ELSTAB Technology

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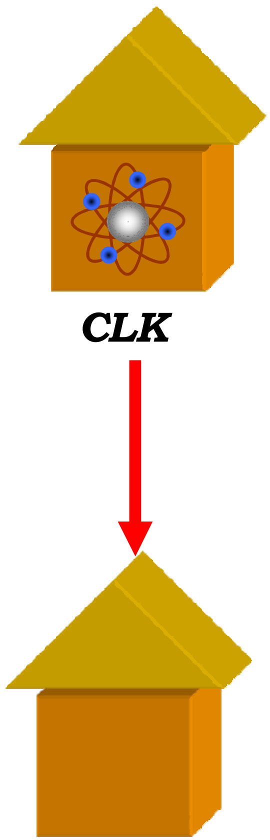
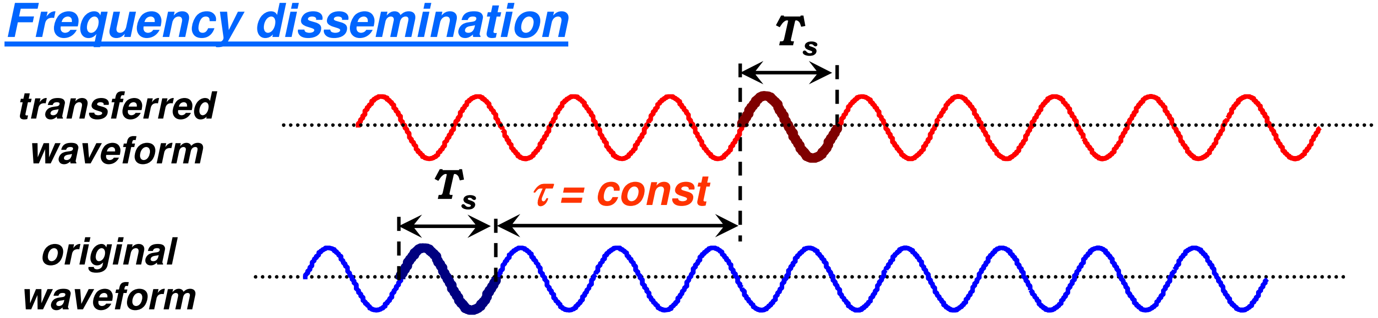
CLONETS
CLOCK NETWORK SERVICES

A general idea *T/F dissemination*

T/F dissemination

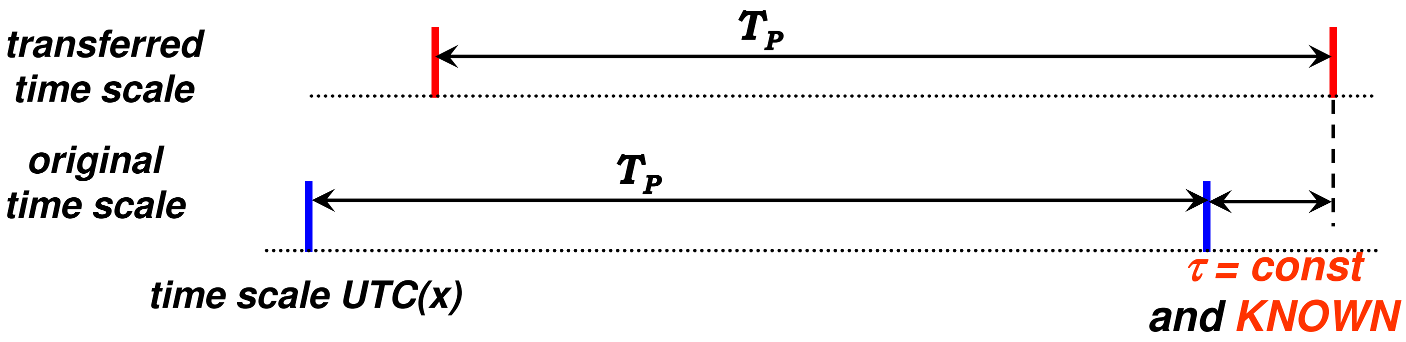


Frequency dissemination



f = 5 MHz, 10 MHz, 100 MHz, optical frequencies (~200 THz)

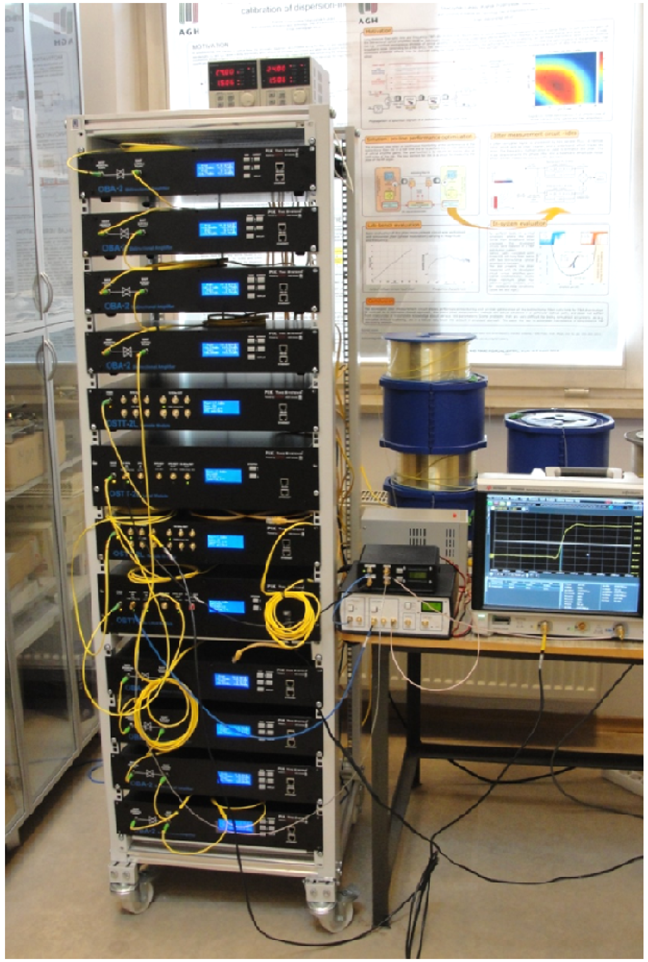
Time scale dissemination



1PPS (Pulse Per Second)

What is ELSTAB technology?

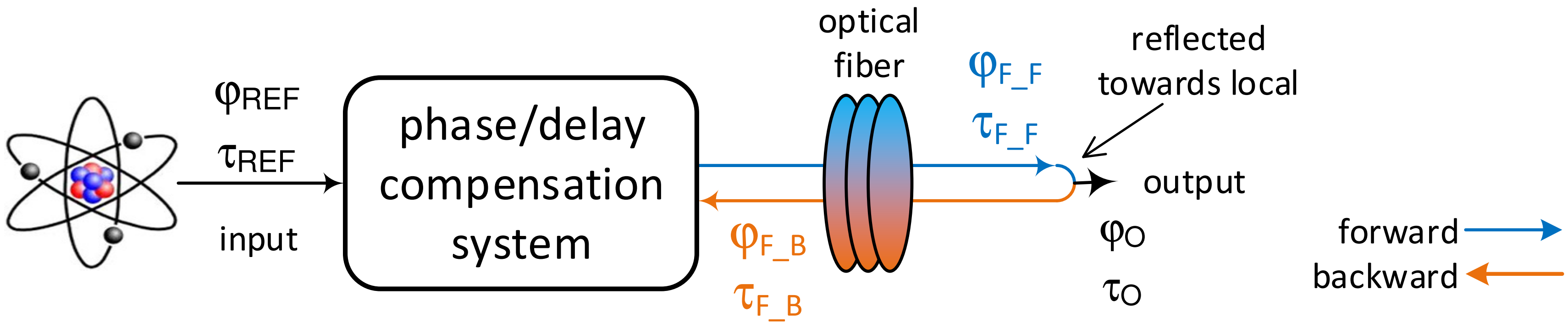
- fiber optic T/F dissemination (5/10/100 MHz + 1/100 PPS)
- based on active compensation of fiber delay fluctuations
- typically uses dark fiber, but dark channel is also possible
- compensation range: 100 km (standard) or up to 1000 km (LR version)
- ADEV < 3×10^{-13} for 1 s averaging, < 3×10^{-17} for 10^5 s averaging
- TDEV < 2 ps for 10 s averaging, < 1 ps for 10^5 s averaging



Stabilized T/F transfer *general idea*

Local side

Remote side



phase stabilization:

$\varphi_O = \varphi_{REF} + \varphi_{DF} + \varphi_{F\_F}$

$\varphi_{RT} = \varphi_{DF} + \varphi_{F\_F} + \varphi_{F\_B} + \varphi_{DB}$

if $\varphi_{RT} = 0$ (kept by feedback)
then

$$\varphi_O = \varphi_{REF} + \left.\begin{array}{l} + (\varphi_{DF} - \varphi_{DB})/2 + \\ + (\varphi_{F\_F} - \varphi_{F\_B})/2 \end{array}\right\} \cong 0$$

delay stabilization:

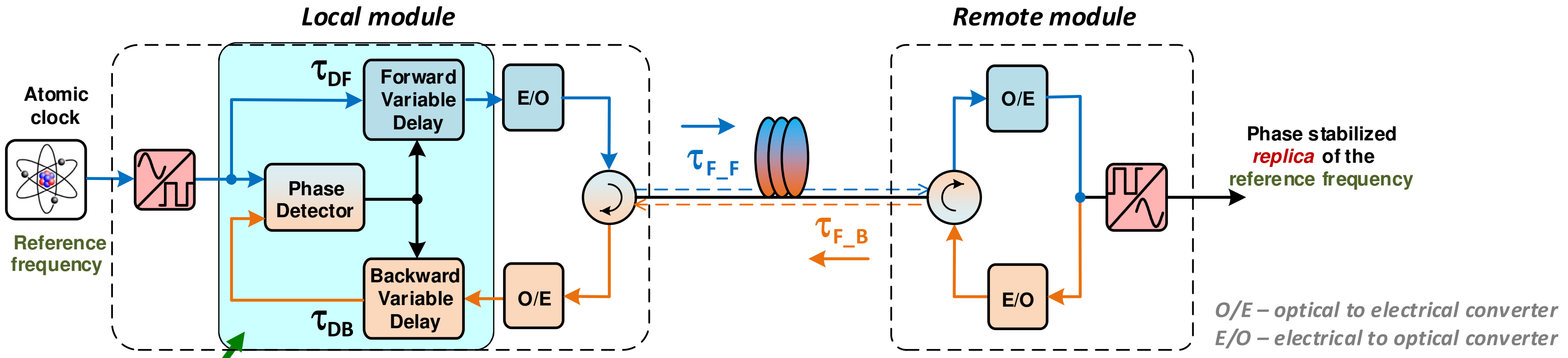
$\tau_O = \tau_{REF} + \tau_{DF} + \tau_{F\_F}$

$\tau_{RT} = \tau_{DF} + \tau_{F\_F} + \tau_{F\_B} + \tau_{DB}$

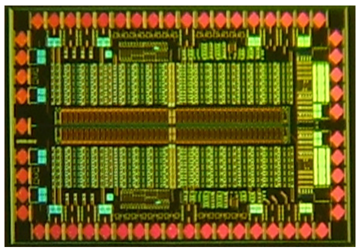
if $\tau_{RT} = \textit{const.}$ (kept by feedback)
then

$$\tau_O = \tau_{REF} + \tau_{RT}/2 + \left.\begin{array}{l} + (\tau_{DF} - \tau_{DB})/2 + \\ + (\tau_{F\_F} - \tau_{F\_B})/2 \end{array}\right\} \cong 0$$

ELSTAB approach *frequency transfer*



custom designed ASIC



DLL equilibrium condition:

$$\tau_{DF} + \tau_{F\_F} + \tau_{F\_B} + \tau_{DB} = \text{const} \quad (1)$$

$$\Delta\tau_{DF} + \Delta\tau_{F\_F} + \Delta\tau_{F\_B} + \Delta\tau_{DB} = 0 \quad (2)$$

Constant delay requirement:

$$\tau_{DF} + \tau_{F\_F} = \text{const} \quad (3)$$

$$\Delta\tau_{DF} + \Delta\tau_{F\_F} = 0 \quad (4)$$

$\Rightarrow$ $\Delta\tau_{F\_B} + \Delta\tau_{DB} = 0$, $\Delta\tau_{F\_F} = \Delta\tau_{F\_B}$ (~ ps) $\Rightarrow$ $\Delta\tau_{DF} = \Delta\tau_{DB}$

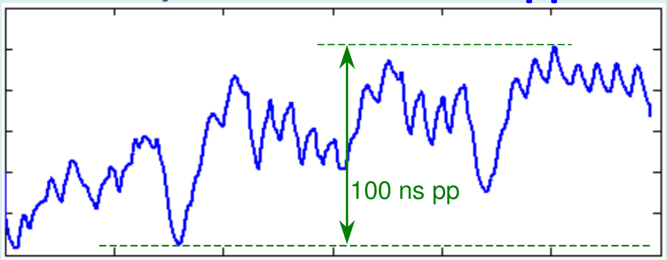
delay lines have to be matched

Performance

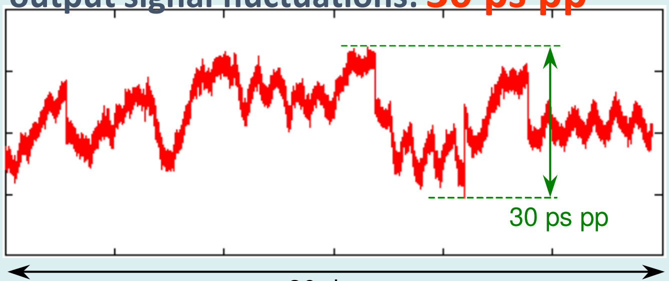
Example:

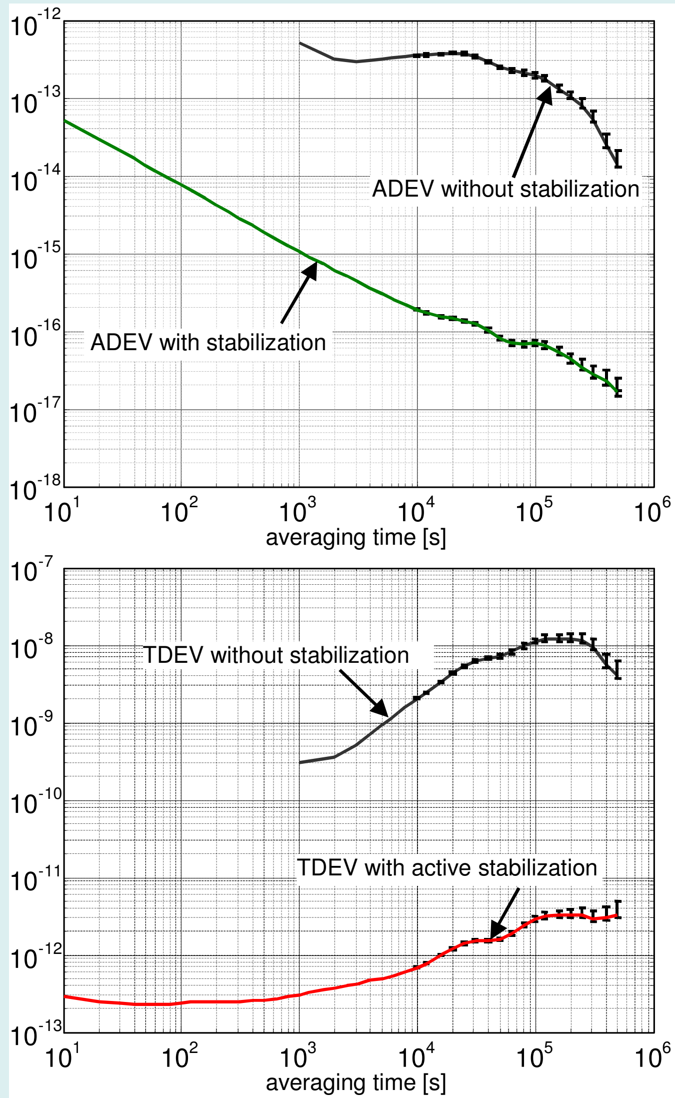
stability of 615 km long-distance transfer using ELSTAB

fiber delay fluctuations: 100 ns pp

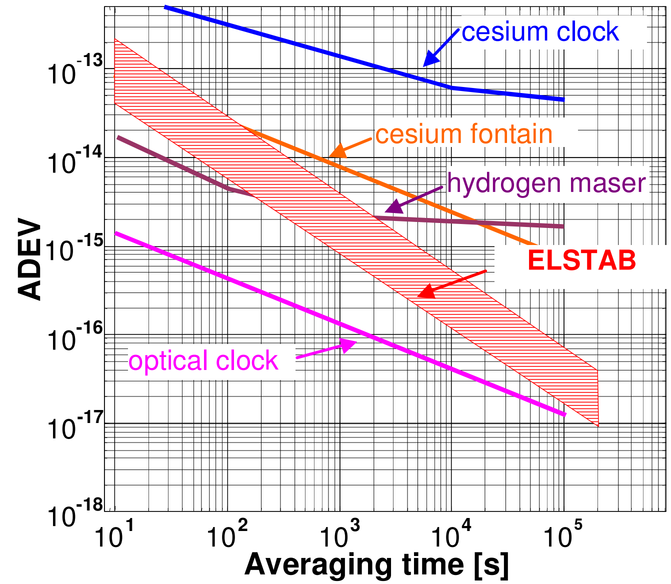


output signal fluctuations: 30 ps pp

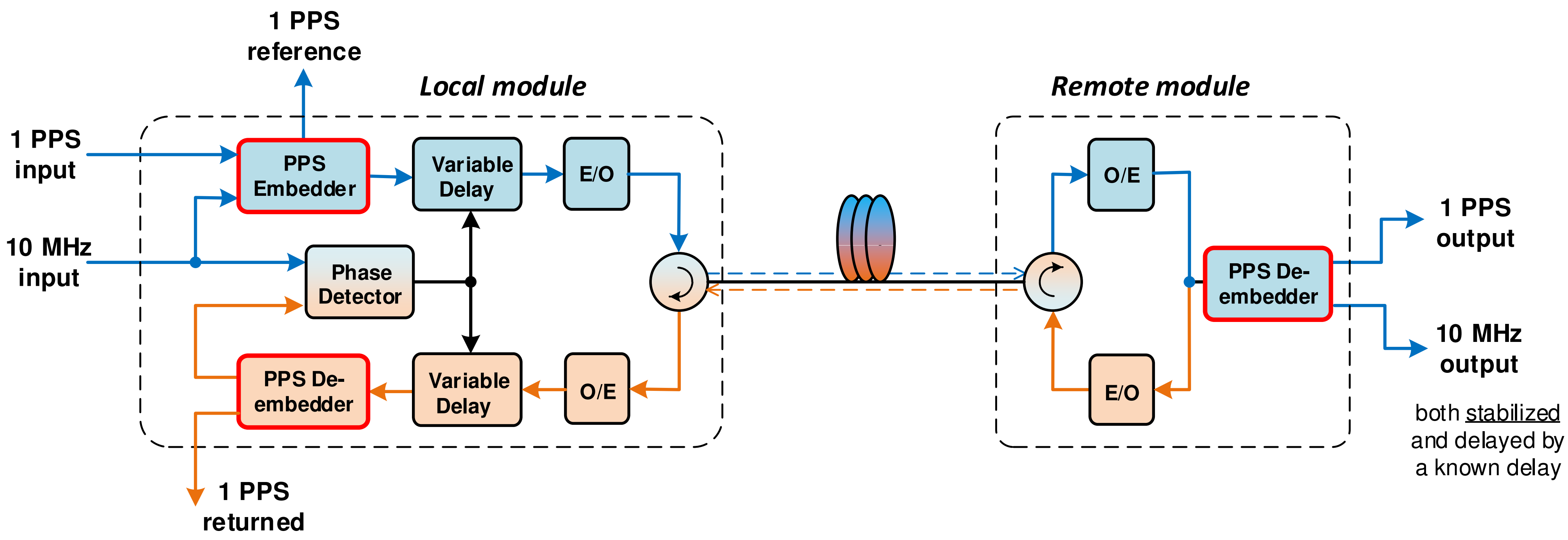




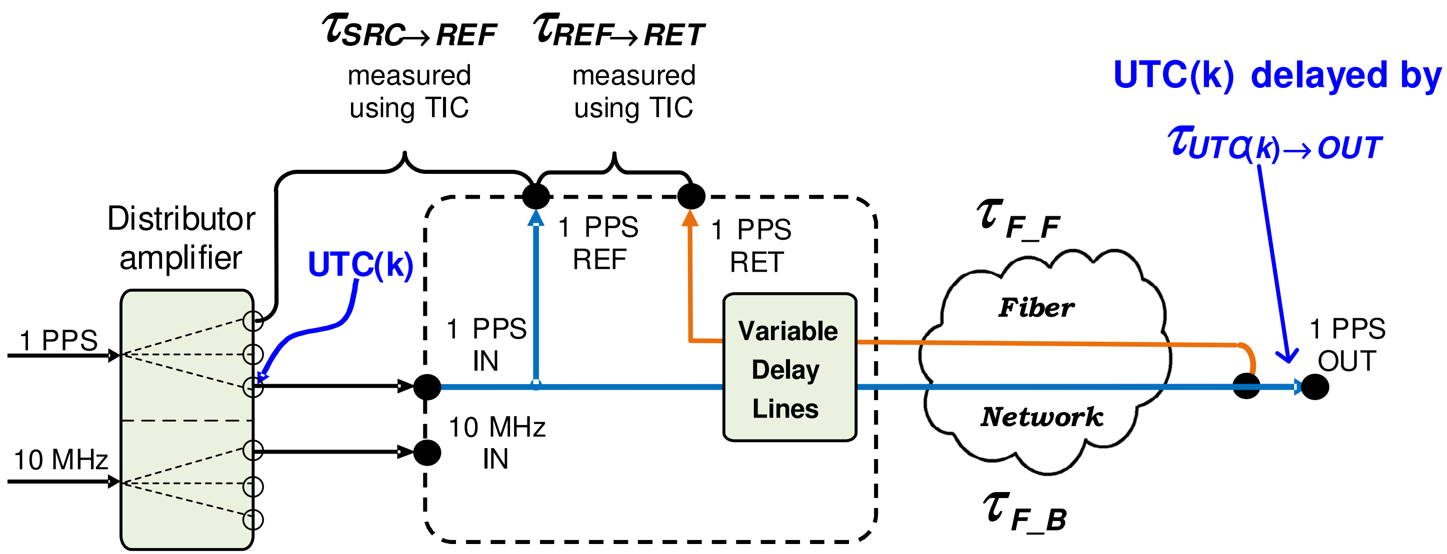
ELSTAB performance
vs
clocks instability



ELSTAB approach *joint T/F transfer*



Basics of link calibration



Basic calibration formulas:

$$\tau_{REF\to OUT} = \frac{1}{2}\left[\tau_{REF\to RET} + \left(\tau_{F\_F} - \tau_{F\_B}\right) + \tau_C\right]$$

$$\tau_{UTC(k)\to OUT} = \tau_{UTC(k)\to REF} + \tau_{REF\to OUT}$$

Fiber forward-backward asymmetry:

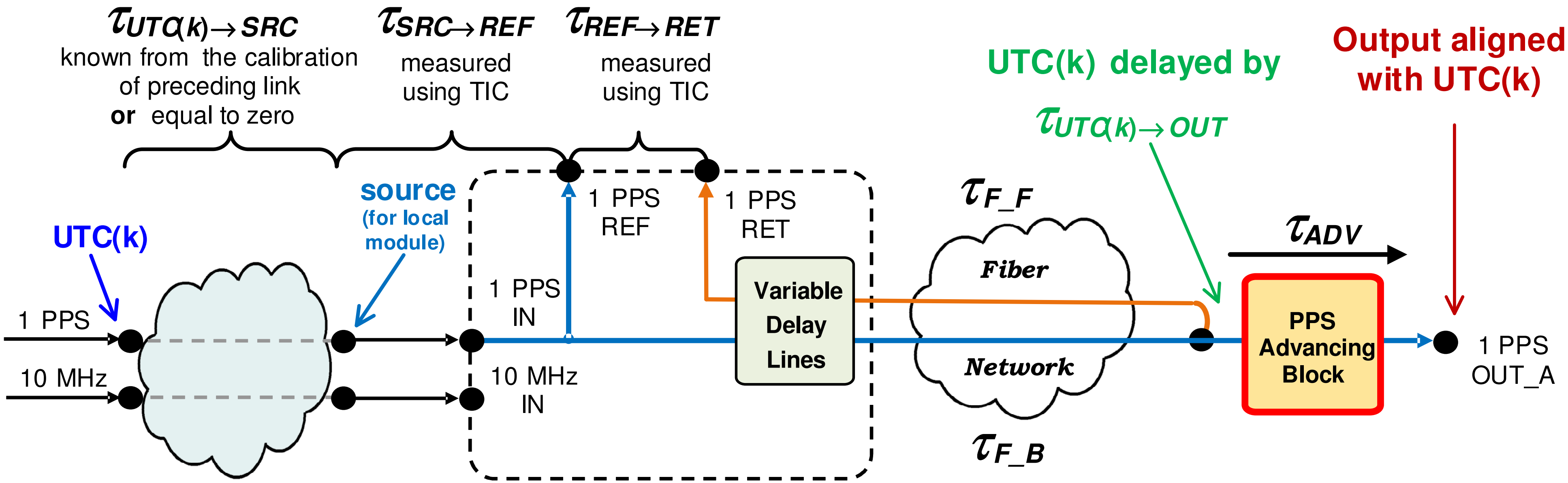
$$\tau_{F\_F} - \tau_{F\_B} = D_T\left(\lambda_F - \lambda_B\right) \pm \frac{4\omega A_E}{c^2} + \tau_{BIR}$$

Local & remote modules asymmetry:

$$\tau_C = \left(2\tau_{REF\to OUT} - \tau_{REF\to RET}\right)\Big|_{\substack{SHORT\\PATCHCORD}}$$

All the calibration measurements are done at the local side only

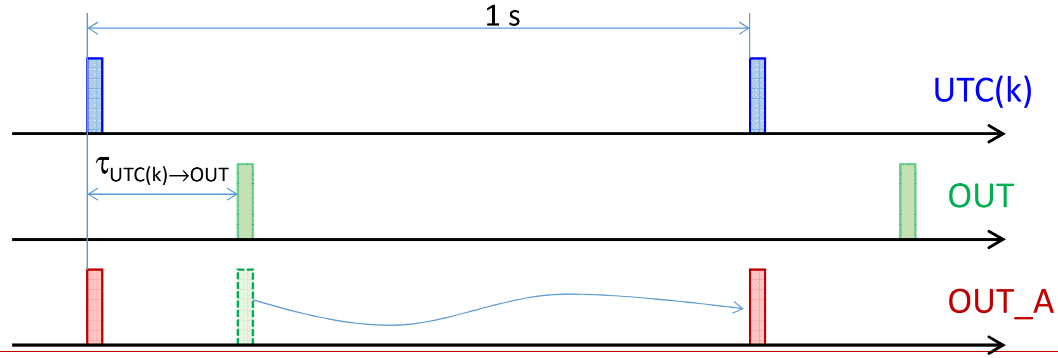
Delay compensation *towards autonomous system 1*



Calibration formulas:

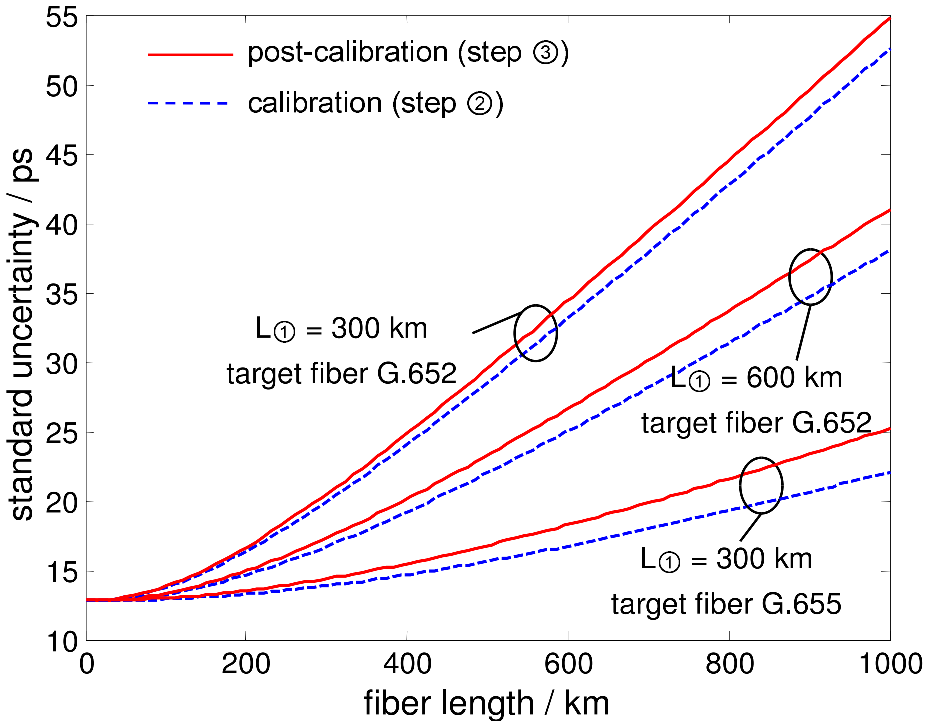
$$\tau_{UTC(k)\rightarrow OUT} = \tau_{UTC(k)\rightarrow SRC} + \tau_{SRC\rightarrow REF} + \tau_{REF\rightarrow OUT}$$

$$\tau_{UTC(k)\rightarrow OUT\_A} = \tau_{REF\rightarrow OUT} - \tau_{ADV}$$



Calibration uncertainty

Source	Standard uncertainty	Sensitivity coefficient	0 km	300 km G.652
$\tau_{UTC(k)\rightarrow REF}$	10 ps	1	10 ps	10 ps
$\tau_{REF\rightarrow RET}$	10 ps	0.5	5 ps	5 ps
Γ	0.002	$D\cdot L\cdot(0.4\text{nm})$	0 ps	4.1 ps
$\Delta\tau_{REF\rightarrow RET}$	10 ps	1.4	14 ps	14 ps
$\Delta\lambda_L$	1.5 pm	$D\cdot L\cdot 1.4$	0 ps	10.7 ps
$\lambda_L-\lambda_R$	1.5 pm	$D\cdot L\cdot 0.5$	0 ps	3.8 ps
$\Delta\tau_{SAGNAC}$	~ 0.05 ps/km	$L\cdot 0.5$	0 ps	7.5 ps
τ_C	7.2 ps	0.5	3.6 ps	3.6 ps
τ_{ADV}	3.7 ps	1	3.7 ps	3.7 ps
		combined uncertainty:	18.6ps	23.4 ps

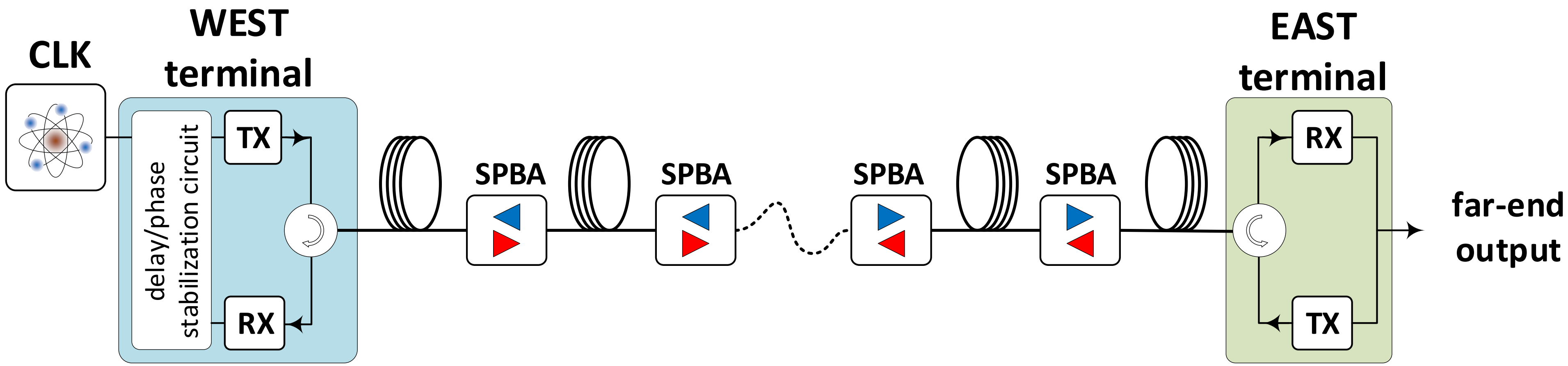


Details in:

Calibrated optical time transfer of UTC(k) for supervision of telecom networks

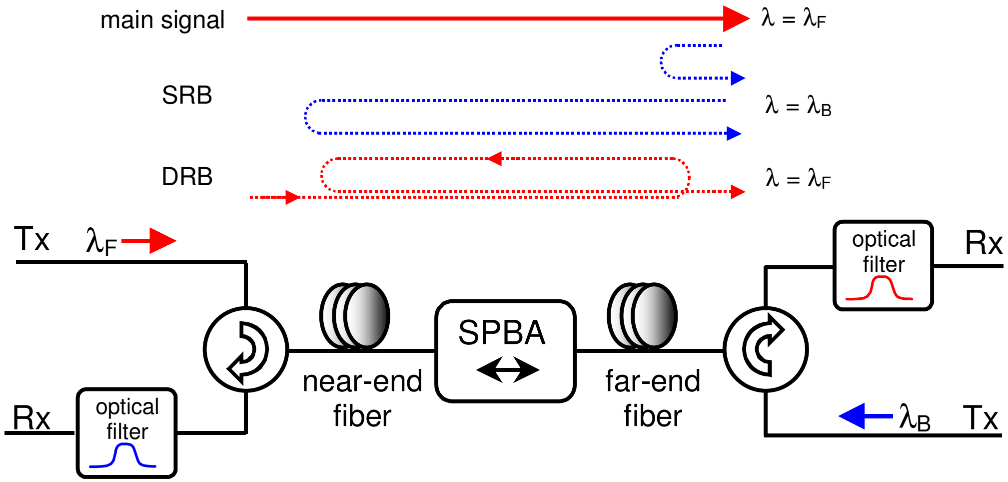
Metrologia, **56** 015006, 2019

Long distance transfer *Single Path Bidirectional Amplifiers*

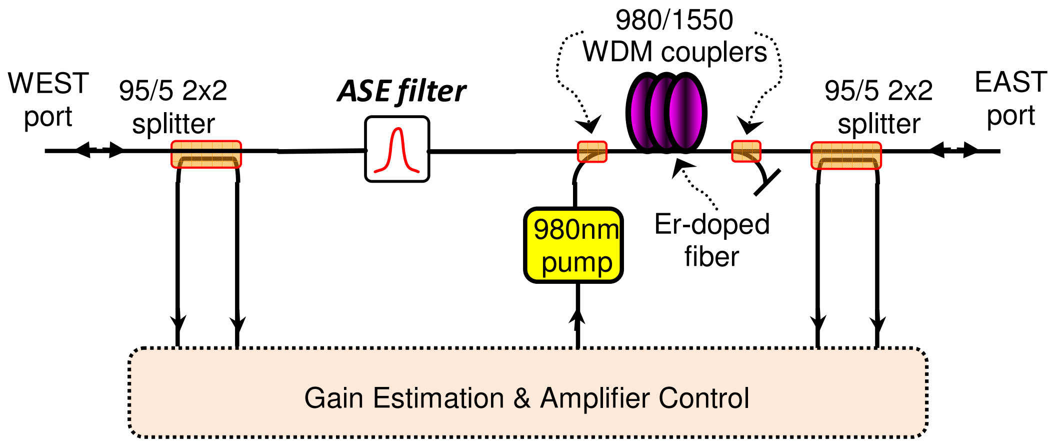


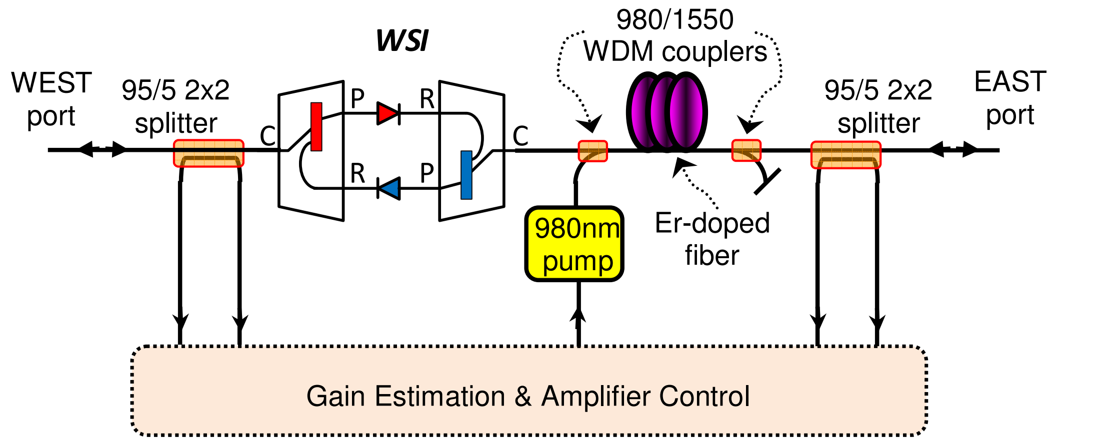
Usage of SPBAs implicates:

- risk of lasing caused by backscattering and reflections
- lowered threshold for Stimulated Brillouin Scattering
- unlimited propagation of single and double Rayleigh backscattered signals → beating noise



Long distance transfer *Wavelength Selective Isolator*





Generic SPBA:

- equal delays for forward and backward directions
- equal gains for bi-directional signals **but**
- also equal gains for backscatering

so

gains should be chosen judiciously

SPBA with WSI:

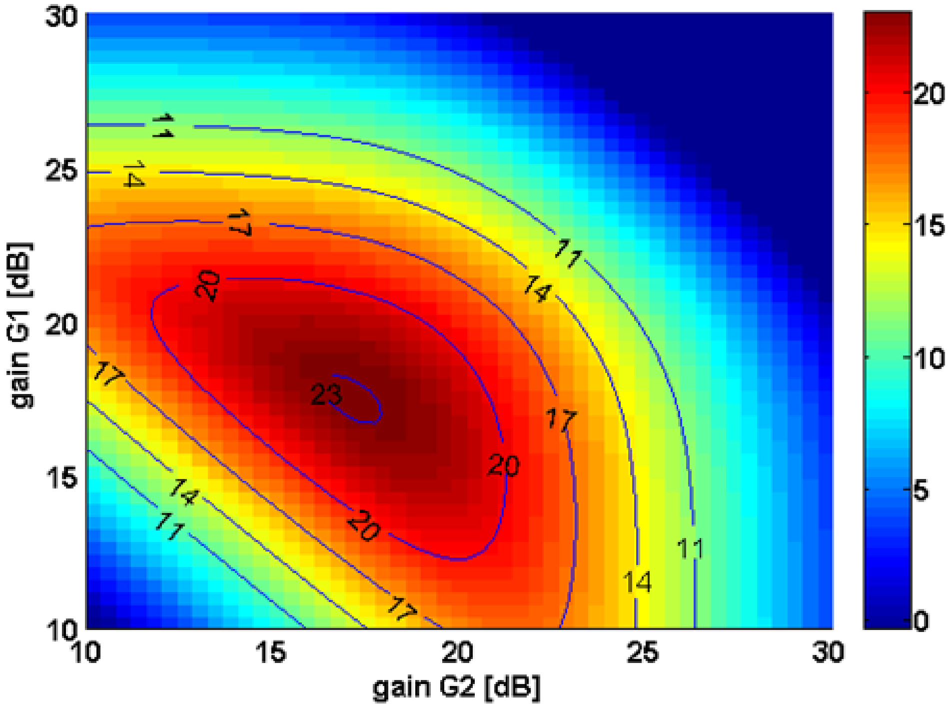
- strong asymmetry for signal and backscattering **but**
- unequal propagation delays (calibration required)
- residual thermal sensitivity

so

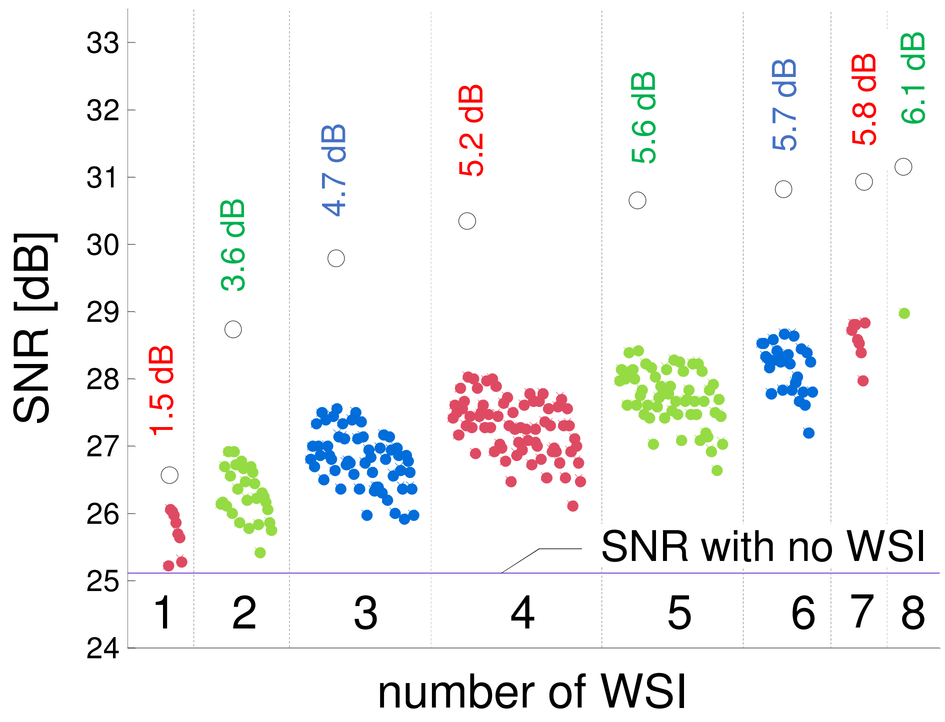
number of WSIs should be kept at a reasonable minimum

Link optimization

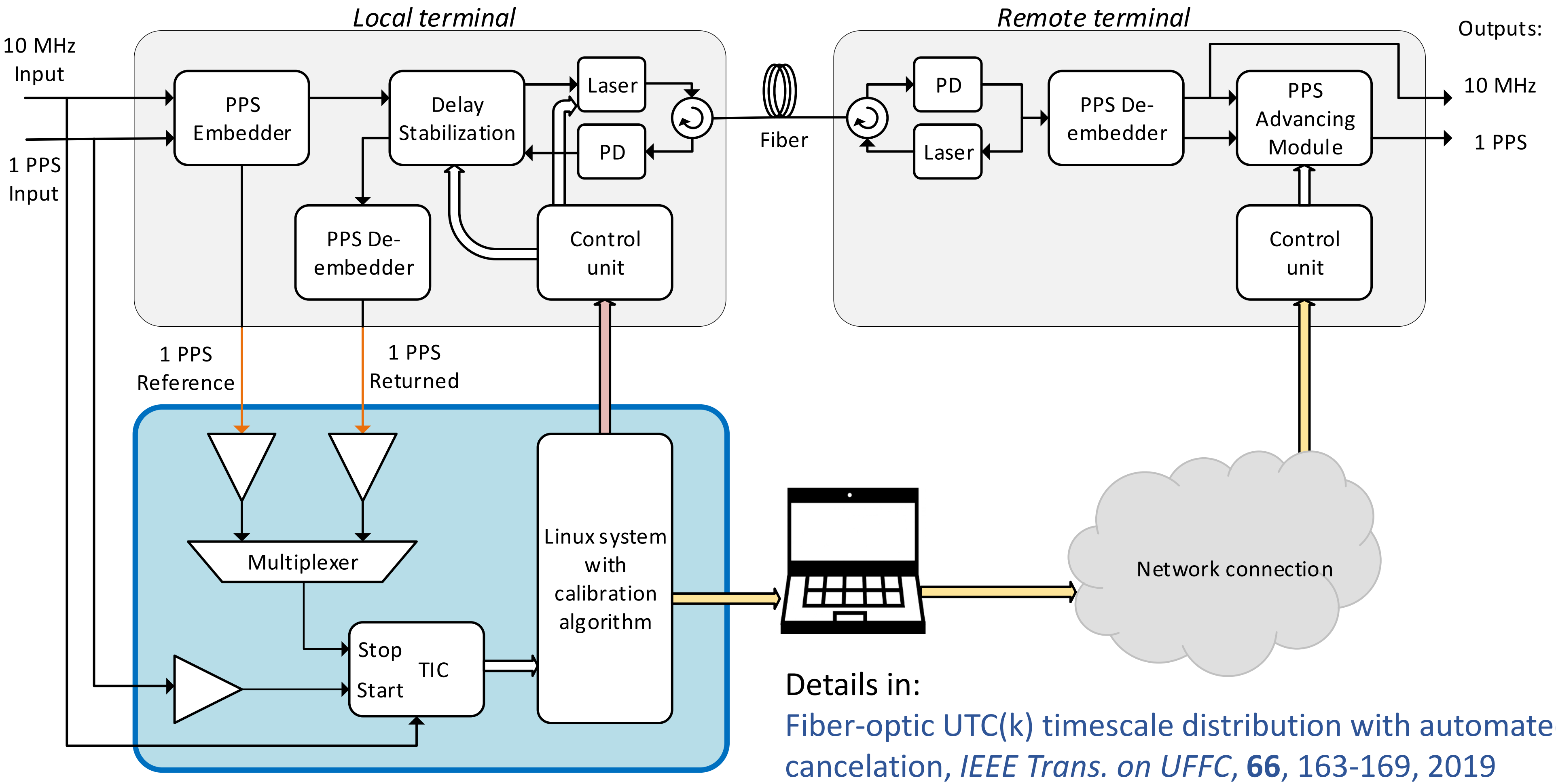
3 x 100 km + 2 SPBA, no WSI



420 km + 8 SPBA + n WSIs



Automatic calibration Towards autonomous system 2



Details in:
Fiber-optic UTC(k) timescale distribution with automated link delay cancelation, *IEEE Trans. on UFFC*, **66**, 163-169, 2019

Literature references

1. P. Krehlik , Ł. Śliwczyński, Ł. Buczek, . Kolodziej, M. Lipiński, ELSTAB- fiber optic time and frequency distribution technology - a general characterization and fundamental limits, *IEEE Trans. Ultrason. Ferroel. Freq. Contr.,* **63,** 993-1004, 2016
2. Z. Jiang , A. Czubla , J. Nawrocki , W. Lewandowski , F. Arias , Comparing a GPS time link calibration with an optical fibre self-calibration with 200 ps accuracy, *Metrologia,* **52,** 384-391, 2016
3. C. Barnes, A. Hati , C. Nelson, D. Howe, Practical evaluation of a 50 km fiber link utilizing a commercial modem, *Proc. 2016 IEEE International Frequency Control Symposium,* pp. 1-4, 2016
4. Ł. Śliwczyński, P. Krehlik, J. Kołodziej, H. Imlau, H. Ender, H. Schnatz, D. Piester, A. Bauch, Fiber optic time transfer for UTC-traceable synchronization for telecom networks, *IEEE Communications Standards Magazine*, **1**, no. 1, pp. 66-73, 2017
5. Ł. Śliwczyński, P. Krehlik, J, Kołodziej, H. Schnatz, A. Bauch, D. Piester, H. Imlau, H. Ender, Calibrated optical time transfer of UTC(k) for supervision of telecom networks, *Metrologia,* **56** 015006, 2019
6. P. Krehlik, Ł. Śliwczyński, Ł. Buczek, J. Kołodziej, Fiber-optic UTC(k) timescale distribution with automated link delay cancelation, *IEEE Trans. on Ultrason. Ferroel. Freq. Contr.*, **66**, 163-169, 2019

Thank you for your attention

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CLONETS – CLock NETwork Services

Strategy and innovation for clock services over optical-fibre networks

Proposal ID: **731107**
Topic: **INFRAINNOV-2016**
Duration: **30 months**
Start date: **1st January 2017**
Web page: **http://www.clonets.eu**

Coordinator

Participants

Third Parties