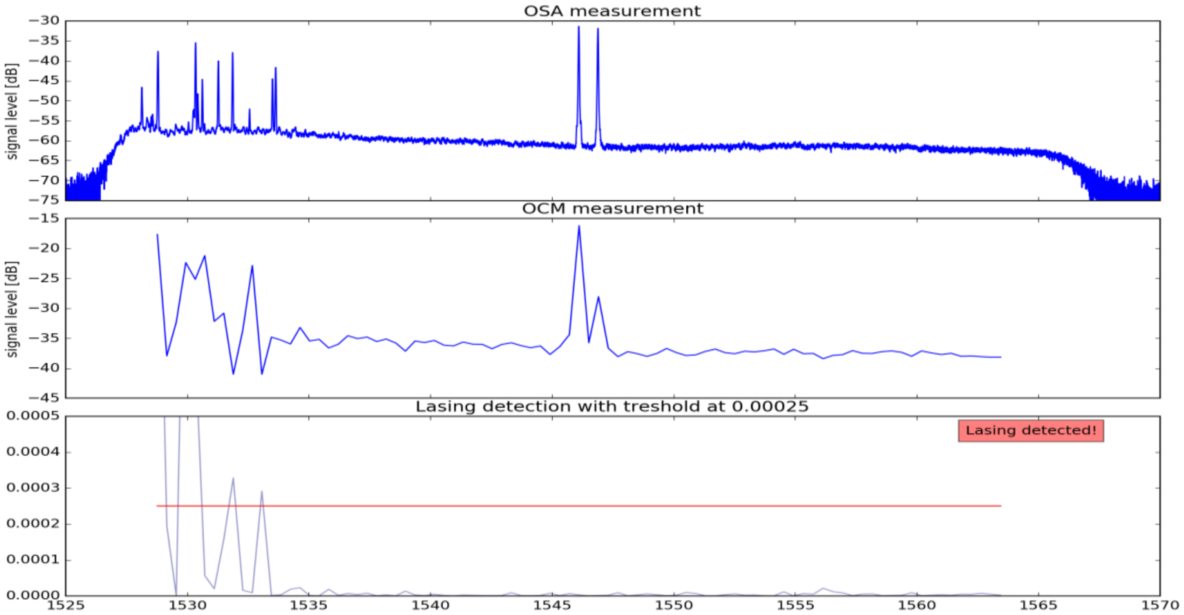




Challenge – All Optical Amplification

- Lasering has higher dispersion both amplitude and spectral compared to common noise
- When averaging sufficient amount of samples, the noise practically disappears, yet lasering phenomena is apparent even with higher scale of average value of the signal in the area of lasering,
- After deducting the average from the specific measurement the detected peaks keep being caused by lasering.
- Data are normalized to the range of 0-1. The average value of calibration measurements is deducted from the measurement currently being processed and the differences are squared. If the result exceeds the threshold value 0.00025 (determined experimentally), the lasering is detected.

Challenge – All Optical Aplification



For comparison, there are measurements by OSA (top), by OCM (middle) and currently processed signal (bottom blue) with marked threshold value 0.00025 which is limitation for detection of unwanted lasering

Summary

- 401 km line deployment will be finished this week (dark channel over bridges ROADMs, WSSs and passes through single fiber with bidirectional transmission)
- Value of uncompensated attenuation and stability of complete line to be determined
- Based on results gain maximization in critical points can be used to improve parameters
- Still backup solution with distributed Raman gain

Acknowledgement

Jaroslav Jedlinský, Jakub Mer, Josef Verich, Václav Novák

Thank You very much for Kind Attention!

Questions?

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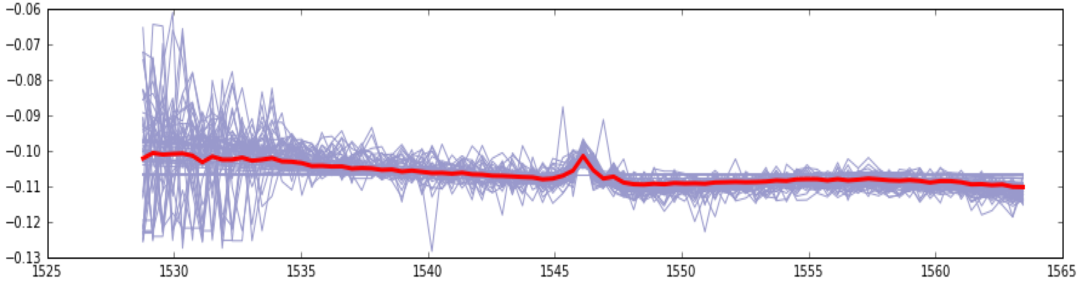
Lasering detection



Normalized partial processes of 72 measurements by OCM (blue) with supressed local maximum in the area of 1446 nm and the resulting average value (red)

Transfer stabilisation