

**WHERE IS RIGHT SPECTRAL GAP FOR
ACCOMMODATION OF EMERGED PHOTONIC SERVICES
OF TIME AND FREQUENCY OR QKD?**

(APPROACHING 10 YEARS AND PLAN TO MOVE FROM C BAND)

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- T/F transfers over shared fibre
- T/F infrastructure CESNET
- Spectrum Exhaustion
- Alternatives
- Performance verifications
- Clonets

T/F Transfers Over Shared Fibres

- Why T/F transfers over shared fibre? On dedicated it is easier.
- Example fibre line length: 1 400 km
- Fibres rental annual cost (based on average price*)
 - EUR 420 000
- **Share T/F infrastructure with data**

- Core network example – project CLONETS



T/F Transfers Over Shared Fibres

Examples C band (1530-1565 nm)

- T - lambdas - IPE-BEV/CESNET-ACONET
- T - lambdas - MIKES/CSC/FUNET
- T - lambdas - RISE/SUNET

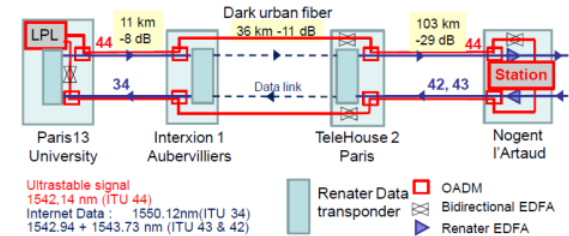
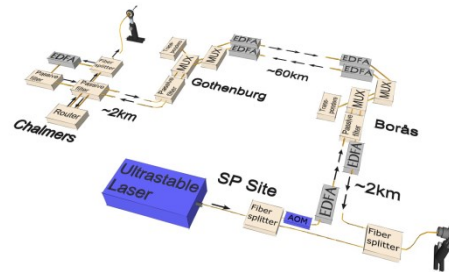
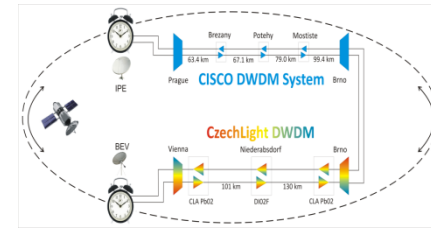
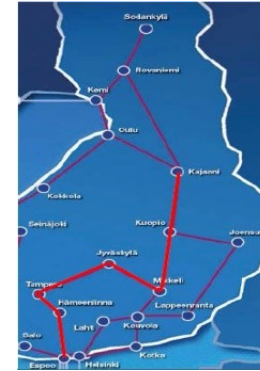


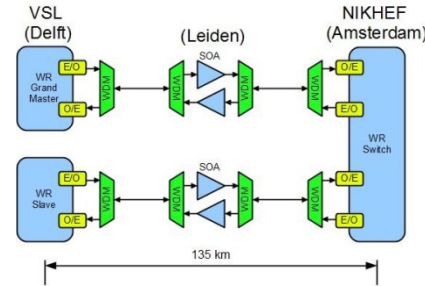
Fig. 3. Scheme of the 2 x 150 km cascaded optical link.

- F - lambdas - RISE/SUNET
- F - dark channel bidi amplified (ch 44) – LNE-SYRTE/RENATER
- F - dark channel bidi amplified (ch 46-39) – ISI/CESNET

T/F Transfers Over Shared Fibres

Examples out of C band

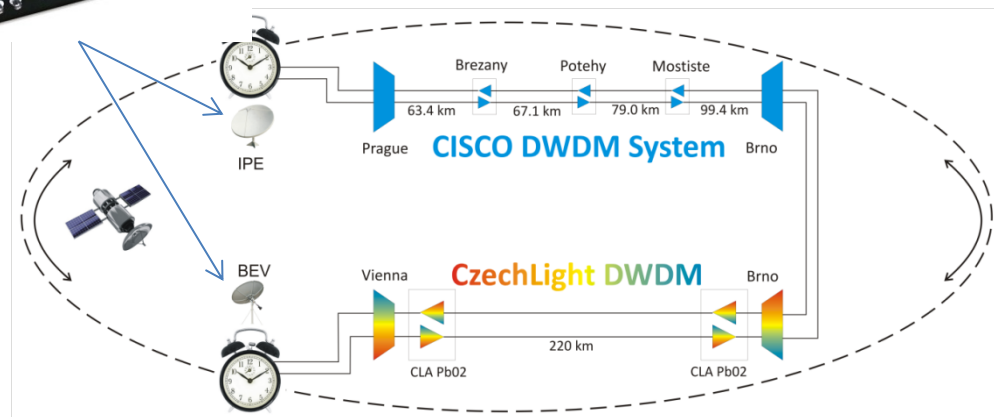
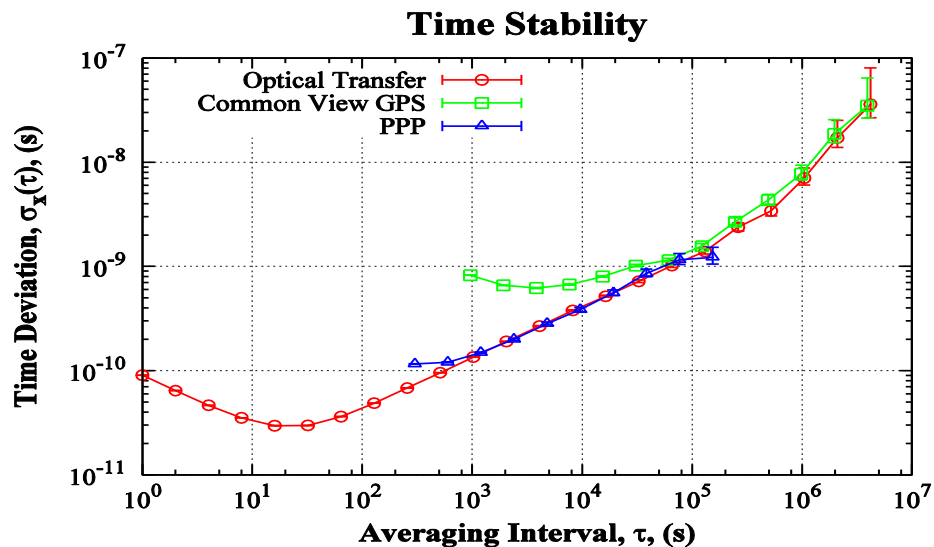
- T - dark channel semibidi amplified – VSL-NIKHEF/SURFNET
 - 1470/1490nm
 - 1nm in 1510
 - C band



Under construction

- F - dark channel bidi amplified (1570 nm C/L) – METAS, ETH Zurich/SWITCH
- T - lambdas (C band) – GARR

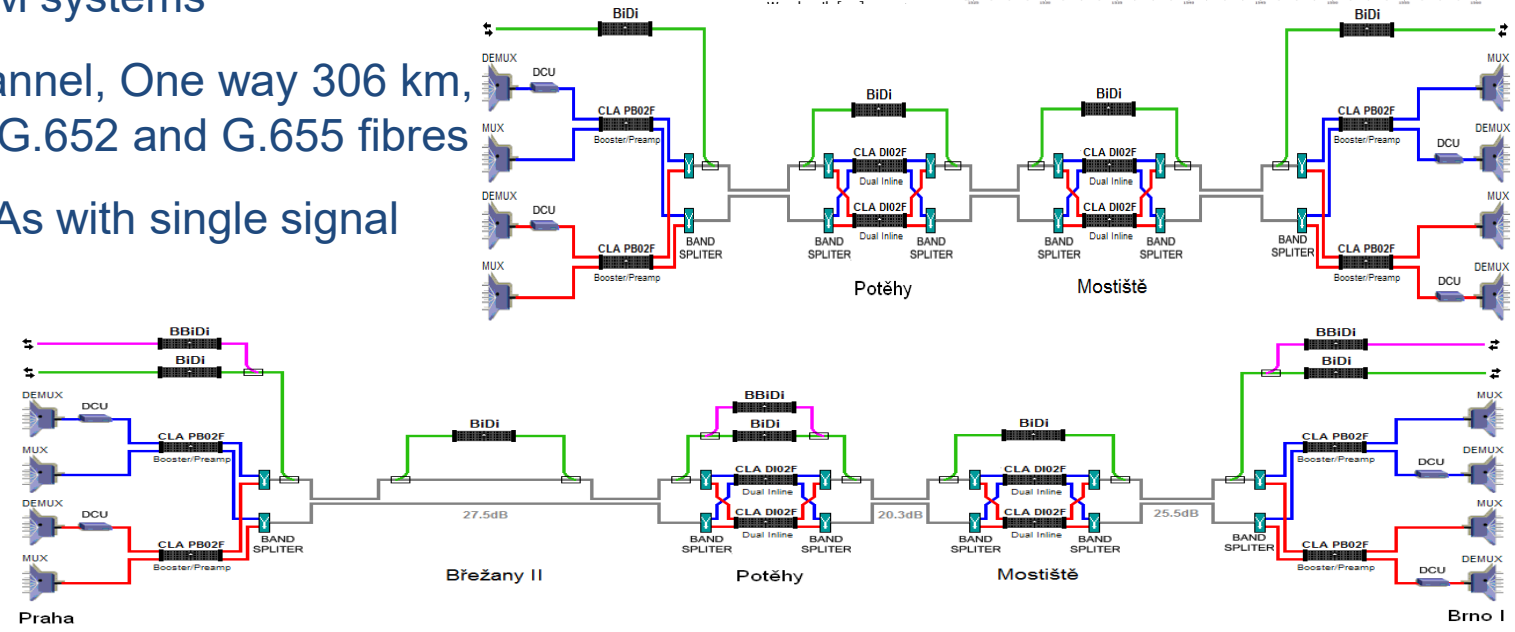
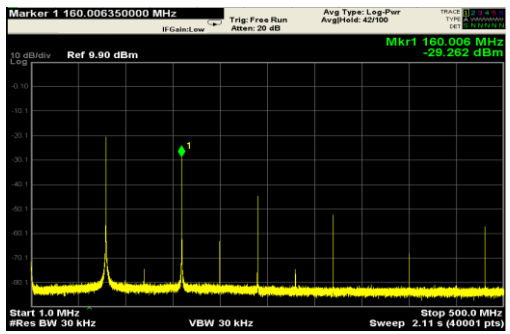
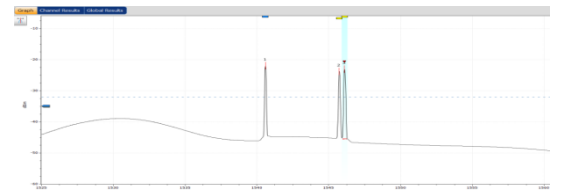
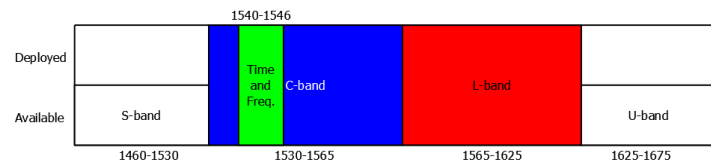
2011 – alien wave



- Comparison of time scales UTC(TP) and UTC(BEV), Caesium beam 5071A/001 atomic clocks, since Aug 2011
- One way distance 550km/340miles (including 220km/137miles NIL) 137 dB
- C band channel any

2014

- Already C and L DWDM systems
- Amplified **800 GHz** channel, One way 306 km, 85 dB, combination of G.652 and G.655 fibres
- 4, later 5 pcs bidi EDFAs with single signal path



Time and Frequency Infrastructure

Research and Education Network CESNET2

- > 5800 km of dark fibre lines

- T/F transfer

- Fibres shared with data

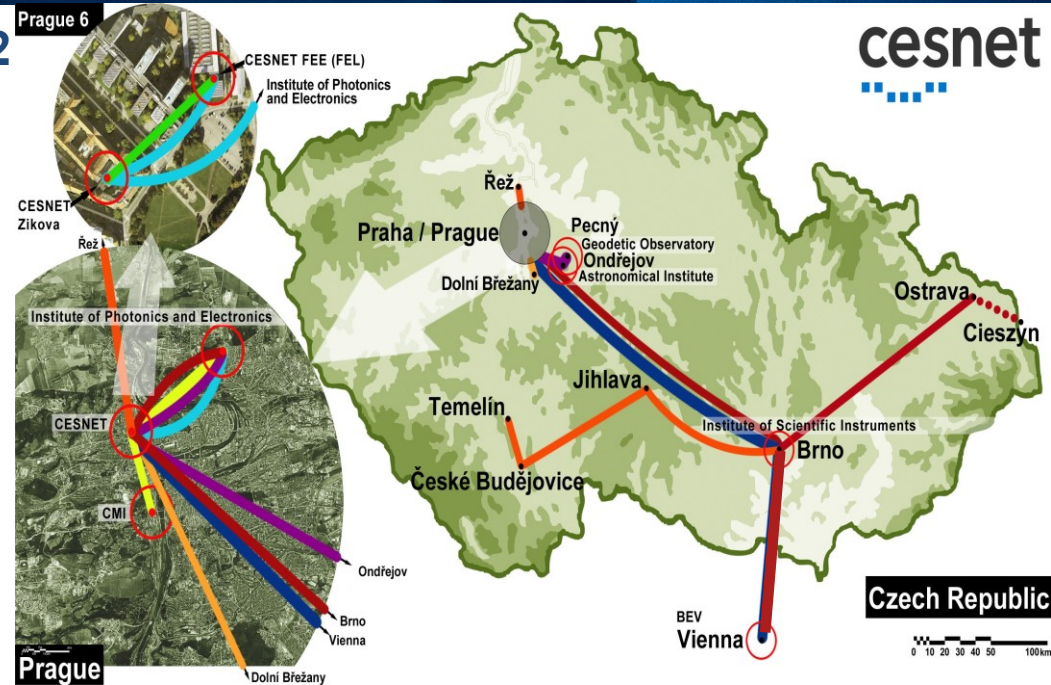
- Dedicated all-optical channel

- 800/400 GHz,

 - Ch 46-39/46-43

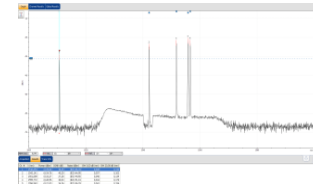
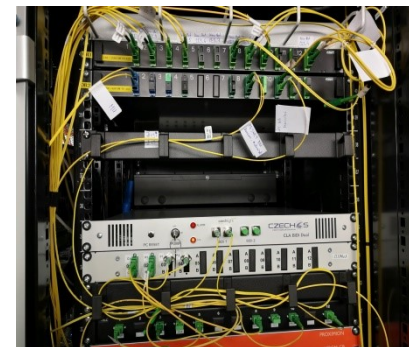
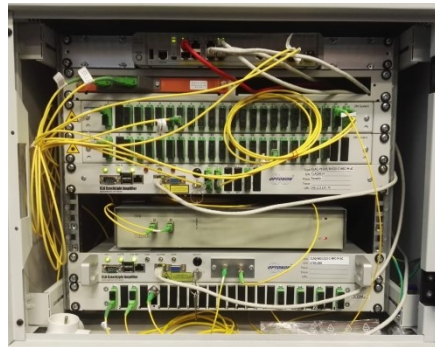
- 700km of lit bidi channels provided as a service

- Projected length 2476 km, transmission 1183 km



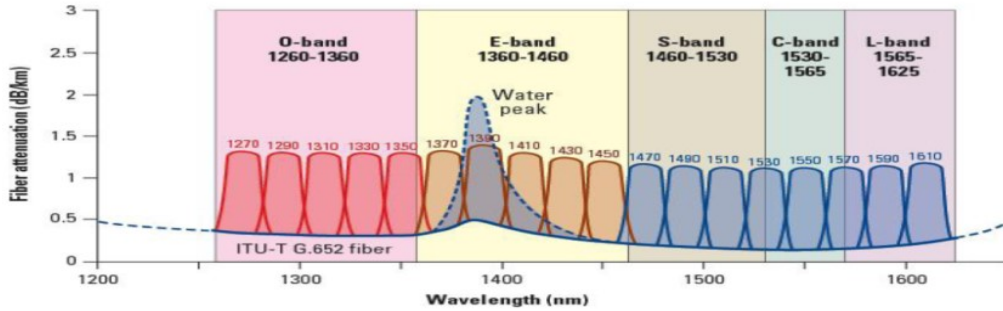
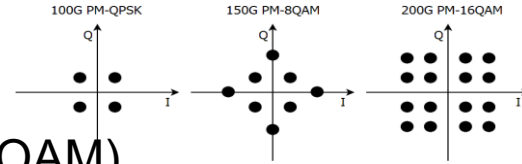
Time and Frequency Infrastructure

- Coherent Optical Frequency
- Metro – Fibre
- Long haul – DWDM bidi channel
- 550 km 800 GHz / 520km 400 GHz
- Operation
 - 840km ch46 1540.5 nm
 - 250km ch44 1542.1 nm



Inceased Spectrum Use

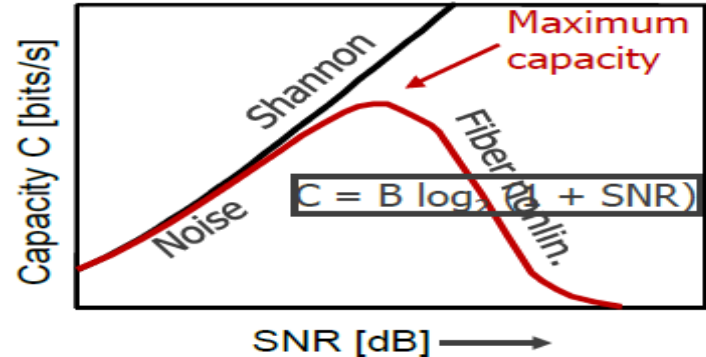
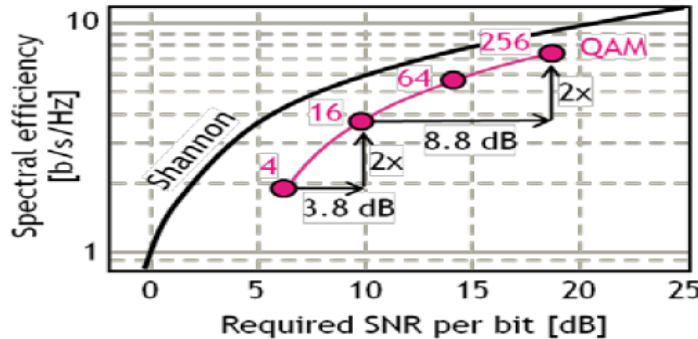
Obsolete	- 96 ch. per 10 Gbit/s	- 0,96 Tbit/s (OOK)
Mature	- 96 ch. per 200 Gbit/s	- 19,2 Tbit/s (DP16QAM)
Present	- 80 ch. per 400 Gbit/s	- 32 Tbit/s (60 GHz , DP16QAM)
L band technology available since late 1990 – 90nm		



■ $OSNR_{ASE} = P_{out} - NF - G - 10 \log(N) + 58$

source: Pecci P. Alcatel Submarine Networks „Design of Submarine Open Cables“

source: cisco.com



- Multiplication of data capacity of single 50 GHz channel capacity with similar reach is no more scaling (Shannon),
- **C** capacity is exhausting (necessary guardbands)
- **L** will have the similar problem soon
- **S** not suitable for long haul (lack of amplification)
- **C/L** typ 4 nm 1566-1570 are skipped because of technological reasons, EDFAs work fine here

Alternative Bands

Coherent Frequency Transmission

	Sources	Detectors	Band Filters	Channel Filters	Amps
C	++	+++	++	+++	+++
C/L	++	+++	+	++	++
L	+	+++	+	+	++
S	0	+++	0	-	SOA, Brill only

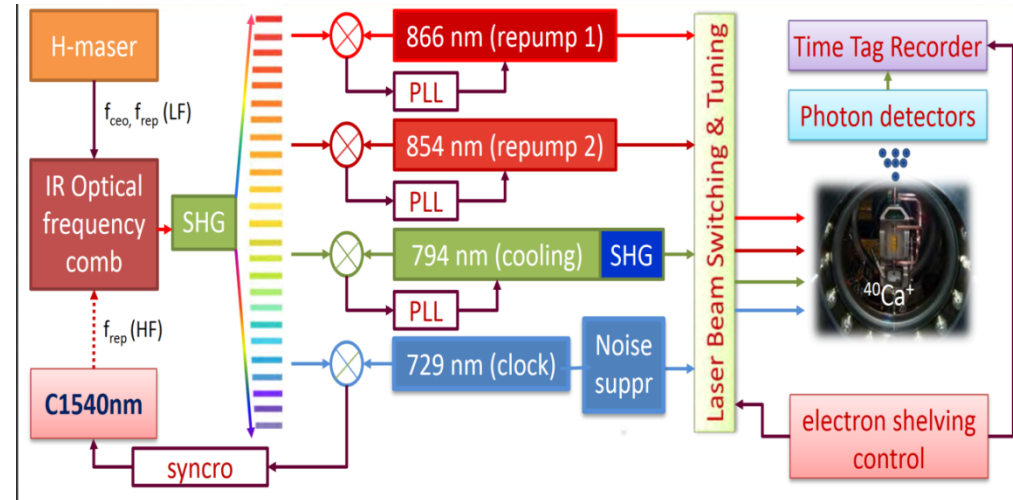
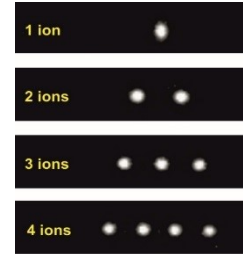
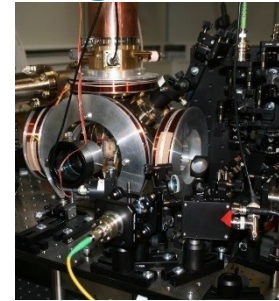
Precise Time Transmission

	Transceivers	Band Filters	Channel Filters	Amps
C	+++	++	+++	+++
C/L	++	+	++	++
L	+	+	+	++
S	CWDM only	0	-	SOA only

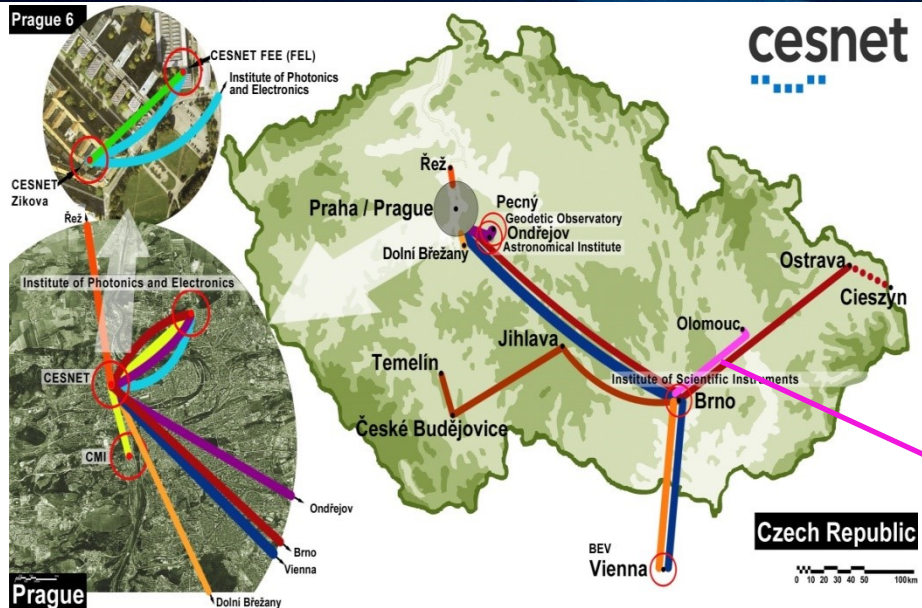
Multi Channel TF Infrastructure

- Coherent Optical Frequency
- Optical clock $^{40}\text{Ca}^+$ ion
- Transfer of second harmonic of 729 nm (1458)
- Requested transfer channels:
 - Classical: C band ch. 46
 - 1570 nm C/L band
 - S band (1458 nm)

$^{40}\text{Ca}^+$ ion clocks @ 729 nm

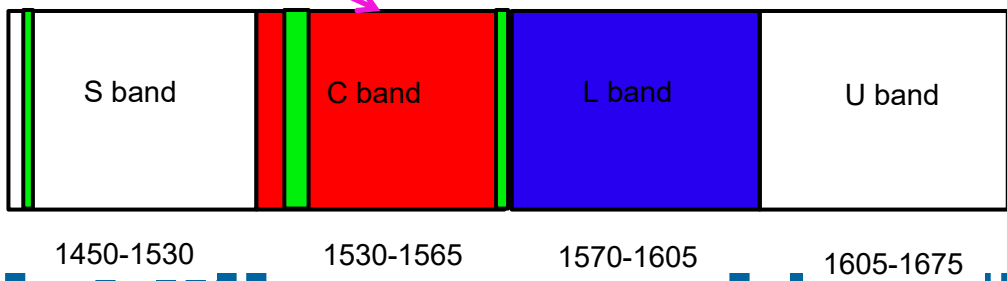


Multi Channel TF Infrastructure



Optical clock based on trapped and cooled single ion $^{40}\text{Ca}^+$ Direct output at: 729 nm

Distance: 20km, 29 dB

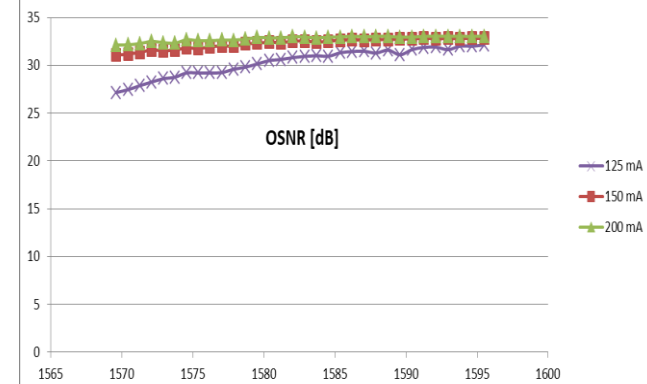
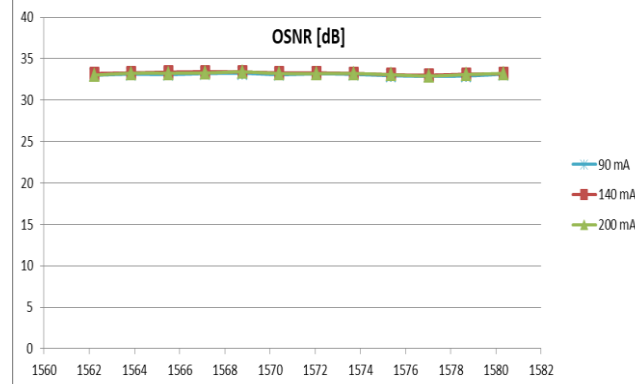
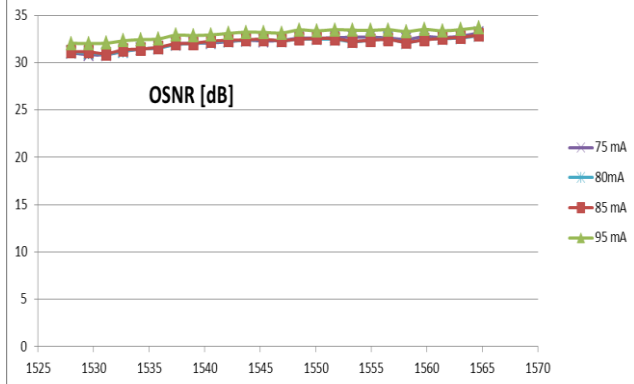
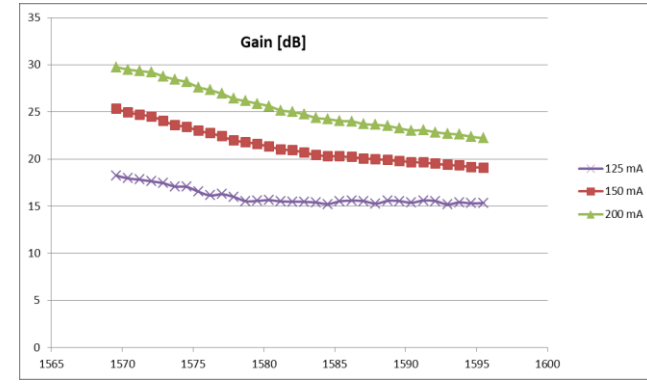
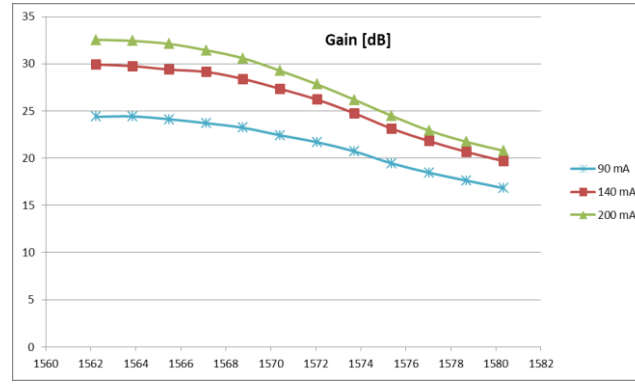
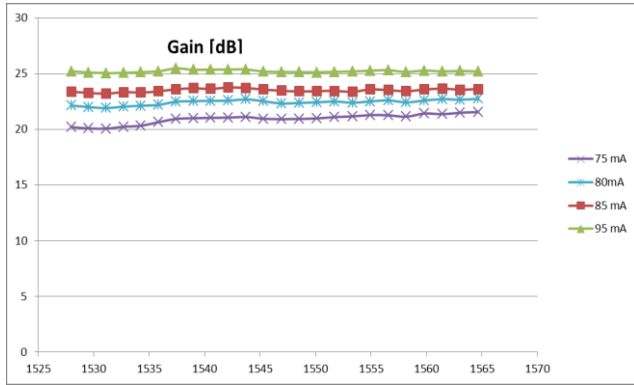


Performance Verification of 1570 nm-bidi EDFAs CzechLight

C

1570 nm

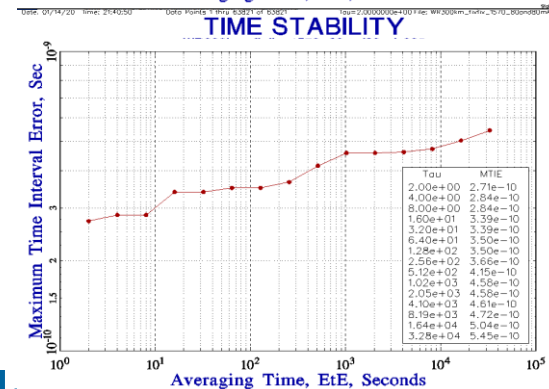
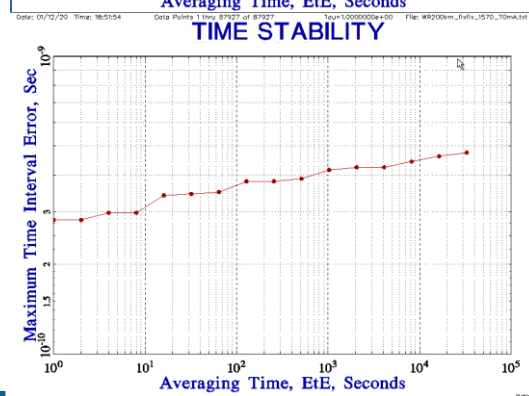
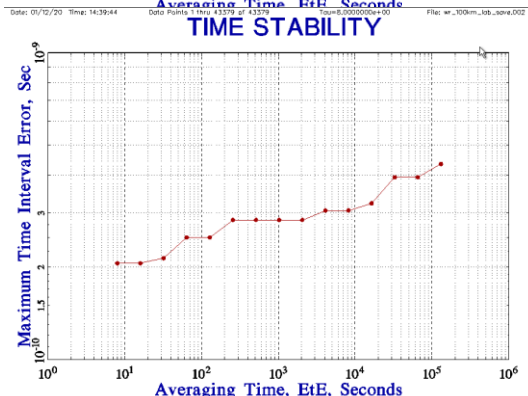
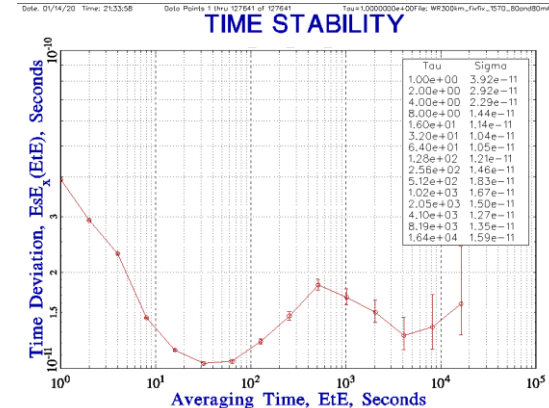
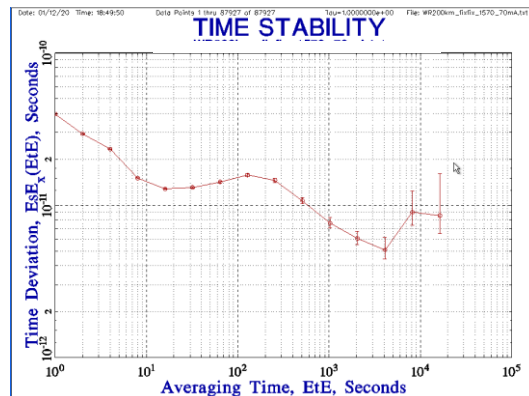
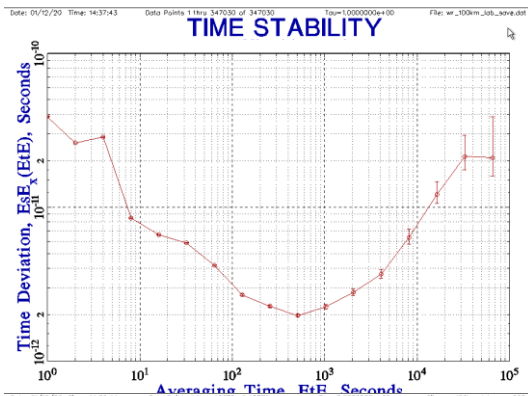
L



Vojtech J., "Alternative spectral windows for photonic services distribution," Proc. SPIE 11128, Infrared Remote Sensing and Instrumentation XXVII, 1112806 (9 September 2019); <https://doi.org/10.1117/12.2529713>

Performance Verification of 1570 nm

- Tested WhiteRabbit in 1570 nm band, dark channel (100 km), bidirectionally amplified channel (200 and 300 km)



- Necessity of significant spectral gap
- Raman energy transfer to lower energies/high wavelengths
- On shared fibres S band looks interesting (no amplifiers necessary)

- 1570 nm to be field tested and deployed soon
- 1458 subject to further tests
- Plans to gradual vacation of channels 44/46 and move to 1570 nm



**Thank You very much for
Kind Attention!
Questions?**

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