Fibre frequency dissemination with a resolution below 10^{-17}

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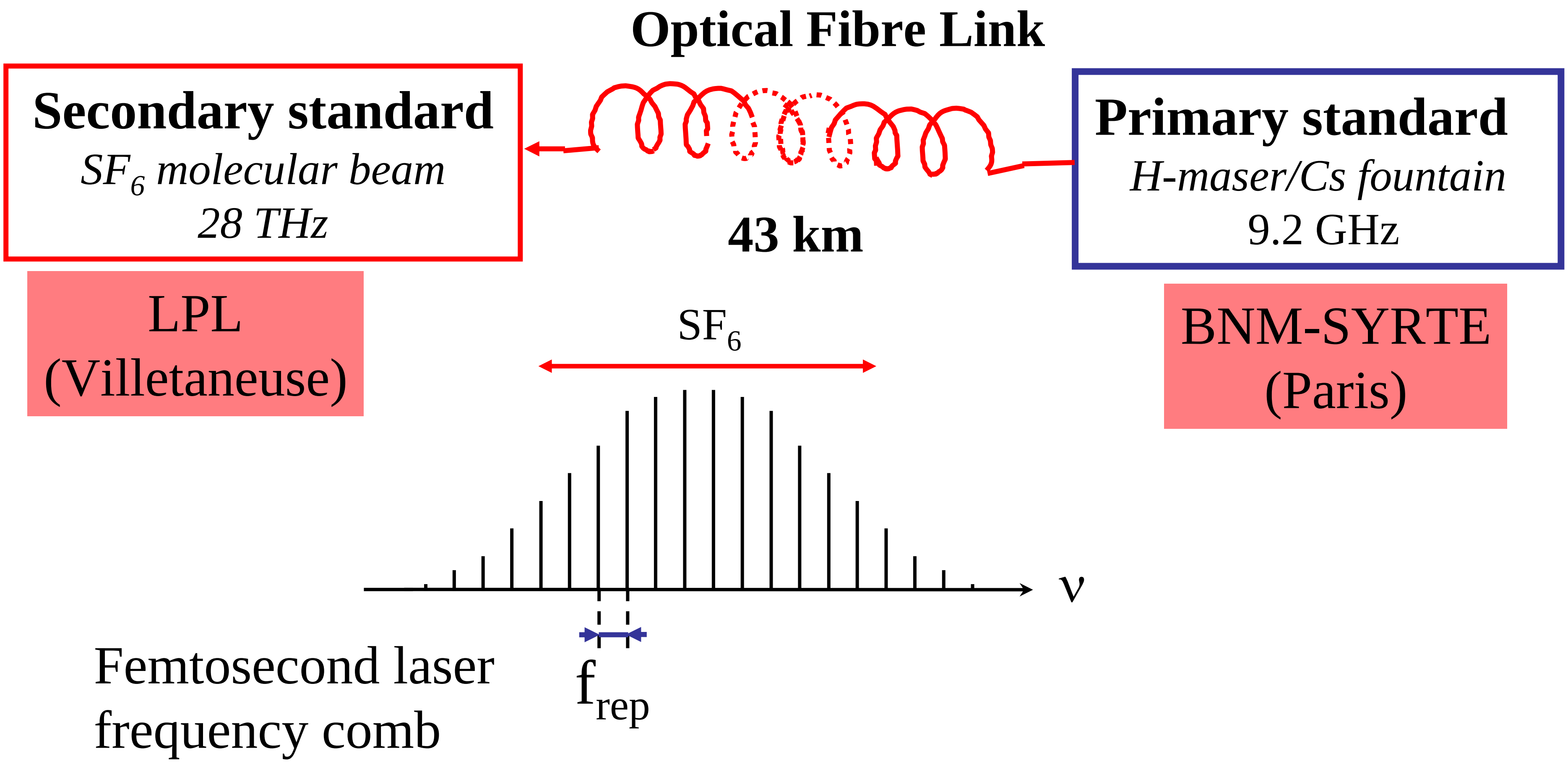
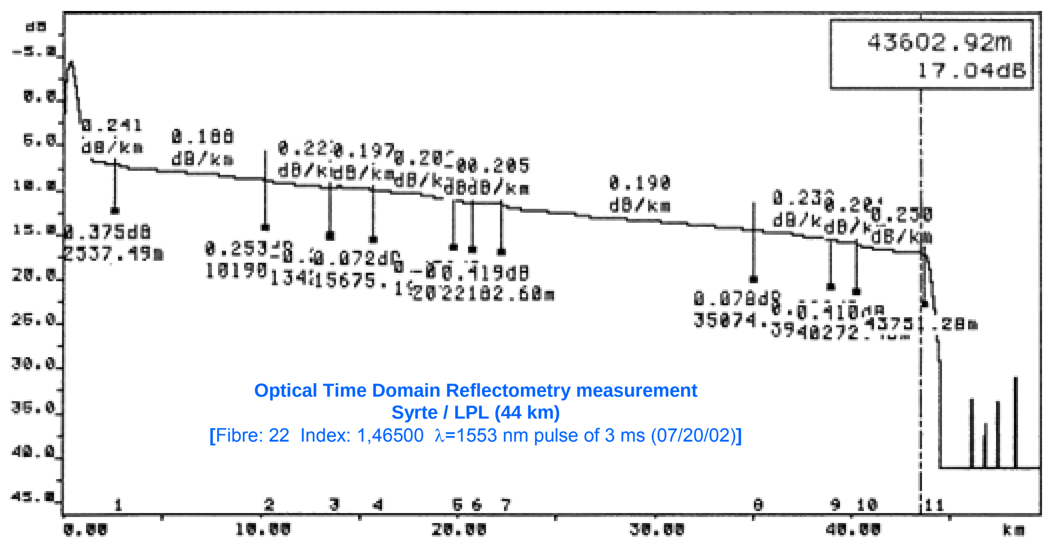

Optical Fibre Link
Secondary standard
SF6 molecular beam
28 THz
43 km
Primary standard
H-maser/Cs fountain
9.2 GHz
LPL
(Villetaneuse)
BNM-SYRTE
(Paris)
SF6
ν
Femtosecond laser
frequency comb
frep

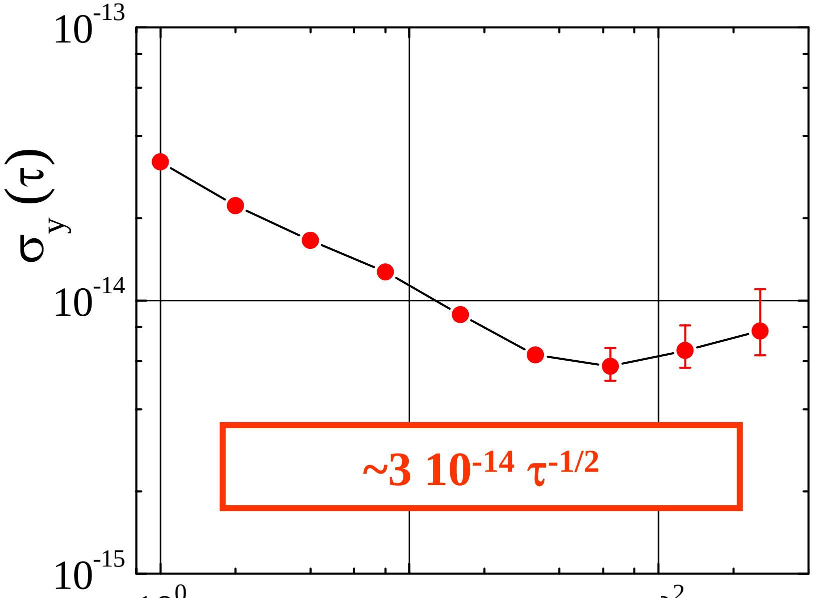
SYRTE to LPL : 43 km telecom fiber optical link

⇨ **Two 43-km dedicated telecom fibers of the Paris metropolitan network**

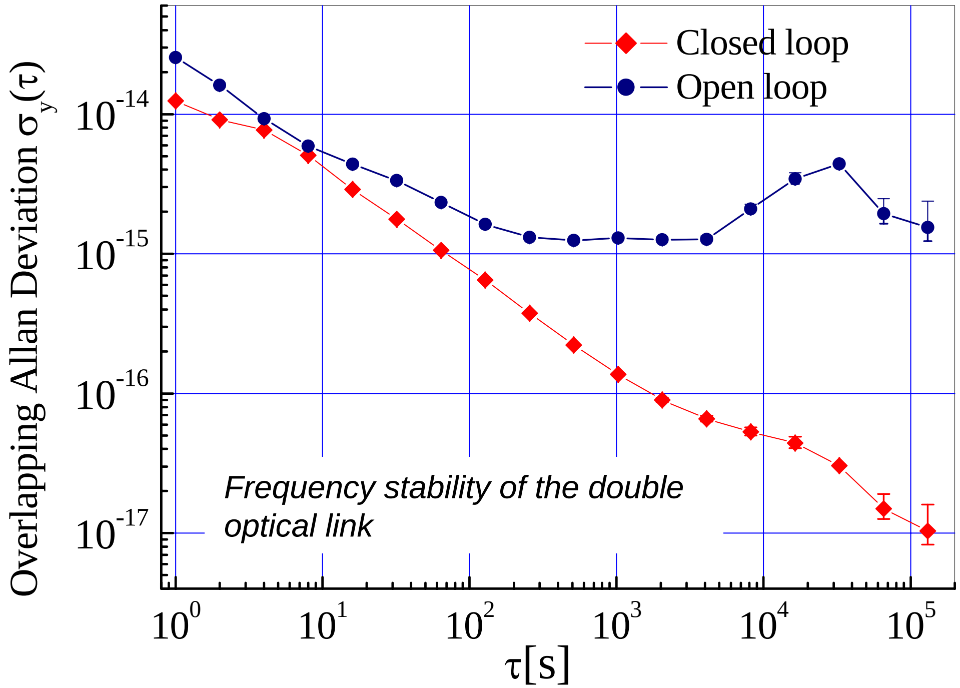
- A few different sections of buried fibre cable
- Splicing to ensure the continuity
- 10 dB one way optical losses (@ 1.55 μm)



Results of the 100 MHz frequency dissemination



LPL CO_2/OsO_4 (30 THz) vs SYRTE CSO (11.9 GHz)

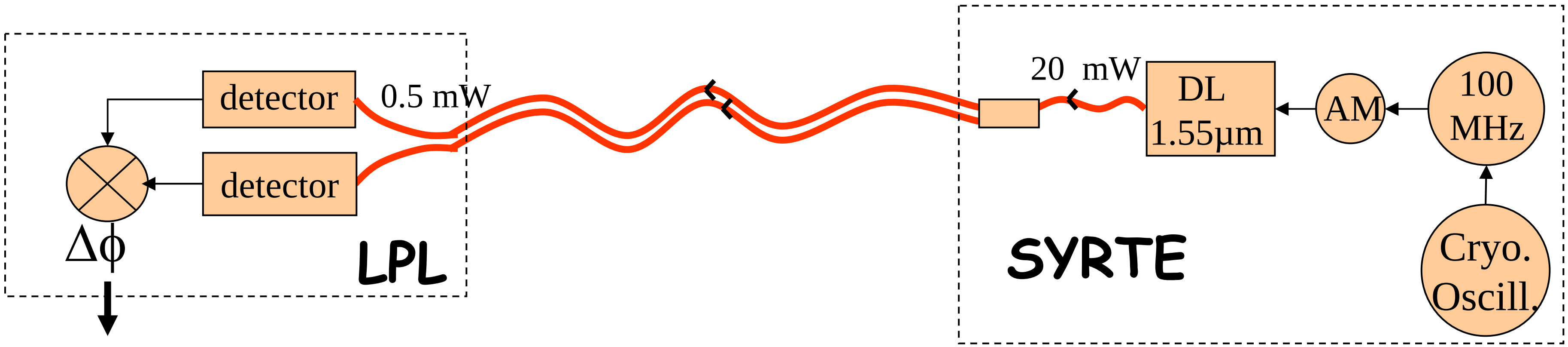


ν_{SF6}= 28 412 764 347 323.0 ± 1.4 Hz

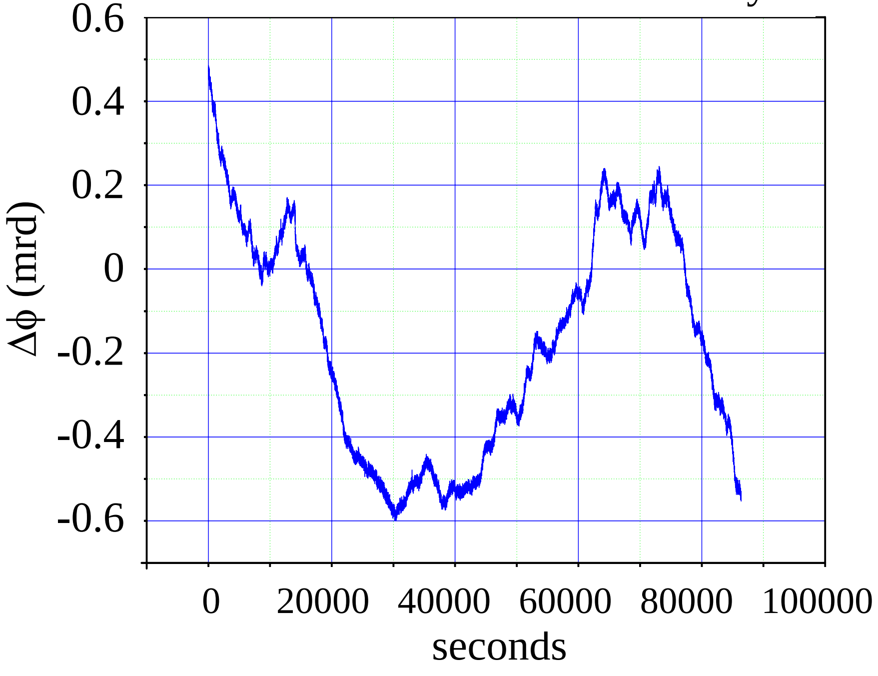
C. Daussy *et al*, *Physical Review Letters*, **94**, 203904, 2005.

F.Narbonneau *et al*, *Rev. of Scient. Instrum.*, **76**, 2006.

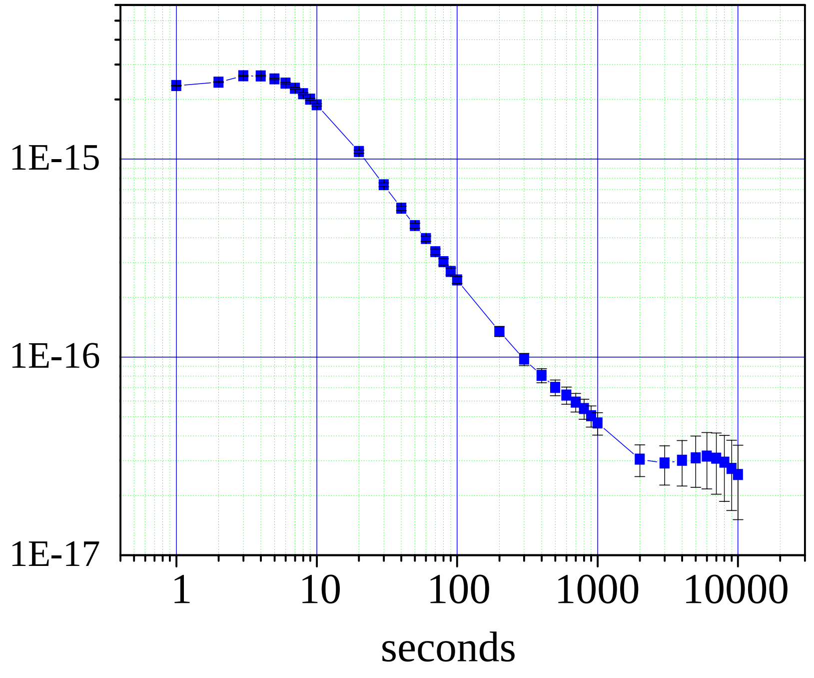
Phase Correlation between the two optical links



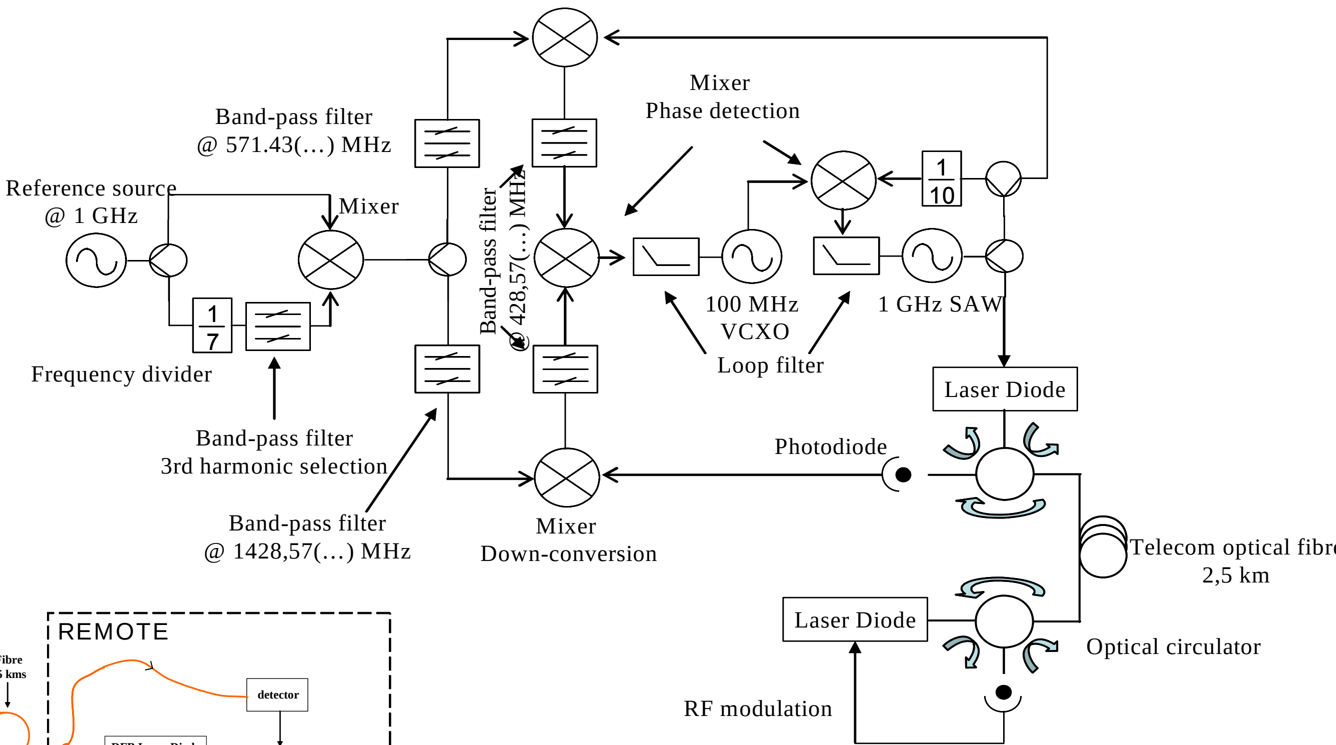
Relative phase fluctuations
between the 2 fibers over one day

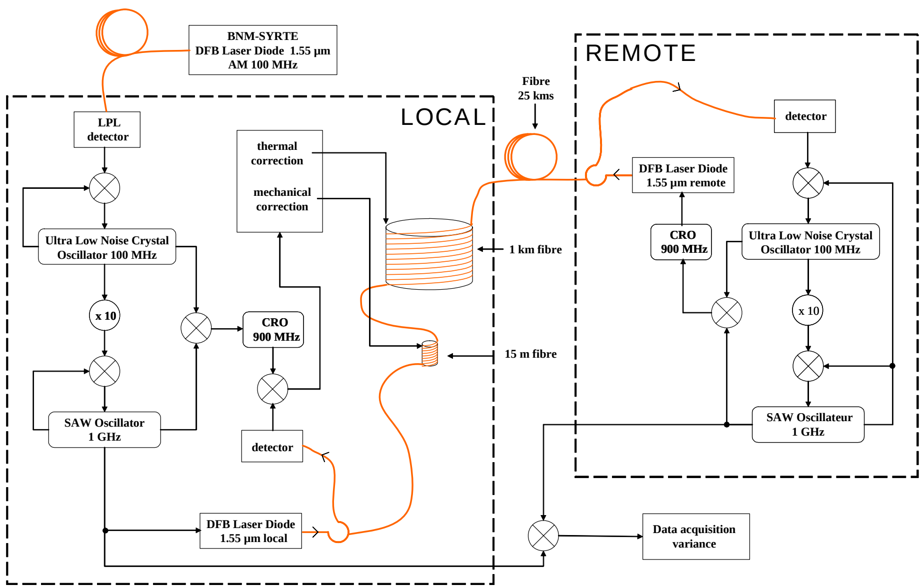


Allan deviation of the relative
frequency between the two fibers

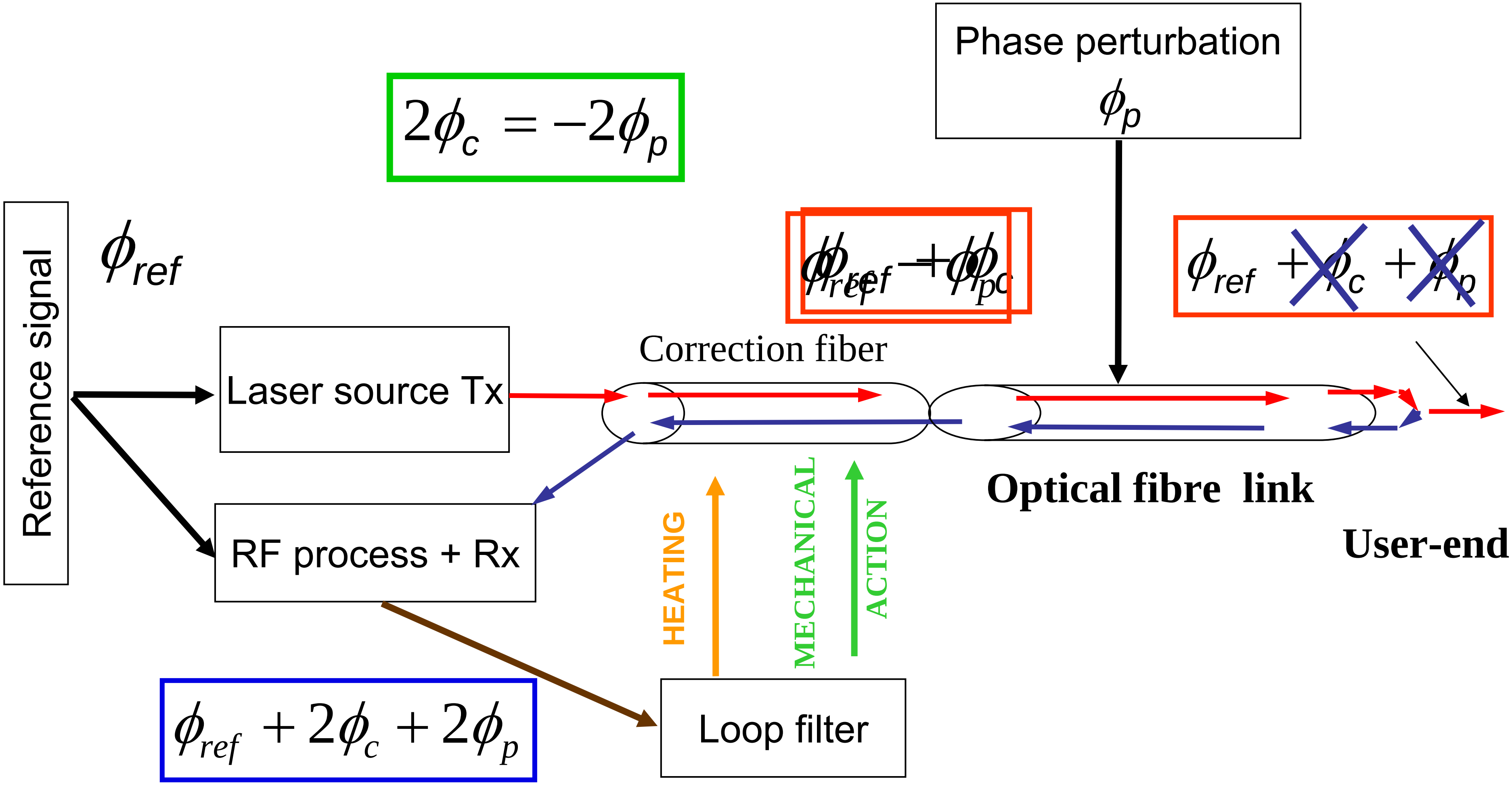


Phase compensation systems operating with 1 GHz carrier frequency





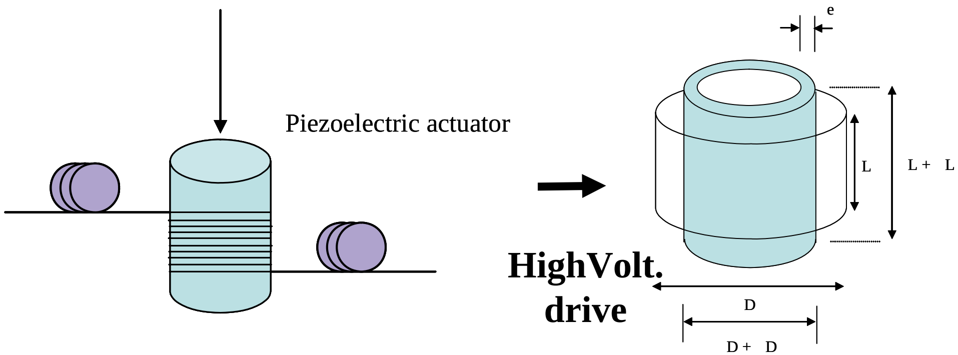
Optical phase compensation principle



Optical phase compensation principle (2)

- Fast small phase correction by fibre stressing on a piezo ceramic

High voltage 0 → 1000V, 15m of fibre (15 ps range, 400Hz BW)



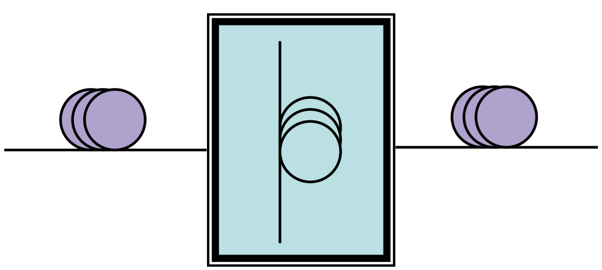
Muller *et al.* arXiv/0511072

Fast phase corrections by thermal excitation of Al or Au coated fiber

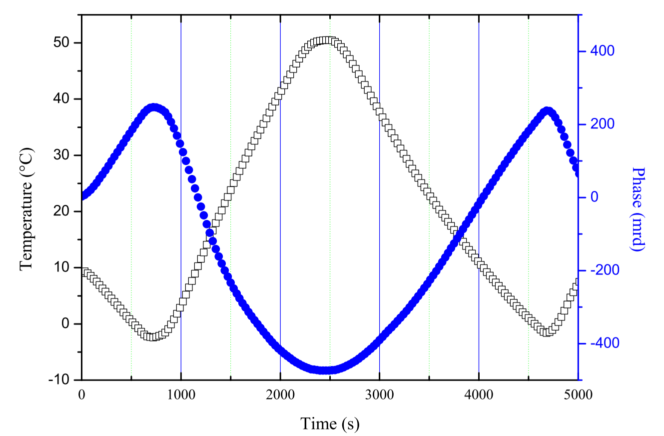
- Slow phase fluctuations correction by fibre heating

Copper wheel

30→ 60 °C 4-km fibre 150 ps /°C, 6 ns dynamic range

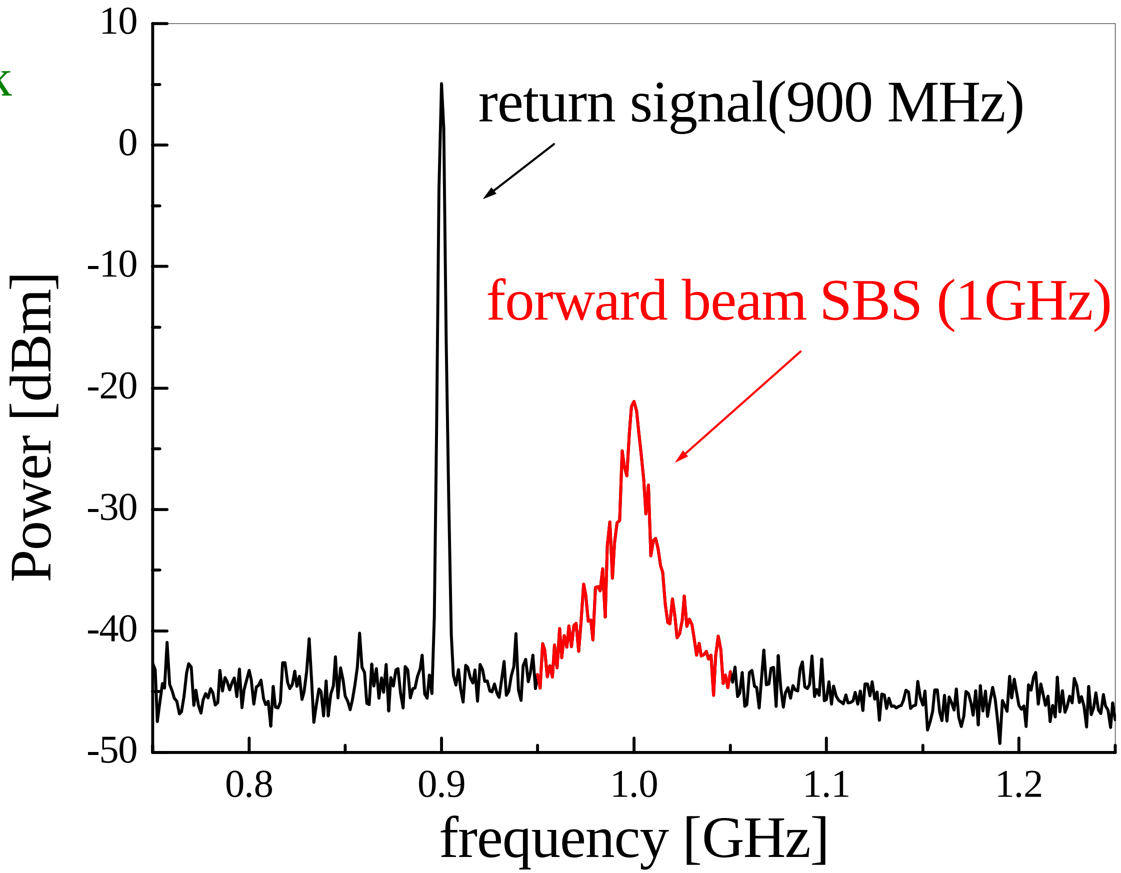


Phase shift



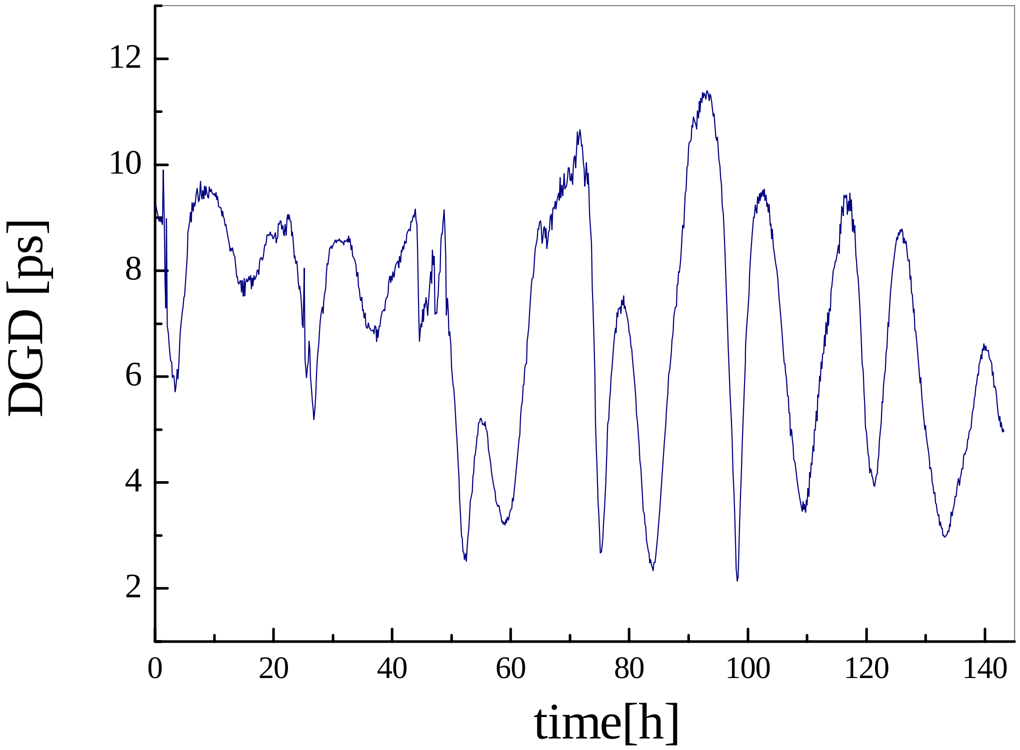
Optical feed-back parasitic effects

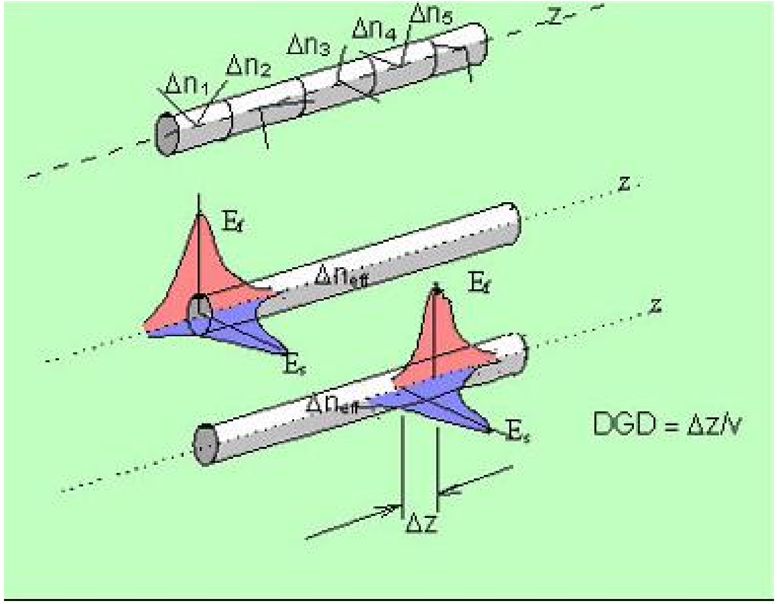
- Reflection on connectors and splicing along the link
- Stimulated Brillouin Scattering (SBS)
- To avoid these effects we use two different modulation frequencies
- **1 GHz** and **900 MHz**



PMD: a limiting effect

PMD (polarization mode dispersion) is caused by the birefringence of the optical fiber due to asymmetry of the fiber (stable in time) mechanical stress on the fiber due to movement or temperature (varies in time stochastically)

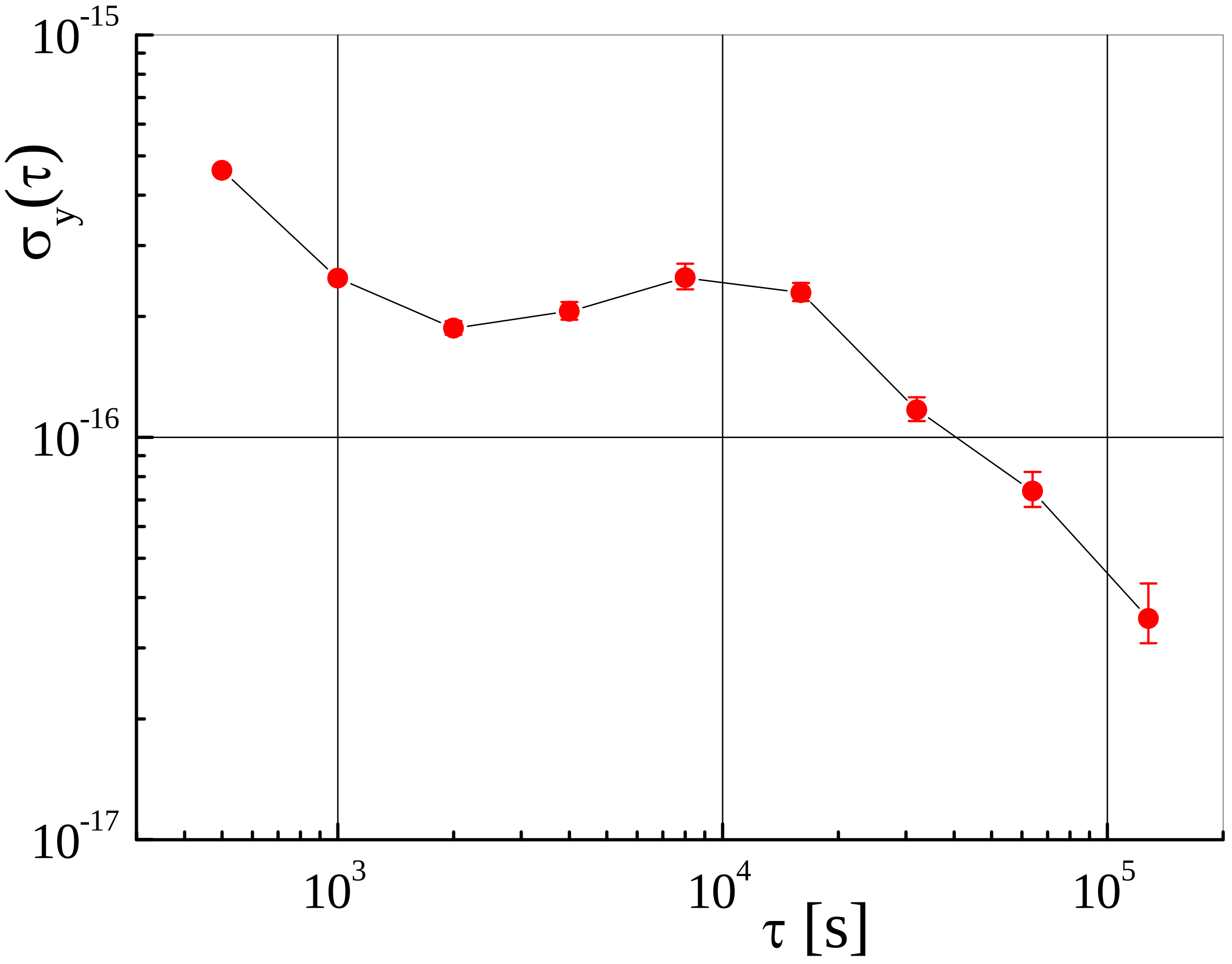




First ord. PMD 1(0.05)ps/$\sqrt{km}$ vintage (modern) fiber for our 86 km fiber the average DGD is about 7 ps and fluctuates on a time scale from 1000 to 30000 seconds.

Forward and backward beams do not experience the same delay the wavelengths are different, the input polarization states at each end fluctuates independently

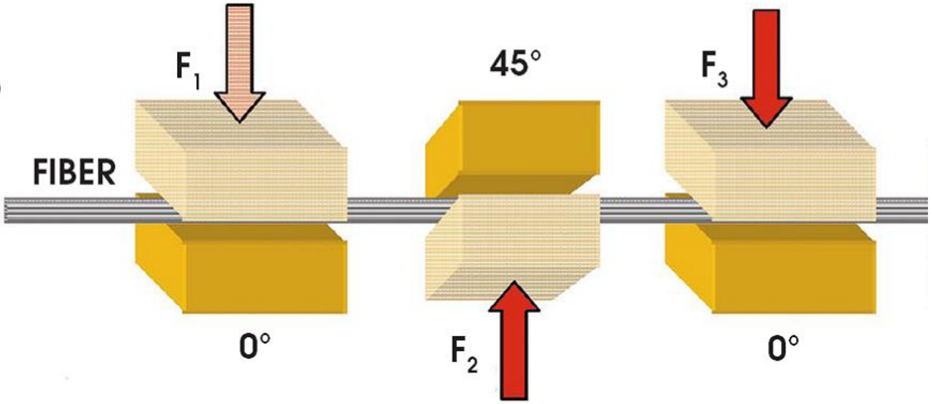
PMD: a limiting effect II



Frequency stability floor due to PMD at 1 GHz and 86 km

Fast Polarisation scrambling: the PMD cure

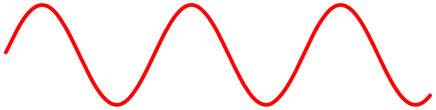
By fast modulation of the input polarization with 3 non harmonically related frequencies we explore all polarization states in the fiber averaging the PMD. The modulation frequencies are close to the piezo electric resonances ranging from 30 to 200 kHz to drive with low voltages (a few Volts) a complete polarization flip of π.



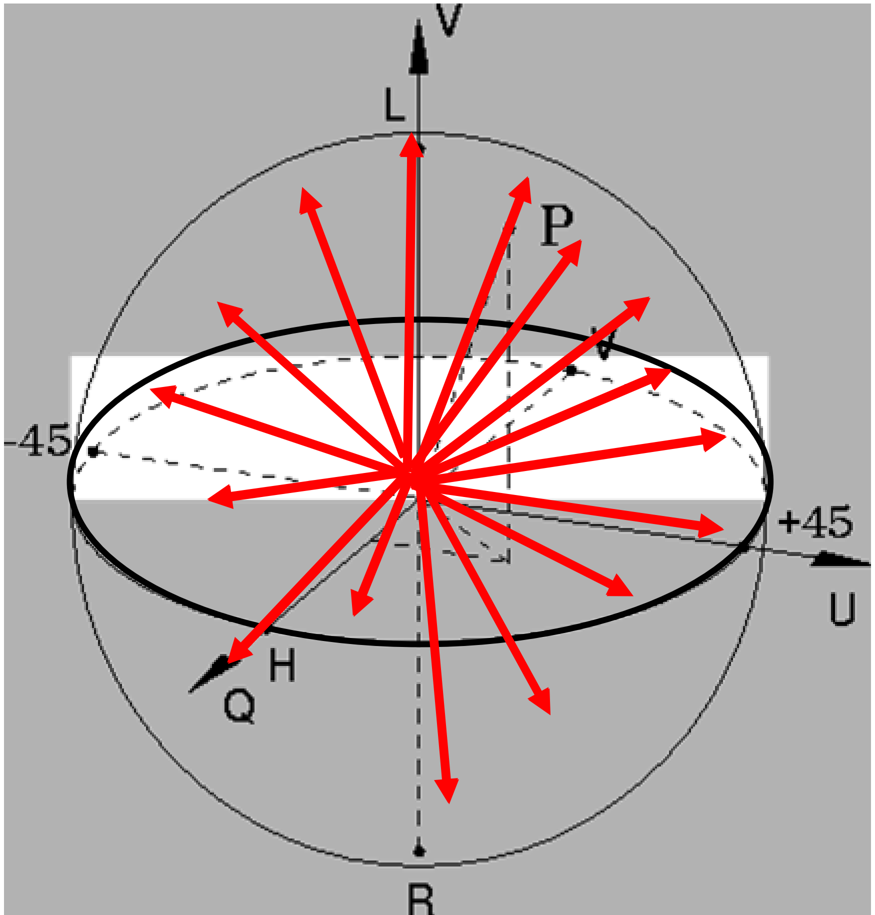
Two polarization scrambler are placed at each end of the optical link. In this way forward and backward beams explore all polarization states on a time scale shorter than the round trip delay (~1ms).

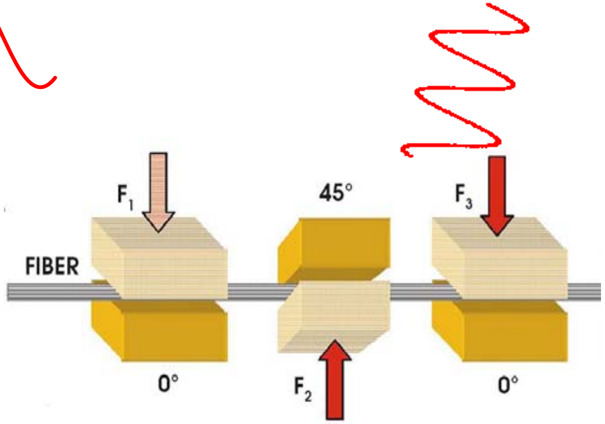
Fast Polarisation scrambling: the PMD cure

Poincare's Sphere

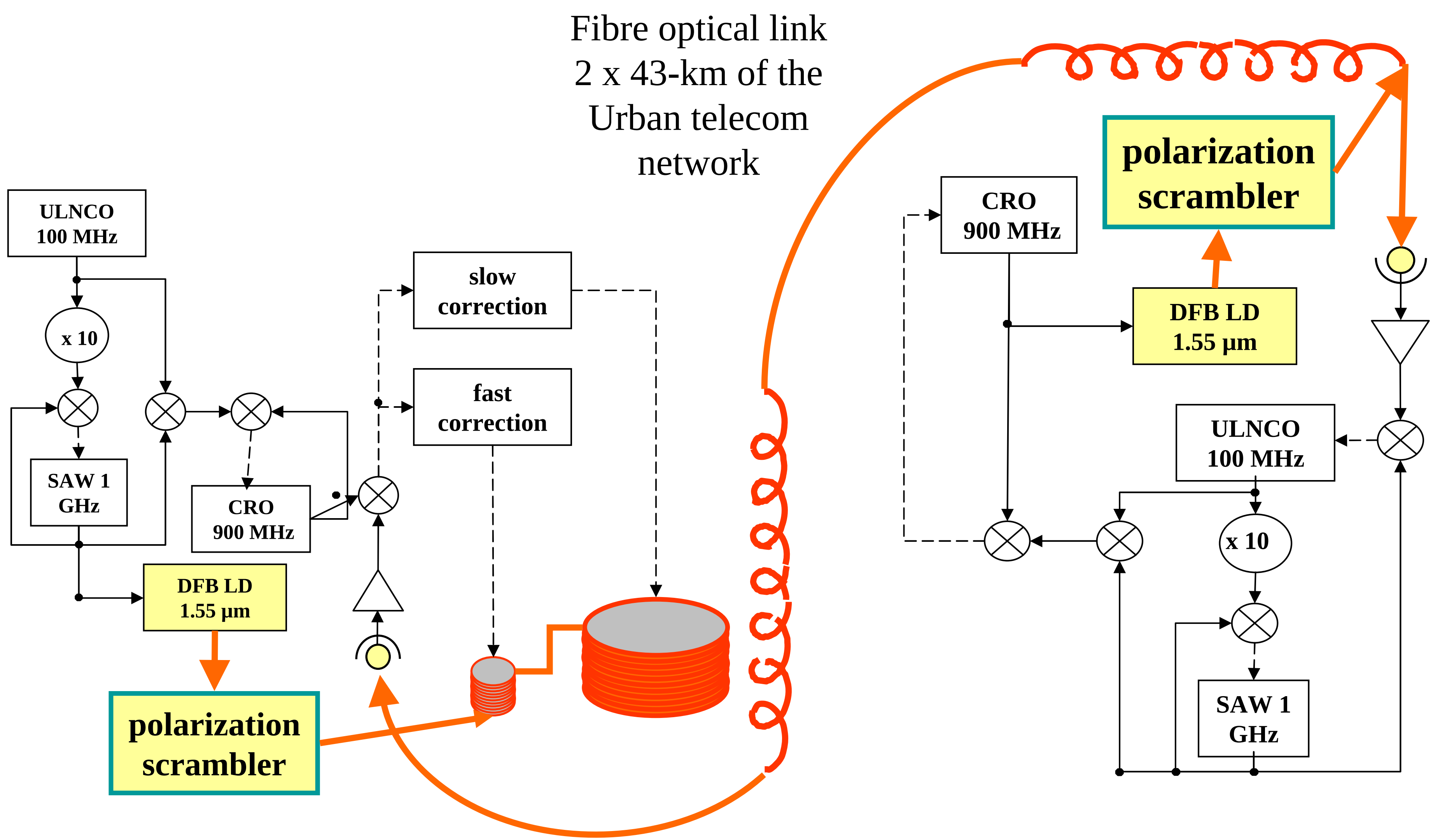


Polarization state vector

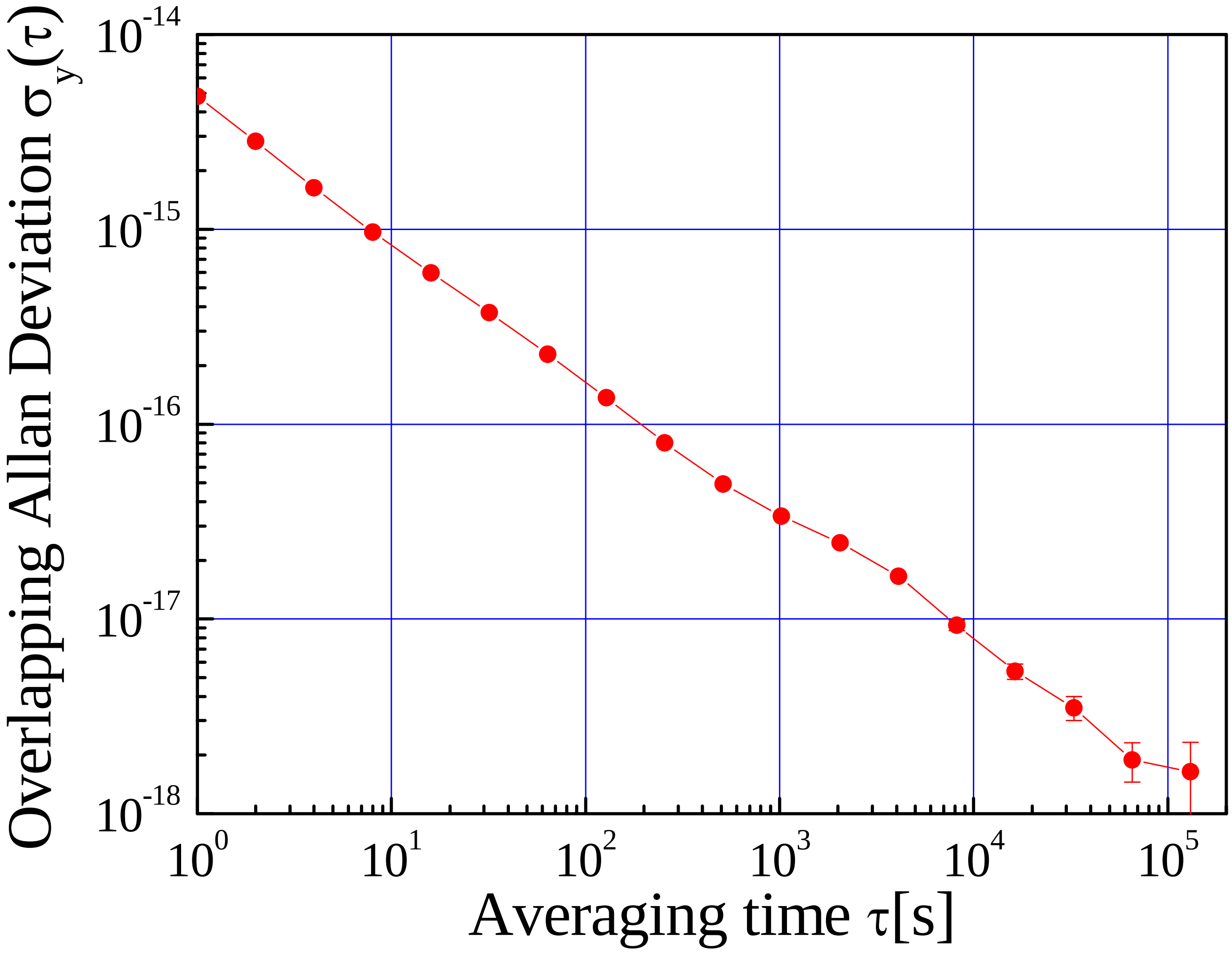




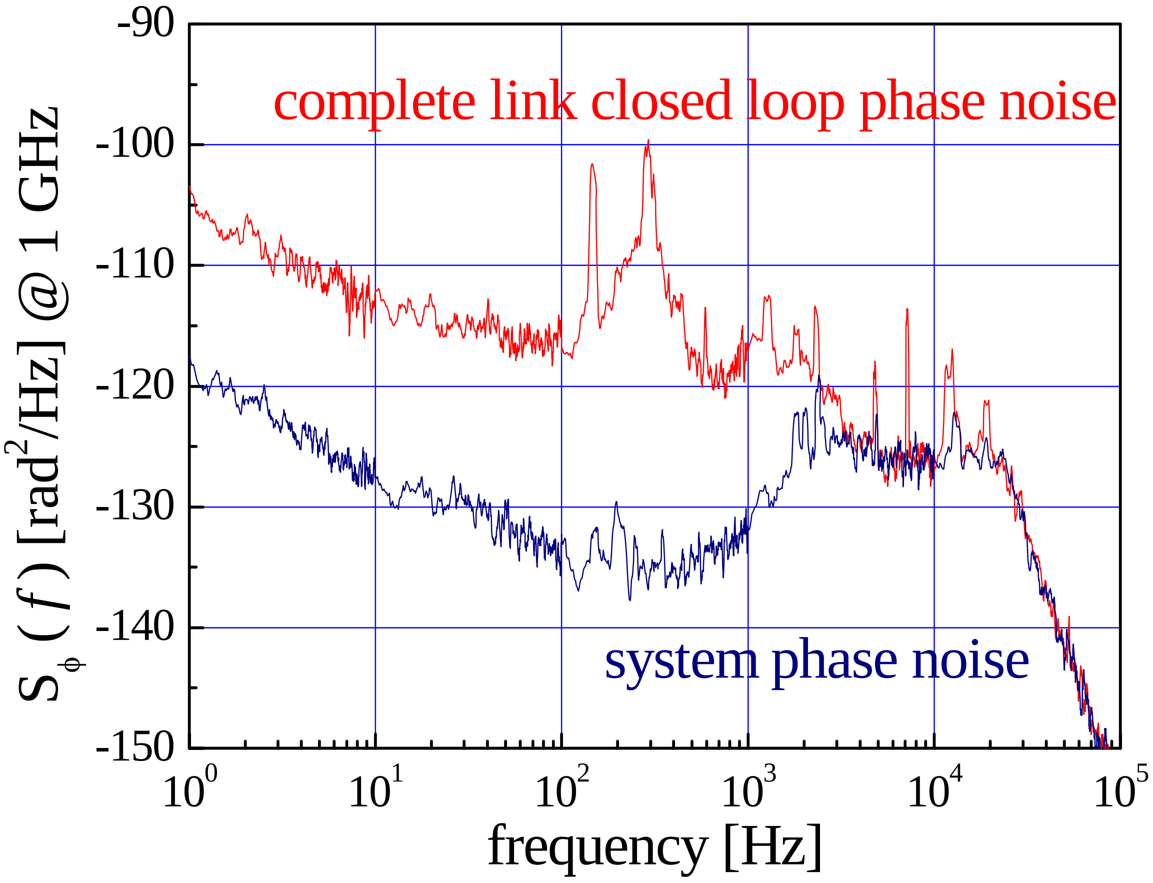
Scrambled Optical Compensator



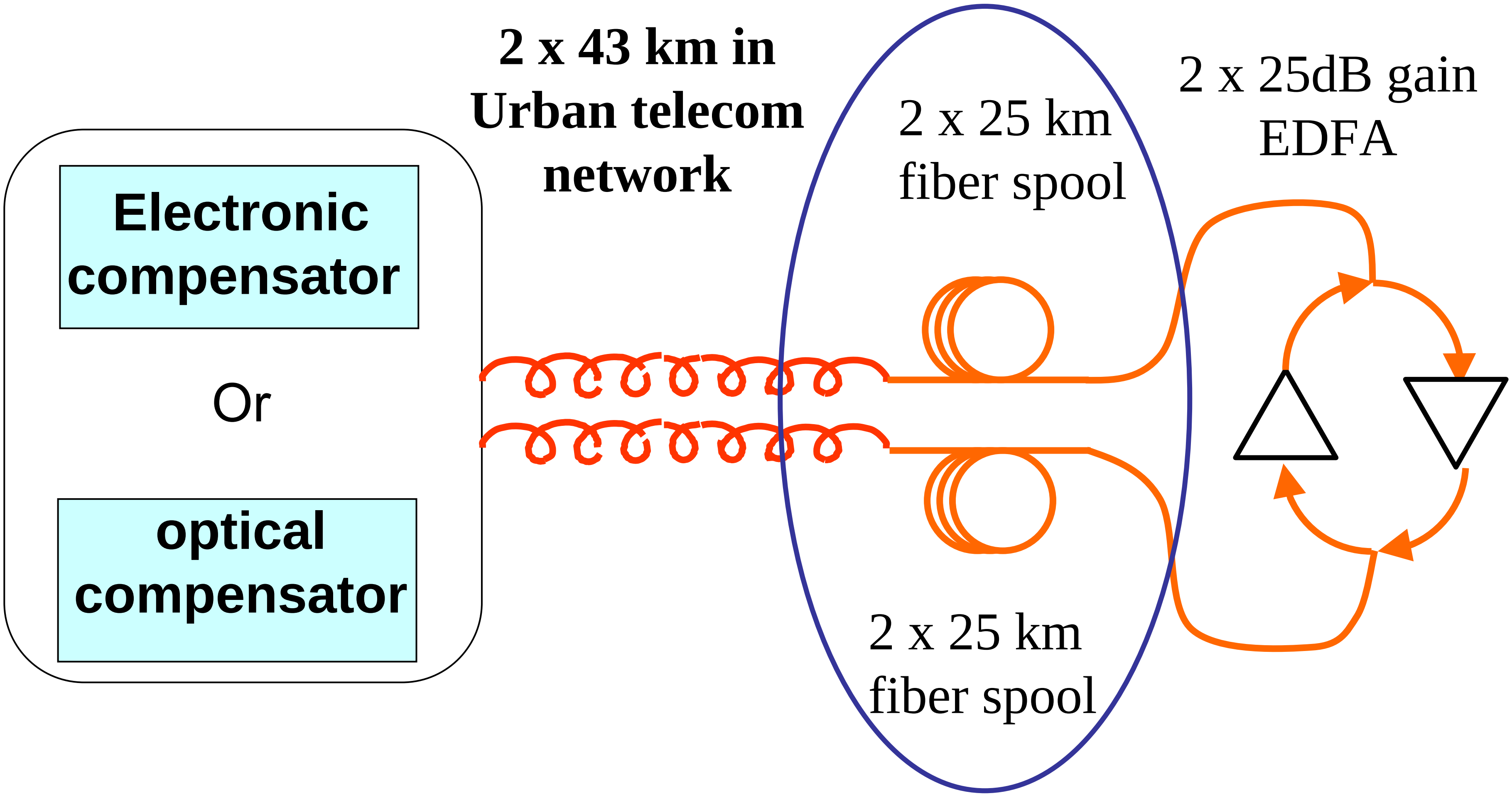
Frequency Stability (86km-1GHz) optoelectronic compensator



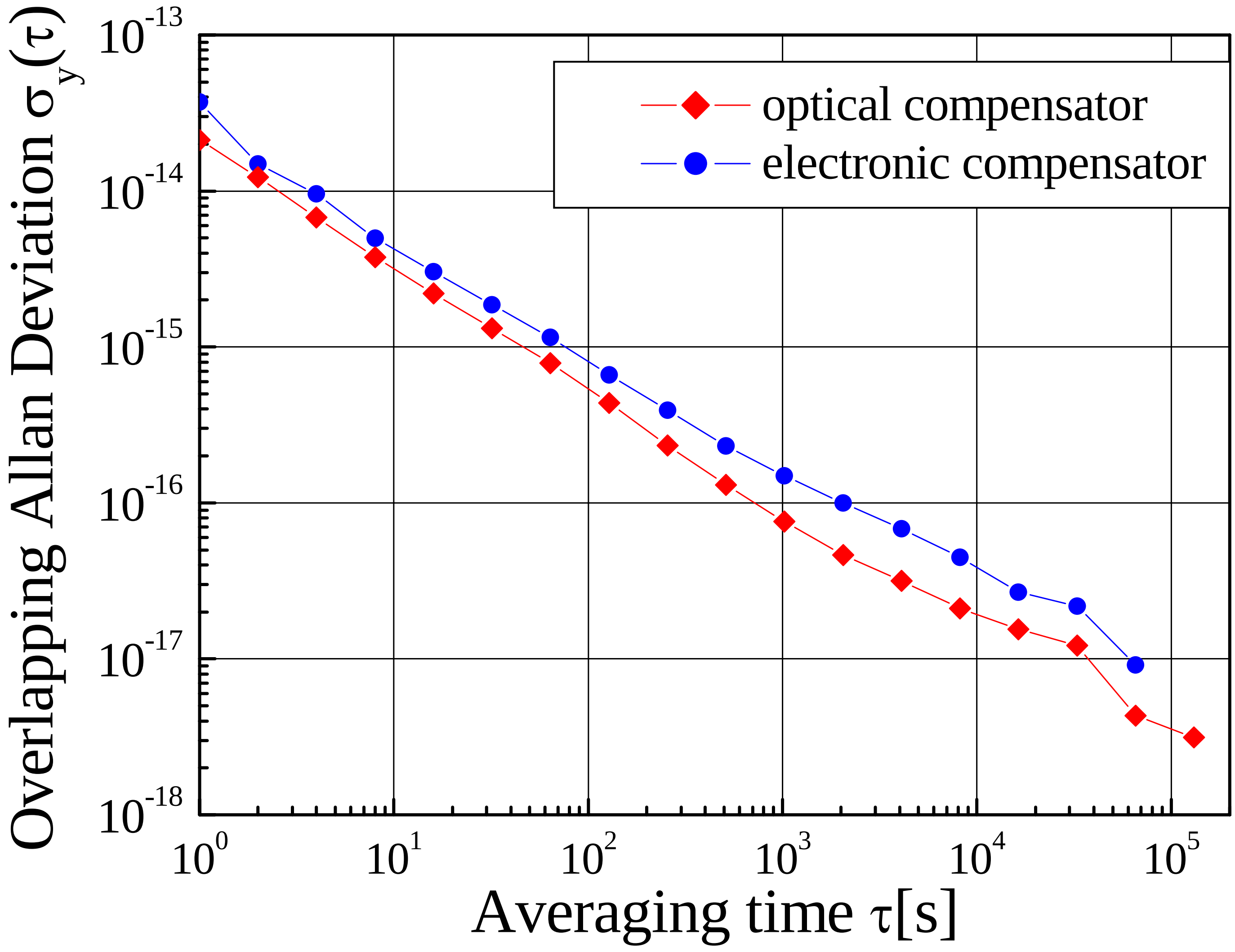
Phase noise spectral density of the system



Measurement scheme for a 186-km link



Preliminary results (186km-1GHz) 2 EDFA



Conclusion & Perspective

	86km distribution system @ 1GHz	186 km distribution system @ 1 GHz
Short-term ADEV	**3-5 10^{-15} @ 1s**	**1-3x10^{-14} @ 1s**
Long-term ADEV	**2-3x10^{-18} @ 1 day**	**~<10^{-17} @ 1 day**

- **In the short term :study of a longer distance link (3-400km) using a microwave carrier (9 GHz) optical link with externally modulated laser diodes and optical amplifiers.**
- **Near future : single tone optical carrier a 1.55 µm for frequency transfer (ANR contract)**

Acknowledgments

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a full European ultra-stable optical fiber link network ?