AGH University of Science and Technology Department of Electronics, Krakow, Poland

Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany

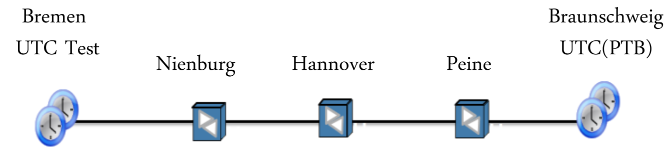
Deutsche Telekom Technik GmbH, Bremen, Germany

Deutsche Telekom together with AGH and PTB @ ATIS-NIST WSTS2016

Optical Time Transfer (OTT): Application in Telecommunication Networks and PoC Results

Helmut Imlau et. al., June, 14th 2016

Optical Time Transfer
Agenda



Partners and participants ....

1. Hierarchical network synchronization and supervision ....

2. Sync network supervision methods: GNSS Common View ....

3. Optical Time Transfer (OTT) ....

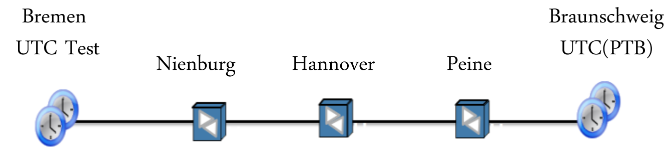
4. OTT Proof-of-Concept (PoC): Purpose and setup ....

5. PoC Results by DT and PTB: Time Error, MTIE and TDEV ....

6. Summary, outlook ....

Optical Time Transfer

Partners, participants



Participants:

Schnatz H., Bauch A., Piester D.
Physikalisch-Technische Bundesanstalt (PTB)
Braunschweig, Germany
Harald.Schnatz@ptb.de

Śliwczyński Ł., Krehlik P.
AGH University of Science and Technology Department of Electronics
Krakow, Poland
sliwczyn@agh.edu.pl

Imlau H., Ender H.,
Barasi, M., Habighorst, U.
Deutsche Telekom Technik GmbH
Fixed and Mobile Engineering
Bremen, Germany
Helmut.Imlau@telekom.de

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[1]

[1]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

Network operation needs a synchronization supply solution

- (1) Ethernet Physical Layer Synchronization (SyncE acc. to G.826x series) in combination with
  (2) Precision Time Protocol (PTP) with Full Timing Support from the network (PTP-FTS) or A-PTS acc. to ITU-T (G.827x series) can disseminate the required time quality.

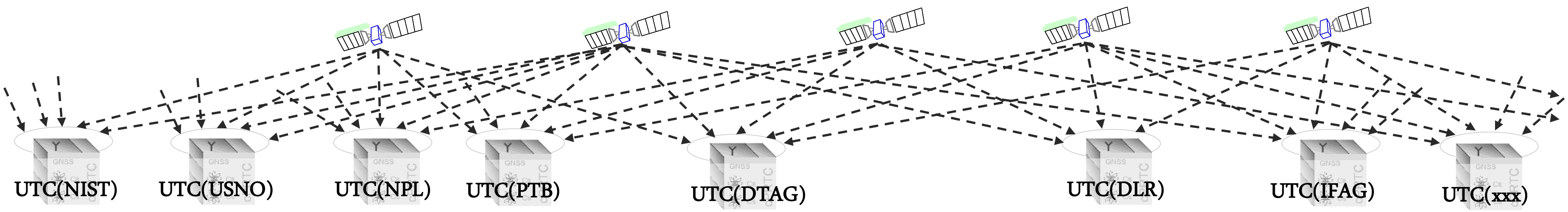
A hierarchical synchronization network consists of several levels

- 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. Network supervision using GNSS Common View



- UTC(k) labs *) operate GNSS dual-frequency code and carrier-phase receivers
- Generate data files according to standard format CGGTTS (ionosphere-free combination L3P) and make them publicly available, specifically for BIPM
- BIPM calculates TAI/UTC and reports UTC-UTC(k) deviation to each contributor (via “Circular T”)

BIPM = Bureau International des Poids et Mesures *) k= NIST/USNO/NPL/PTB/DTAG/.......

CGGTTS = Common GNSS Generic Time Transfer Standard L3P = L (1+2=3) Carrier Phase

For Telecommunication:

- Method could be used by network operators to compare primary clocks
- Expensive specific T&M receivers, calculation effort
- Could be in-build in ePRTC / cnPRTC systems in future ([4] George Zampetti at ITSF 2015)
- No physical synchronization transfer

Optical Time Transfer
3. 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)

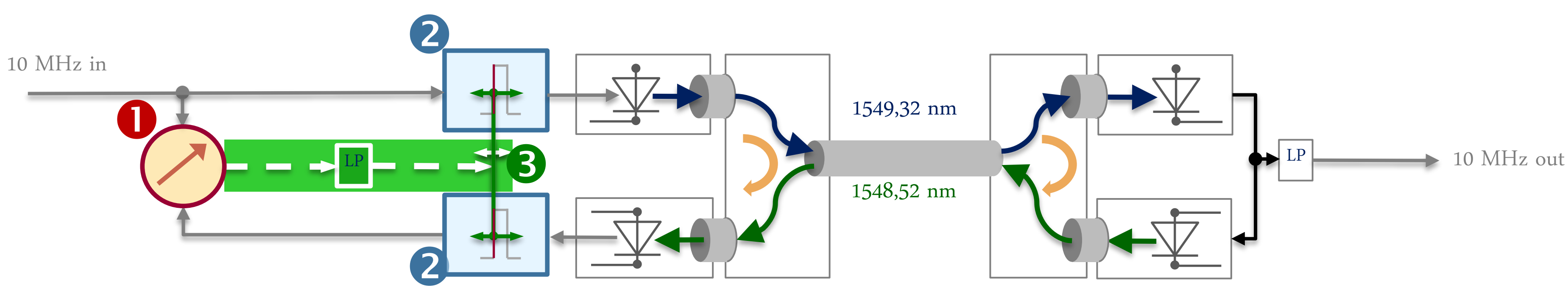
The ELectronic STABilization (ESTAB) solution:

- 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 (ASIC includes phase detector & variable delay lines)



Optical Time Transfer
3. 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

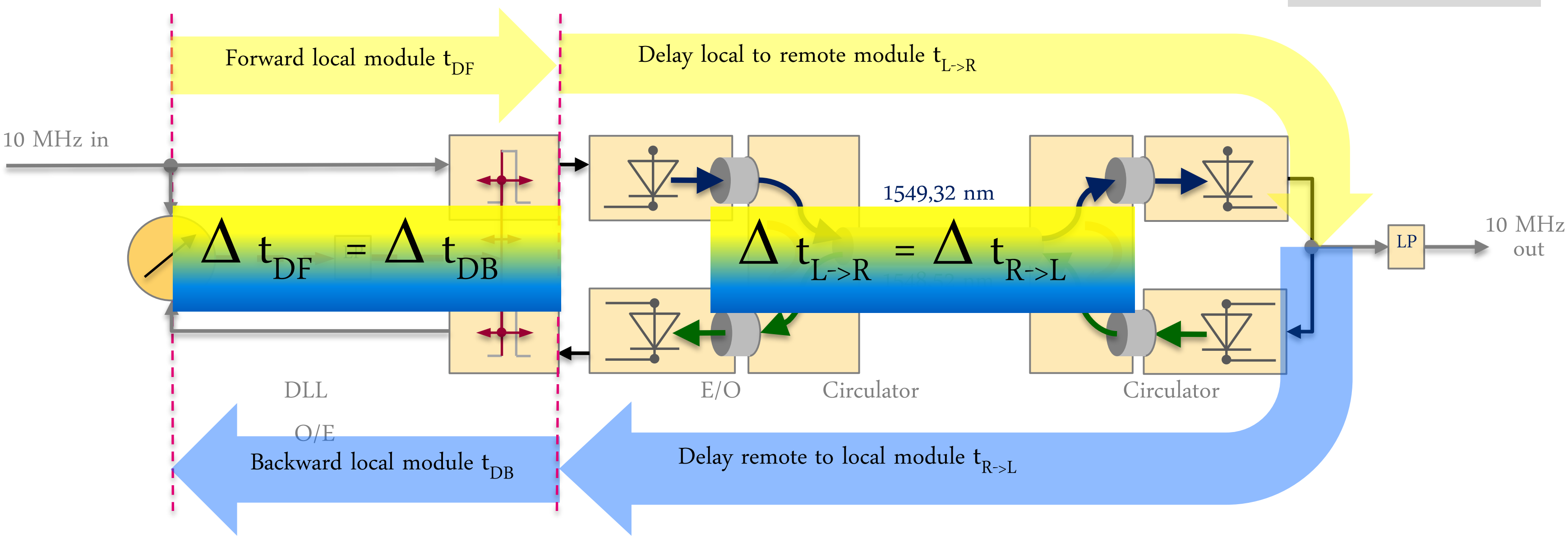
The stabilization solution:

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

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

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

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

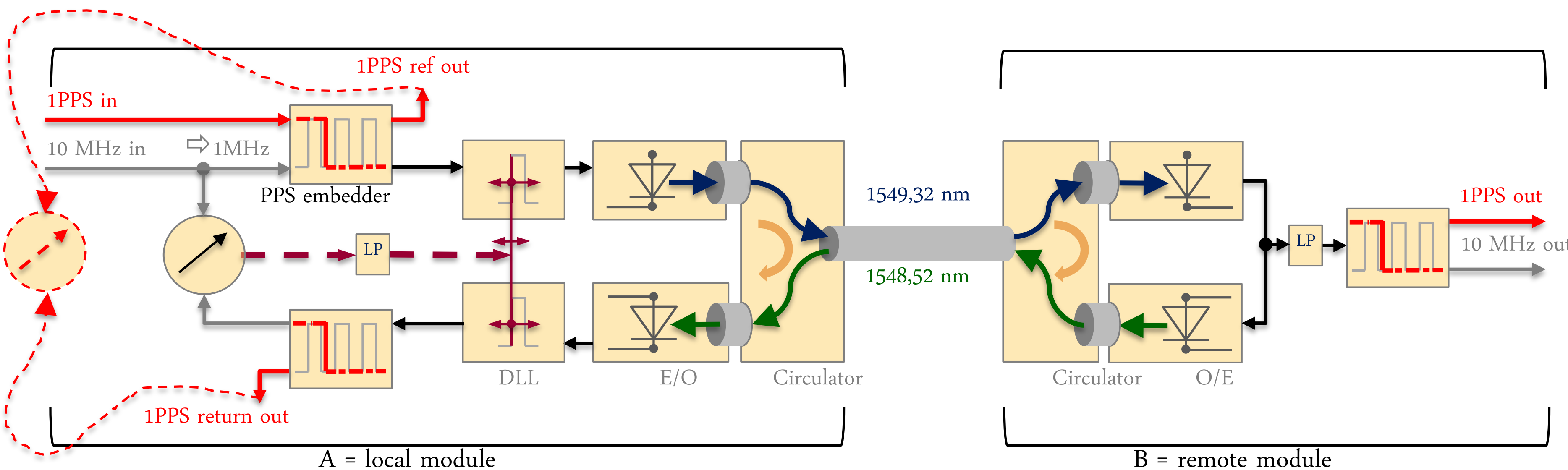


Optical Time Transfer
3. The method (4/4)

Extension for 1PPS transfer

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

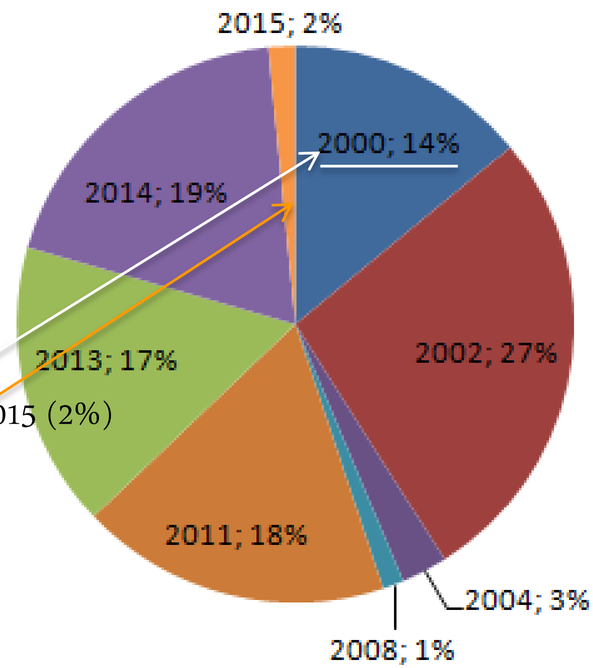
At B:
- 1PPS out calculation with ½ round trip delay
  + corrections due to chromatic dispersion, + Sagnac effect 1ns/100 km east-west correction
- currently manually performed, may be implemented into the OTT ELSTAB system

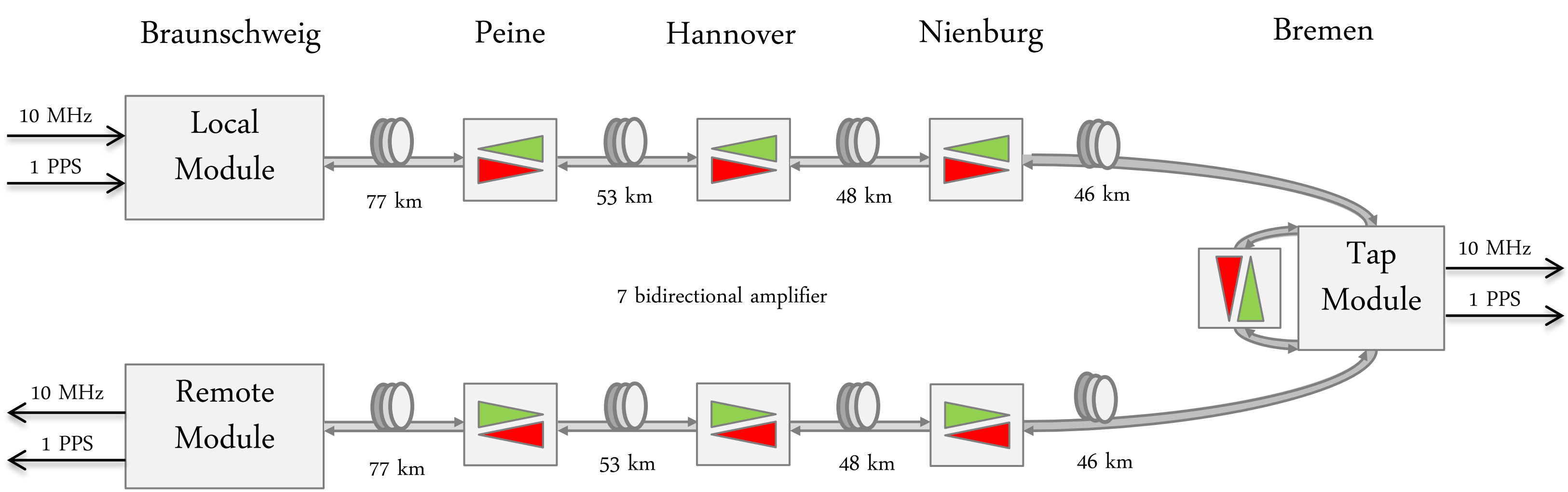


Optical Time Transfer

4. Proof-of-Concept: Purpose and setup

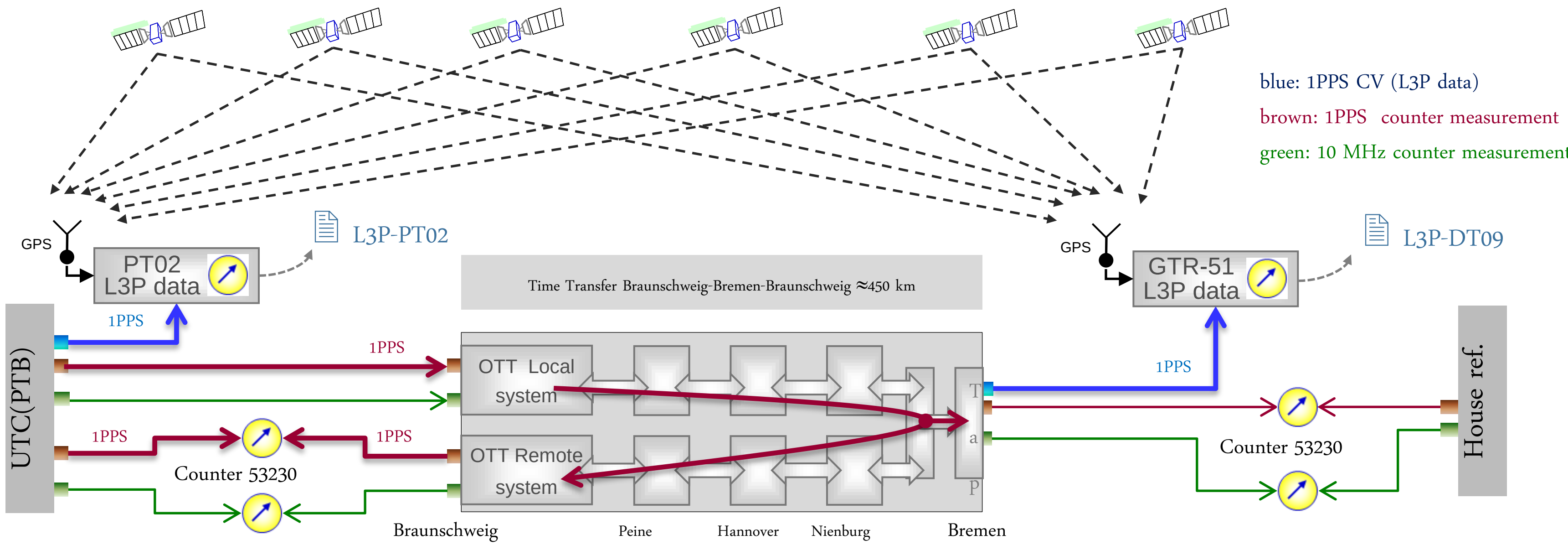
- Feasibility of OTT over an existing fiber network to transfer frequency and phase/time synchronization over around 450 km.
- Use of optical mono-mode fiber cables laid between 2000 (14%) and 2015 (2%)
- Use optical fiber type: ITU-T G.652 acc. to valid specification at installation year

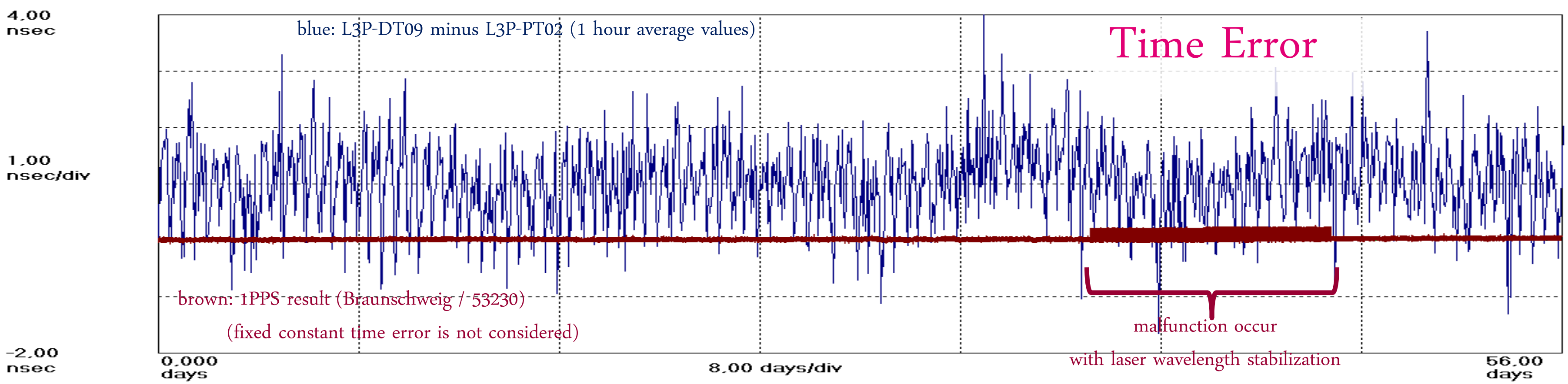




Optical Time Transfer

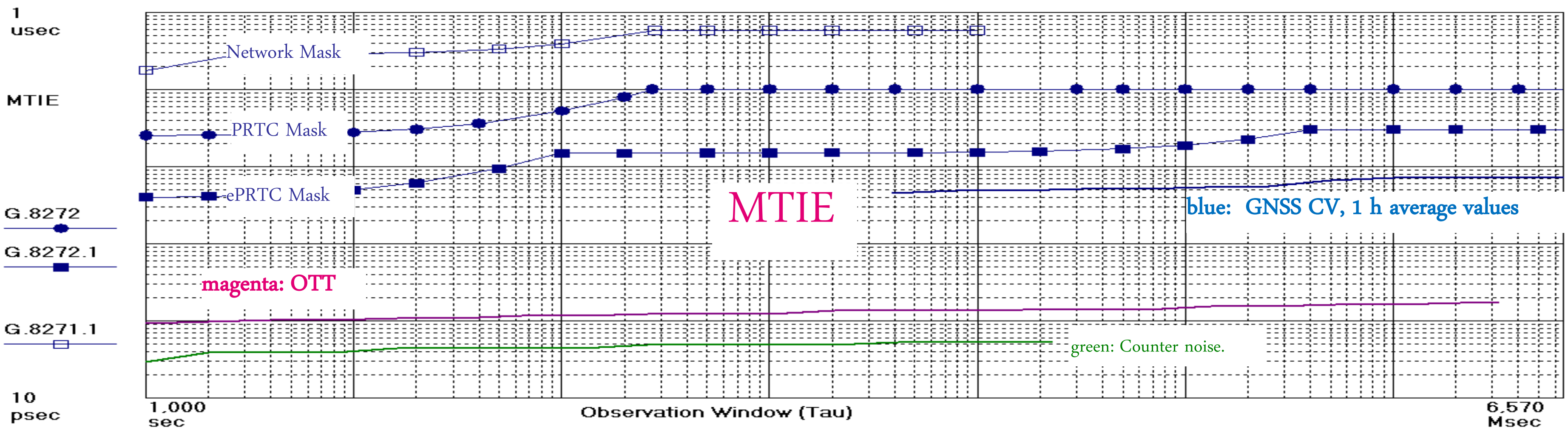
5. Measurements and evaluation by DT

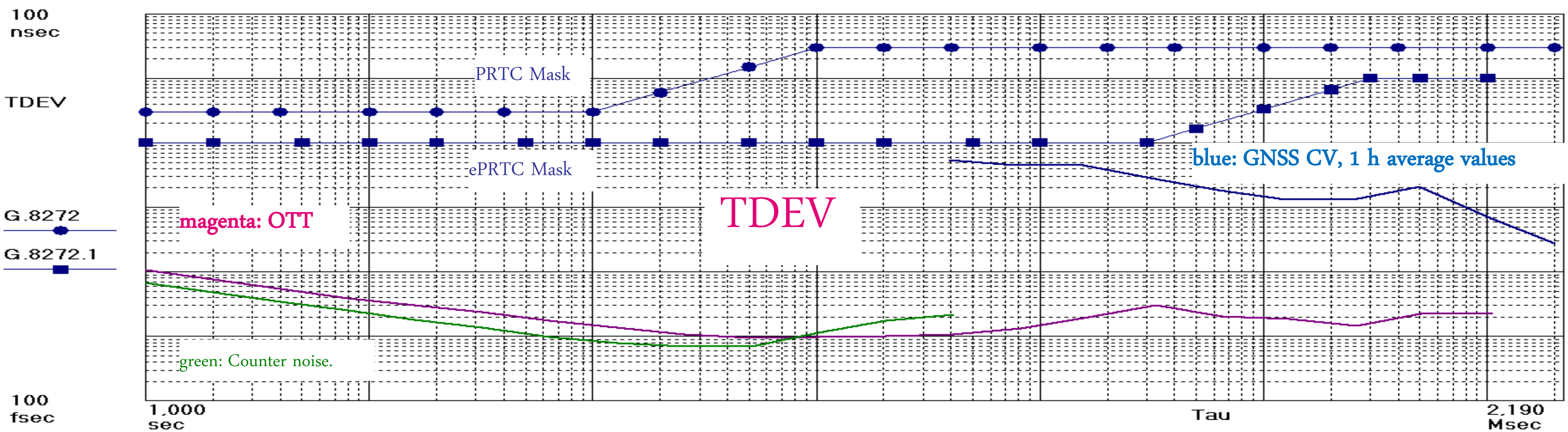




Optical Time Transfer

5. Measurement and evaluation by DT





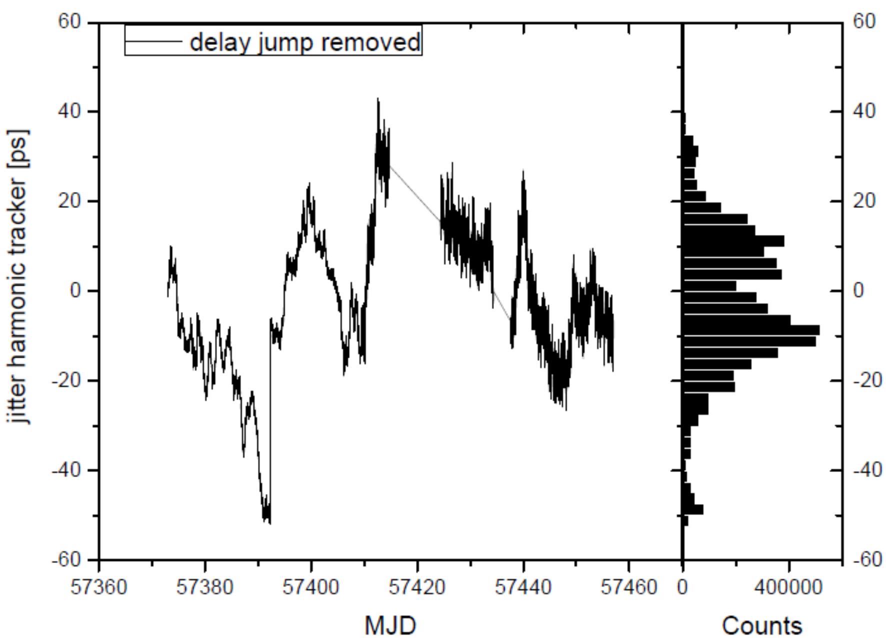
Optical Time Transfer

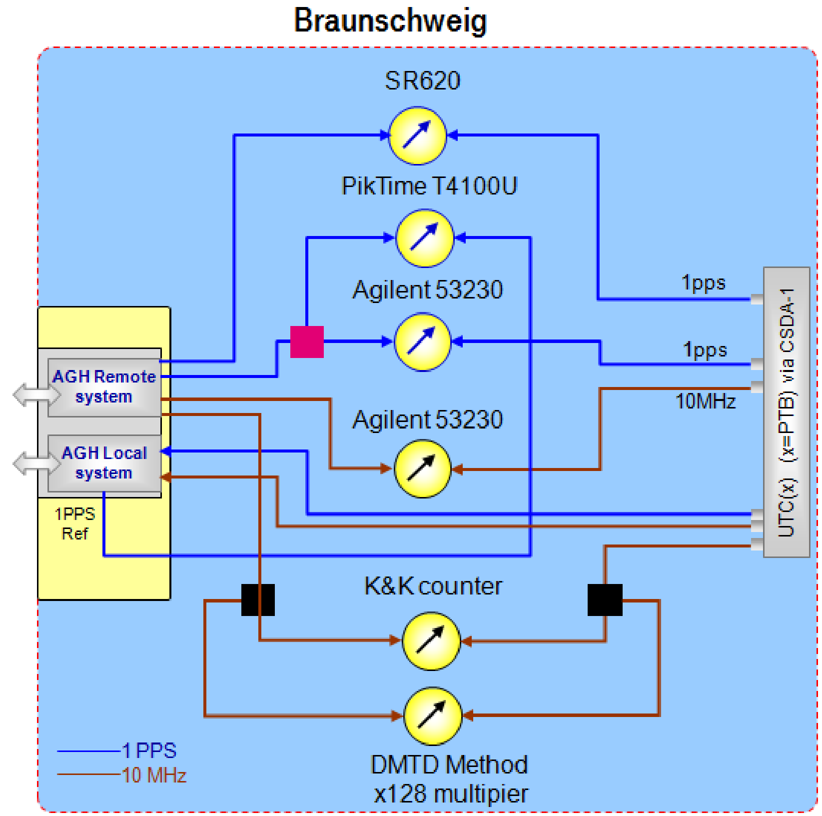
5. PTB view

Measurement setup

10 MHz:
- K&K frequency counter, direct mode
- with frequency difference multiplication by 128 in order to increase the measurement resolution (DMTD = dual mixer time difference method), for stability assessment

1 PPS:
- Evaluations performed using low-noise counters: Stanford Research SR-620, PikTime T4100U





Measurement results:

- TDEV(@ τ=1 s) ≈ 6 ps
  TDEV(@ τ = 10^4 s) ≈ 1 ps

Conclusions for metrological application:

- After initial calibration: time transfer uncertainty in the loop BS-Bremen-BS < 0.1 ns.
- Method suited for UTC(k) comparisons

Optical Time Transfer
Summary

Metrology view:

- Perfect to compare different UTC(k) time scales, like UTC(PTB) ⇔ UTC(DTAG)

Telecommunication network operator view:

- Outstanding performance, well below 1 ns
- Only for a few links at highest accuracy level due to ⇨ need for dedicated optical fiber

,

⇨ need for manual calibration

- Areas for improvements: ⇨ fault, performance and security management via Element Management System (EMS) with North-Bound Interface (NBI) needed

⇨ output squelching in case of problems needed

Currently, a scientific method rather than a telecommunication 'carrier grade solution',
perfect for 'supervision' layer, less perfect for 24/7 'production' layer.

Optical Time Transfer
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

In future, OTT

- may be developed as 'carrier grade solution'
- may be sufficient for synchronization network 'production layer' (if needed)

Thank you very much

Optical Time Transfer

Thank you very much!

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)”,
Latest draft for September 2016 plenary meeting