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Optical Time Transfer (OTT): PoC Results and Next Steps

Helmut Imlau et. al., November, 3rd 2016

Optical Time Transfer
Agenda

Optical Time Transfer: Partners and participants

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Tasks:

- National Metrology Institute, realization and dissemination of UTC(PTB) and German legal time
- Clock and time transfer development

- OTT 'ELSTAB' development (Electronically STABilized fiber optic time and frequency distribution system [1])

- Network operation including synchronization network
- Obtains traceability to UTC via its UTC(DTAG) time scale

For OTT PoC:

- UTC(PTB) provision
- T&F domain measurements

- System installation
- System supervision
- System repair
- Link calibration

- Fiber link and remote access planning and provisioning
- Telecommunication domain and GNSS Common view measurements

The measurement data evaluation was supported by Lee Cosart of Microsemi with Time Monitor software

Optical Time Transfer
1. Hierarchical network synchronization solutions by ITU-T & more

Synchronization supply solutions for network operation can be based on:

(1) Ethernet Physical Layer Synchronization (SyncE acc. to ITU-T G.826x series)

(2) Precision Time Protocol (PTP) with Full Timing Support from the network acc. to ITU-T G.8275.x

(3) Clock functions as specified in ITU-T G.81x, G.826x, G.827x

A hierarchical synchronization network consists of several levels

- A separate layer is recommended for synchronization network supervision (in yellow).

For 24/7 synchronization dissemination:

Based on the needed maximum time error of end-application, a hierarchical synchronization network is needed (in gray)

	Architectural level	max|TE|	No. of Locations	Methods, Systems
Supervision level	Optical Time Transfer	<±1ns	3-5	OTT
	GNSS based Common View	<±10 ns **)	10/20	GNSS CV
24/7 service	Network core level	<±30 ns	10/20	e/cnPRTC*)
	Aggregation level	<±100 ns	1.000	T-BC, PRTC
	Base station level	<±1.1µs	n*10.000	T-TSC

*) For ePRTC / cnPRTC please refer [2] [3], **) averaged values

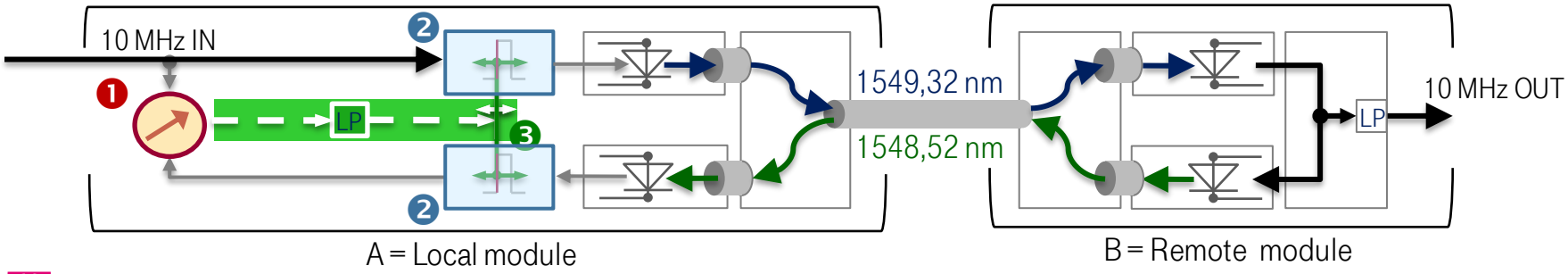
Optical Time Transfer: 2. The method: OTT/ELSTAB (1/3)

The fundamental time transfer problem over optical fibers:

- Delay variation (e. g. wander in a order of 40ps/km/K due to temperature effects over the year) to be compensated (as it is done by time stamp calculation like NTP/PTP method at a lower accuracy level)

The ELectronic STABilization (ESTAB) solution: Round-trip delay kept constant

- Active frequency propagation delay (electronic) stabilization of the of the optical link
  - ❶ Phase detector measures the phase difference between the input and feedback signal (Round-trip including variable delay lines (blue) in both directions)
  - ❷ Variable delay lines in forward and return path (same values for both direction)
  - ❸ Modified delay due to phase measurements .... to keep the delay constant



Optical Time Transfer: 2. The method: OTT/ELSTAB (2/3)

Assumptions:

- Same delay fluctuations (wander) effects in both directions due to same fiber and more or less similar wave length (Only chromatic dispersion and Sagnac effect to be compensated)
- Same values of variable delay compensation in both directions

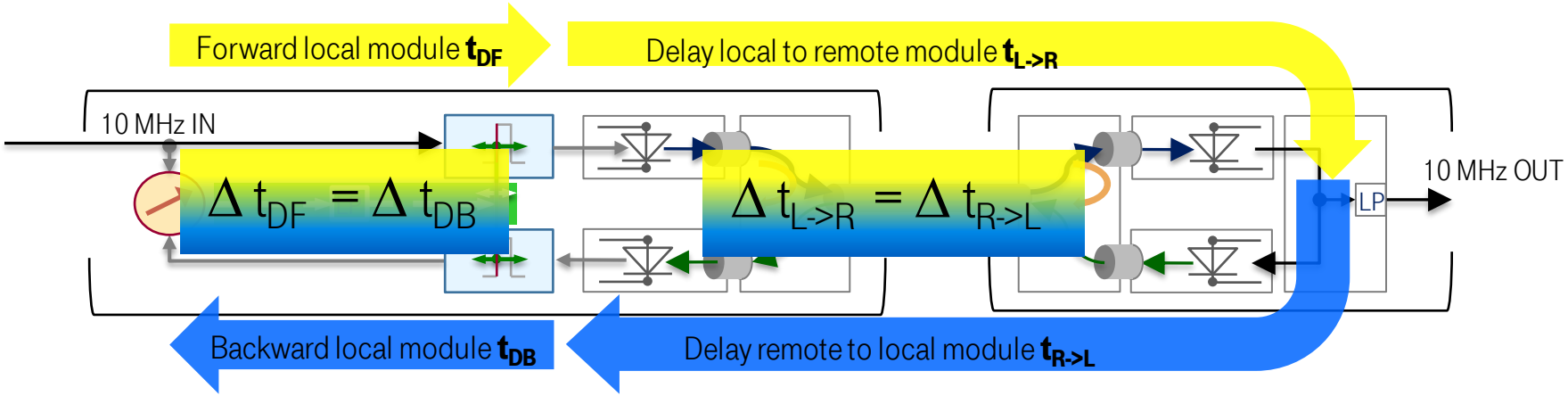
$$t_{DF} + t_{L->R} + t_{R->L} + t_{DB} = \text{const}$$

$$\Delta t_{DF} + \Delta t_{L->R} + \Delta t_{R->L} + \Delta t_{DB} = 0$$

$$\Delta t_{DF} + \Delta t_{L->R} = 0$$

The stabilization solution:

- **DLL (Delay Locked Loop) with variable delay modules keeps round trip delay constant**



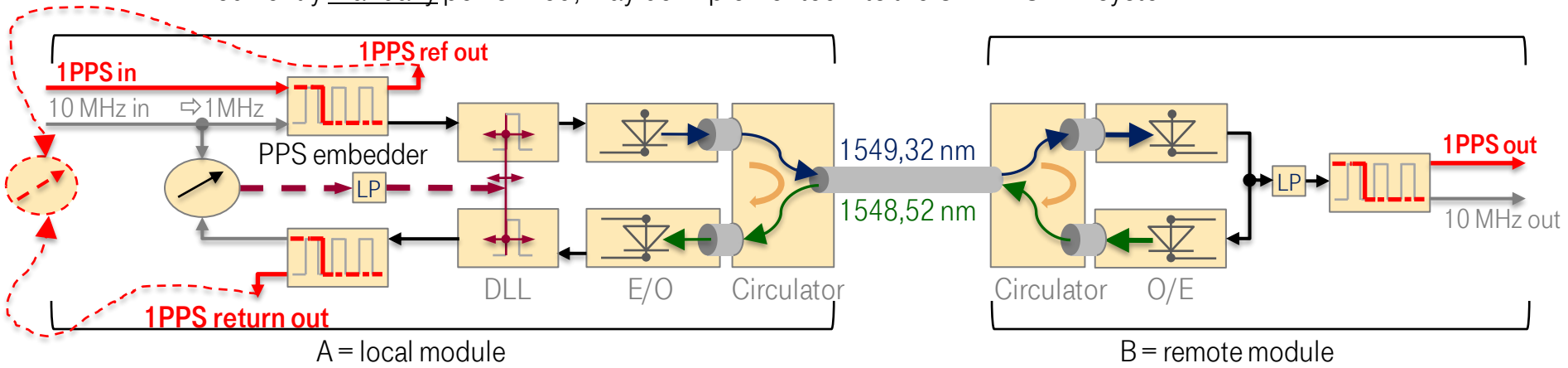
Optical Time Transfer: 2. The method (3/3)

Extension for 1 PPS transfer

At A:
- Every second, specific phase modulation is applied on frequency signal at 'PPS embedder'
- 'De-embedder' extracts the 1 PPS
- Round-trip delay measured between 1 PPS ref out and 1 PPS return out

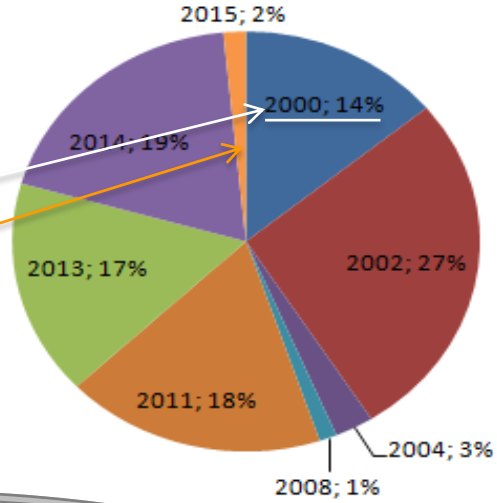
At B:
- 1 PPS out calculation with ½ round trip delay

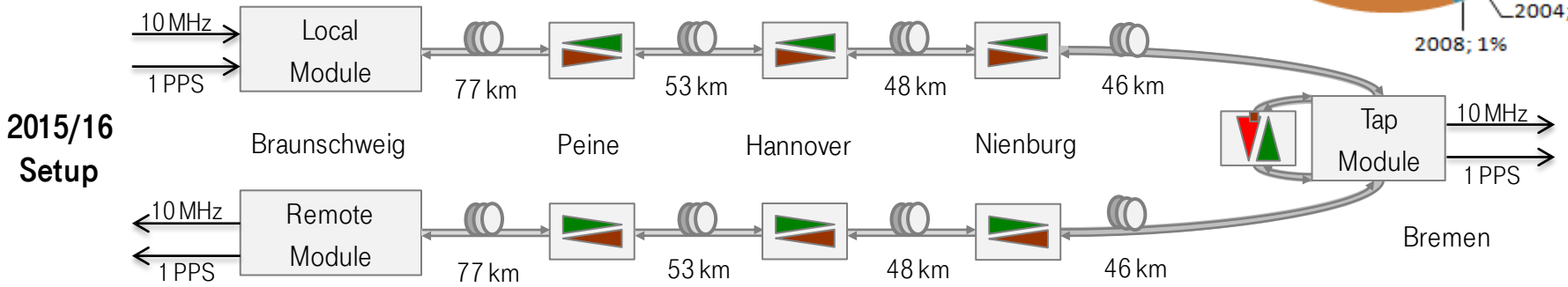
  + corrections due to chromatic dispersion, + Sagnac effect 1 ns/100 km east-west correction
- currently manually performed, may be implemented into the OTT ELSTAB system



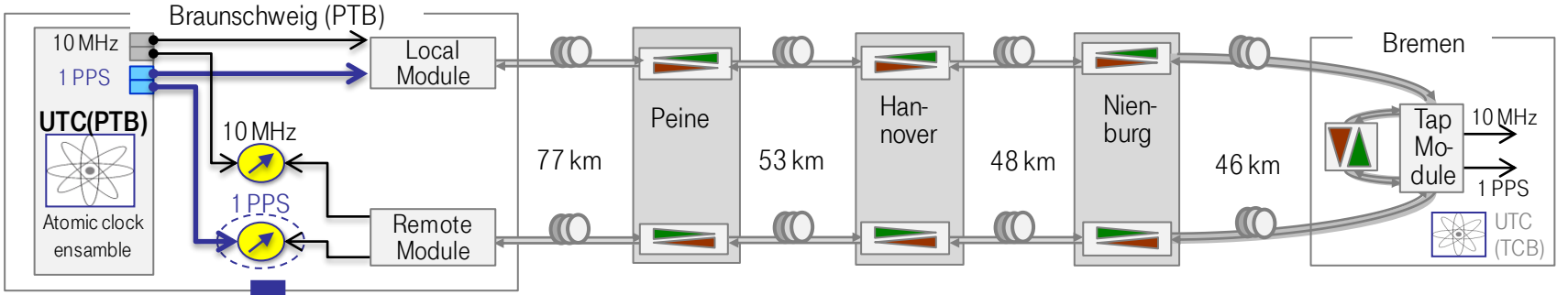
Optical Time Transfer:
3. Proof-of-Concept: Purpose and setup

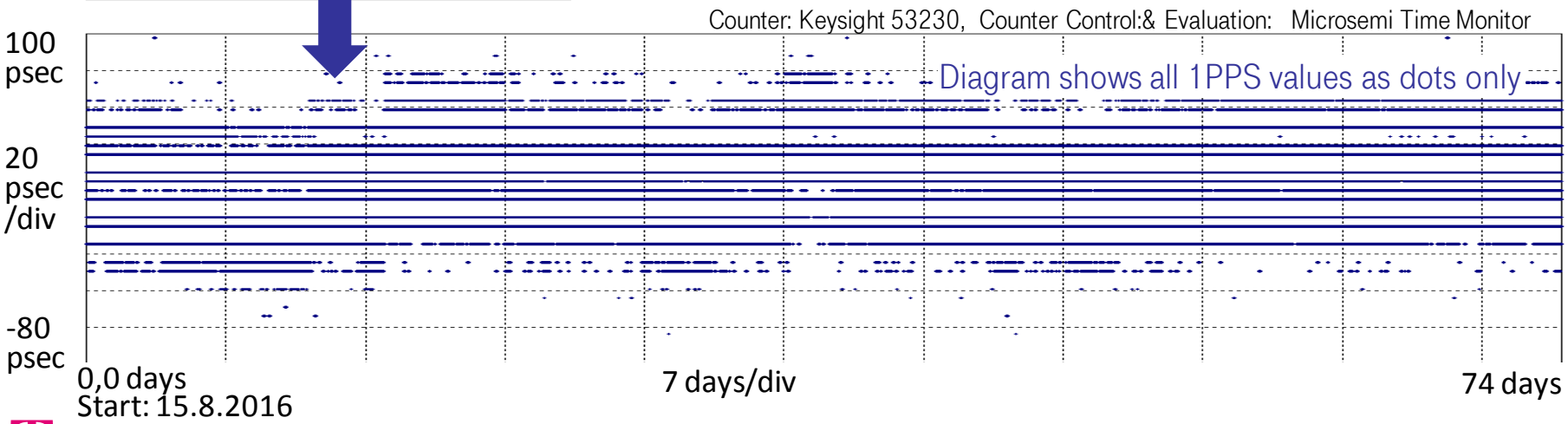
- Feasibility of OTT over an existing fiber network to transfer frequency and phase/time synchronization over around 450 km.
- Use of optical mono-mode fiber cables laid between 2000 (14%) and 2015 (2%)
- Use optical fiber type: ITU-T G.652 acc. to valid specification at installation year



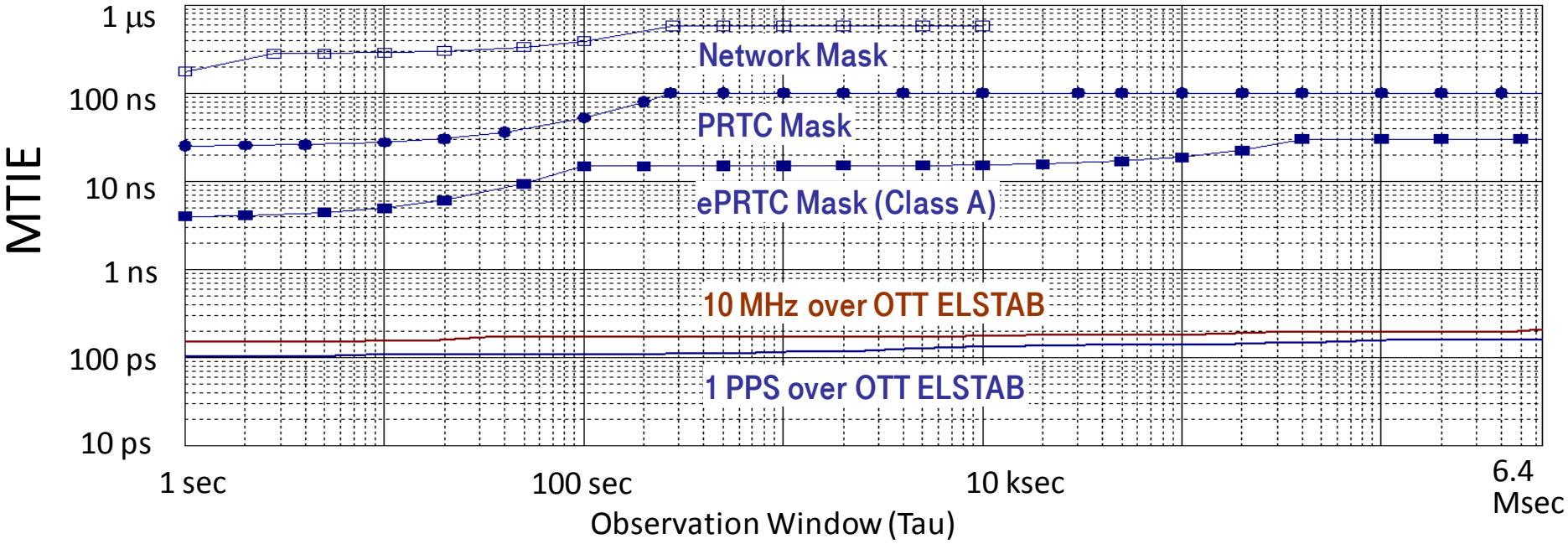


Optical Time Transfer
4. Proof-of-Concept Step1: Latest measurement results – Time Error

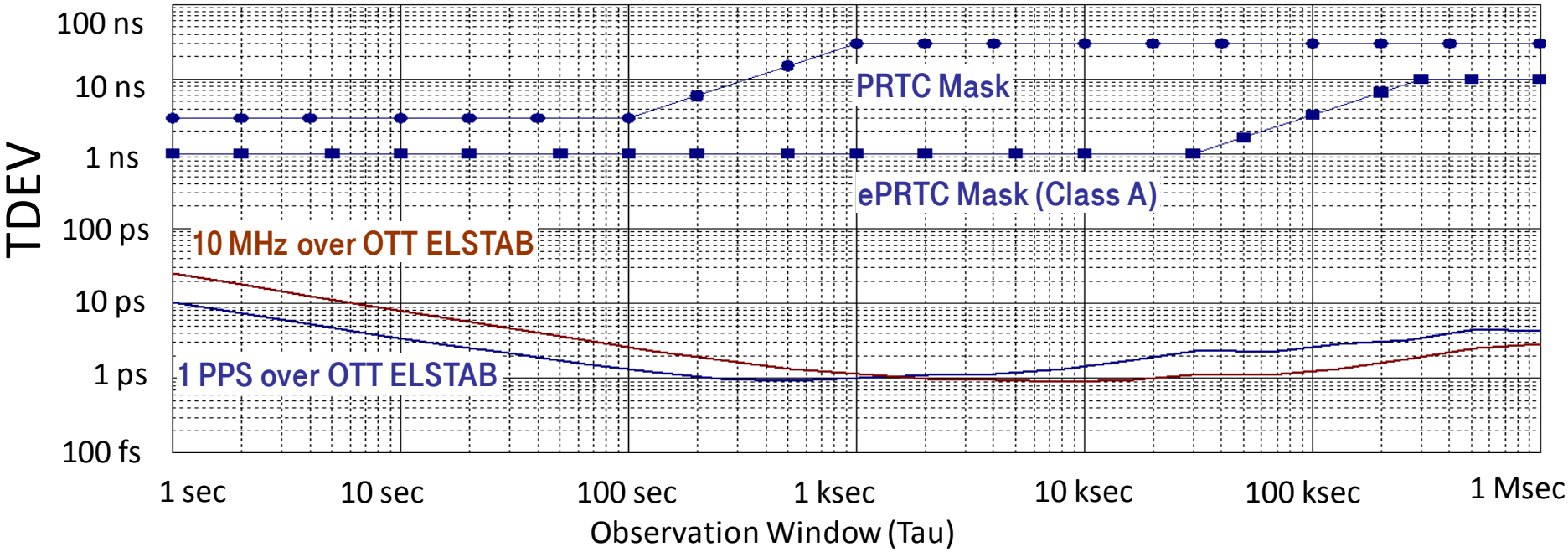




Optical Time Transfer
4. Proof-of-Concept Step1: Latest measurement results - MTIE

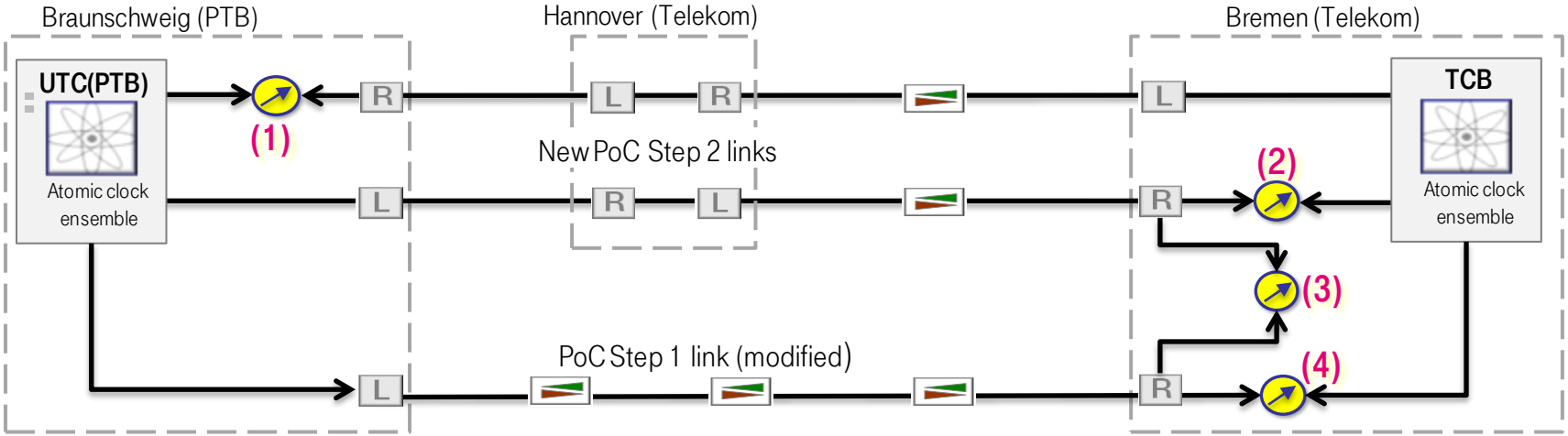


Optical Time Transfer
4. Proof-of-Concept Step1: Latest measurement results - TDEV



Optical Time Transfer: 5. Future Proof-of-Concept Step 2

Objective:
- More complex evaluation scenario
- to see time error variation depending on different systems, cables and fibers
- as final OTT system evaluation prior to UTC(DTAG)-UTC(PTB) setup (next step)



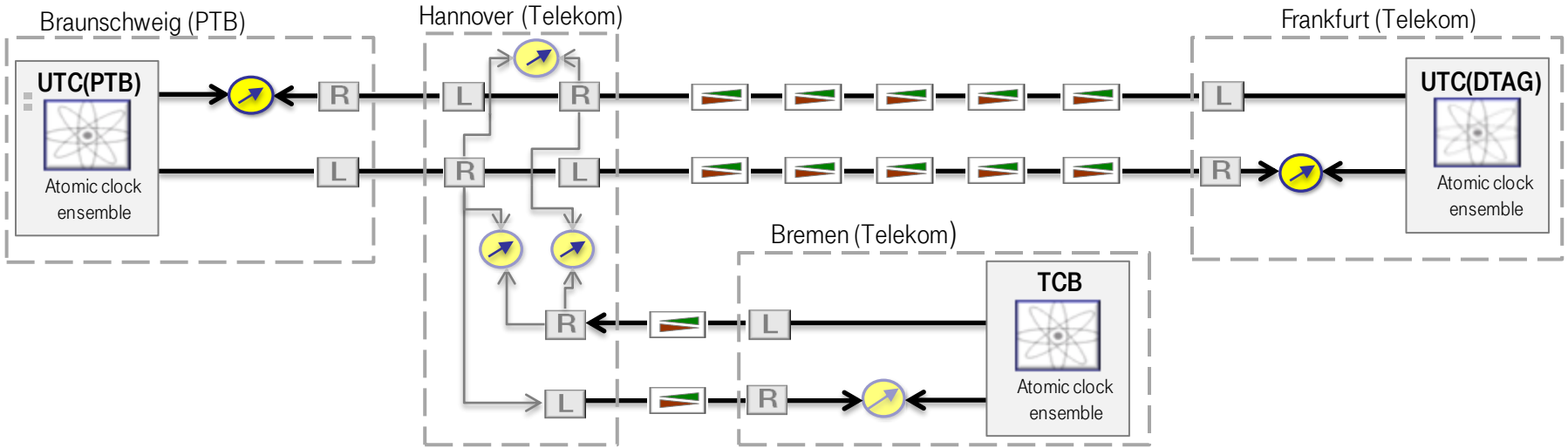
Planned result evaluation:

(1)-(2)	- Same cable, different fibers, different OTT modules
(3)	- Different cables, different OTT setup, L/R module vs. amplifier
(2)-(4)	- like (3)

Optical Time Transfer: 5. Future UTC(k) comparison

Objective:

- UTC(DTAG)-UTC(PTB) measurement at Braunschweig and Frankfurt
- to allow permanent plausibility check
- Test Center Bremen (TCB) supplied for testing (PRTC, ePRTC)
- UTC hub Hannover for future options: ⇨Uni Hannover, ⇨ UTC(DLR) Oberpfaffenhofen, ⇨UTC(BKG) Wetzell
- Results to be delivered for BIPM



Optical Time Transfer
6. Summary and outlook

Currently, OTT

- can be used for time dissemination and /or to measure primary clocks remotely
- allows better primary clock comparison than GNSS CV as used for TAI/UTC
- performs well for telecommunication synchronization supervision (< 1 ns) over existing (including older) fibers
- requires specific operational attendance
- needs a specific separate optical ("dark") fiber

Improvements for PoC Step 2

- improved 1 PPS resolution, improved operational procedures
- extended control range with less operational attendance
- 4 instead of 2 1 PPS outputs
- 1 PPS + 10 MHz squelch
- SNMP interface

In future, OTT

- to be developed as 'carrier grade solution'
- to be sufficient for synchronization network 'production layer'
- to be part of a commercial WDM/OTN system solution, e. g. via OSC (Optical Supervisory Channel)

Optical Time Transfer

Thank you Questions?

References:

[1] P. Krehlik; L. Sliwczynski; L. Buczek; J. Kolodziej; M. Lipinski,
"ELSTAB - fiber optic time and frequency distribution technology - a general characterization and fundamental limits," IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, Year: 2015, Volume: PP, Issue: 99, DOI: 10.1109/TUFFC.2015.2502547

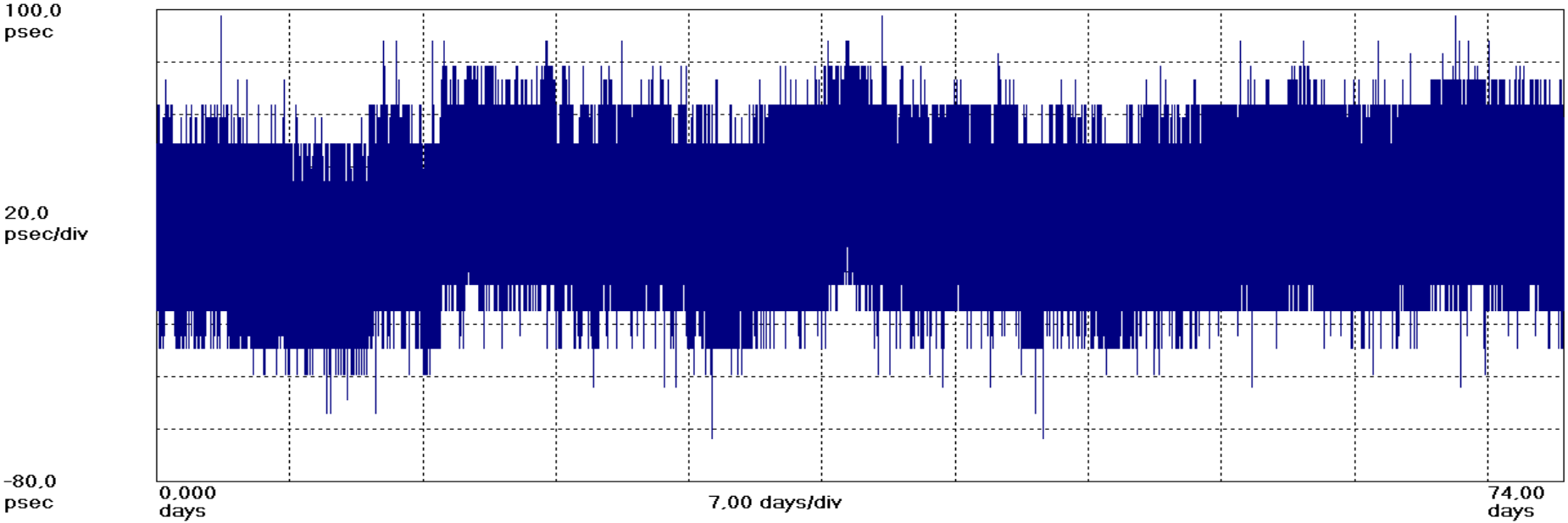
[2] Ł. Śliwczyński., P. Krehlik., H. Schnatz H., D. Piester , A. Bauch, H. Imlau, H. Ender:
„Towards sub-nanosecond synchronization of a telecom network by fiber optic distribution of UTC(k)"
EFTF 2016, York/U.K., 6.4.2016

[3] H. Imlau, "Primary Reference Clocks in Telecommunication Networks: PR(T)C, ePRTC and cnPRTC"
WSTS 2015, San Jose / U.S., 11.3.2015

[4] G. Zampetti: "Coherent Network Primary Reference Time Clocks , (cnPRTC) Simulation and Test Results"
ITSF2015 , Edinburgh/ U.K. 4.11.2015

[5] ITU-T G.8272.1/Y. 1367.1 "Timing characteristics of enhanced primary reference time clocks (ePRTC)",
Consented September 2016 at SG15 plenary meeting

Backup: 1pps


100.0
psec
20.0
psec/div
-80.0
psec
0.000
days
7.00 days/div
74.00
days