Libera

Libera Sync 3 Clock Distribution System

Sebastjan Zorzut, 28.05.2015

Libera

Content

- Principles of operation
- Historical overview
- Measuring methods and results
- Used technologies

Instrumentation Technologies

Clock reference distribution systems are used in geographically distributed systems

- Particle accelerators

- Antena grid arrays

Main performance characteristics

- Long-term phase stability

nx10 fs/dan

- Added jitter

n x 1 fs @ 10 Hz – 10 MHz

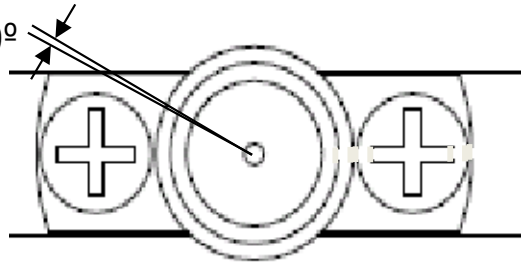
Instrumentation Technologies

Case: Free Electron Laser (FEL) accelerators

	Linac length	Bunch length	Required phase stability
Fermi-Elletra (Italy)	300m	400-600 fs	≤ 50 fs_{RMS}
PSI (Swiss)	780m	30 fs	≤ 10 fs_{RMS}
PAL XFEL (Korea)	1110m	80 fs	≤ 50 fs_{RMS}

10 fs_{RMS} $l = c*dt = 3*10^{8} * 10*10^{-15} = 3*10^{-6}$ m= 3 µm (in the air)

Phase drift in non-compensated materials



10 fs ≙ 3 μm in air or 2μm in typical coax cable or optical fibers or **1.9º turn** of SMA connector

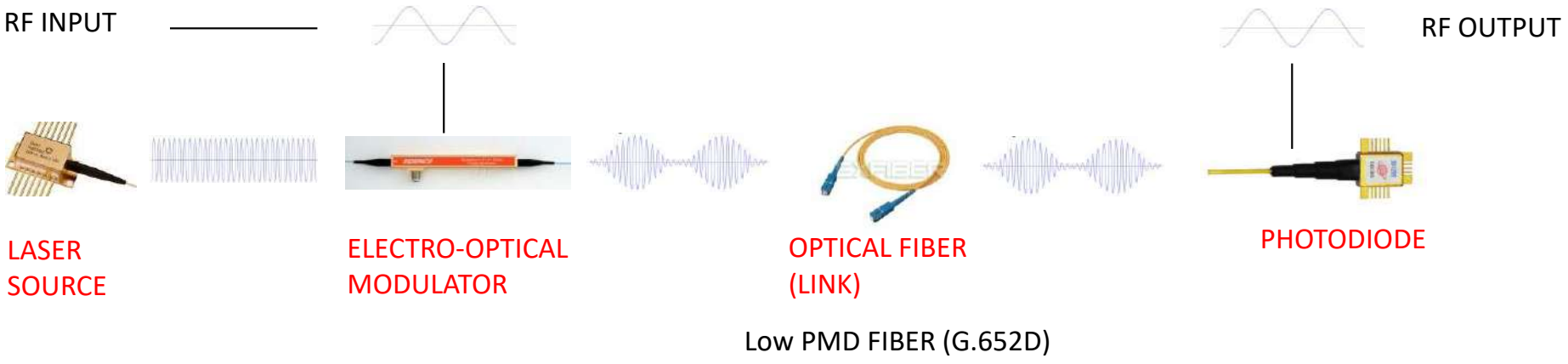
Material		Sensitivity	Timing drift
Steel		15ppm/ºC	50fs/ºC/m
Standard SM fiber	temperature rel. humidity	8ppm/ºC 25ppm/10%RH	40fs/ºC/m 125fs/10%RH/m
temp. optimized fiber Liquid Crystaline Polymer (LCP) coated	temperature rel. humidity	<0.75ppm/ºC 4.1ppm/10%RH	<3.7fs/ºC/m 20.2fs/10%RH/m
Standard coax cable	(bulk PTFE)	-85ppm/ºC	-425fs/ºC/m
temp. optimized coax cable	(air-filled PTFE)	<1..3ppm/ºC	<4.2..12.5fs/ºC/m
Air	temperatura pressure rel. humidity	-3ppm/ºC 2ppm/10mBar 4ppm/10%RH	-10fs/ºC/m 7fs/10mBar/m 13fs/10%RH/m

Dr. Volker Schlott: **Collaborative Development of an Ultra Stable CW Optical Reference Distribution System, *Libera workshop 2012*, Solkan**

Instrumentation Technologies

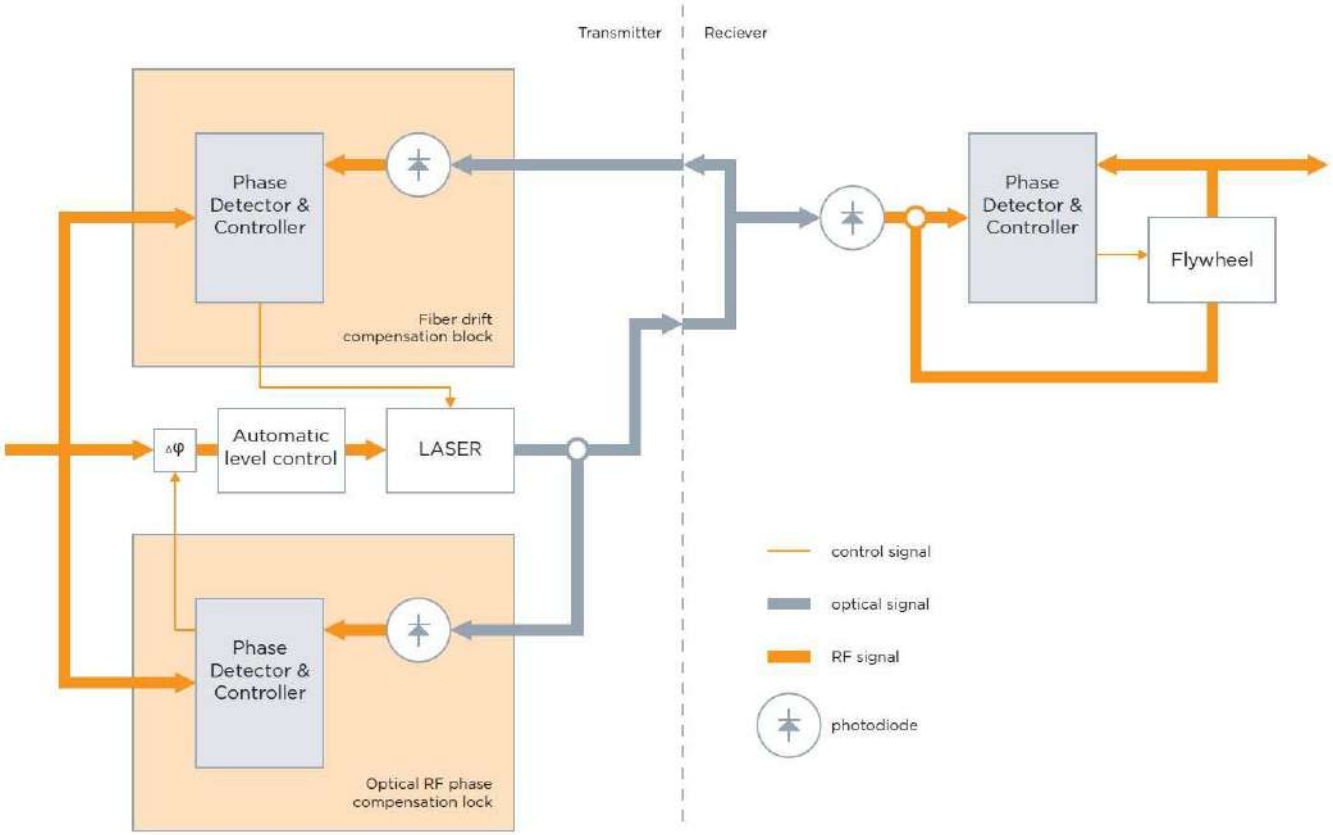
Libera Sync 3 – basic idea

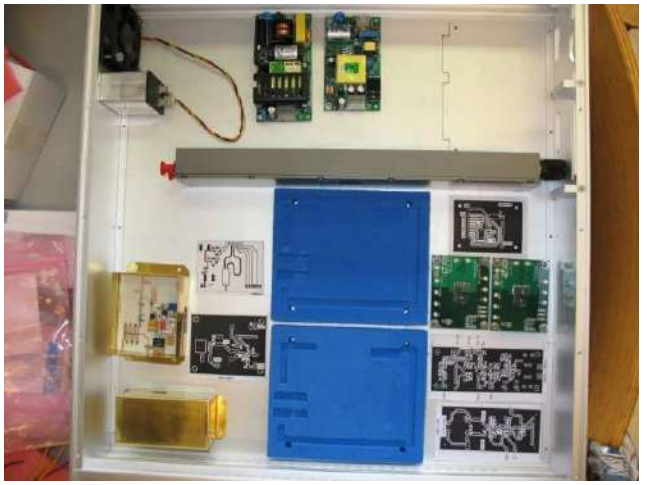
Transfer of clock reference signal over optical fiber– amplitude modulated CW optical carrier



Instrumentation Technologies

2009 First prototype - design phase at the Faculty of Electrical Engineering (2009 patent application)





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Transmitter (TX) and Receiver (RX)

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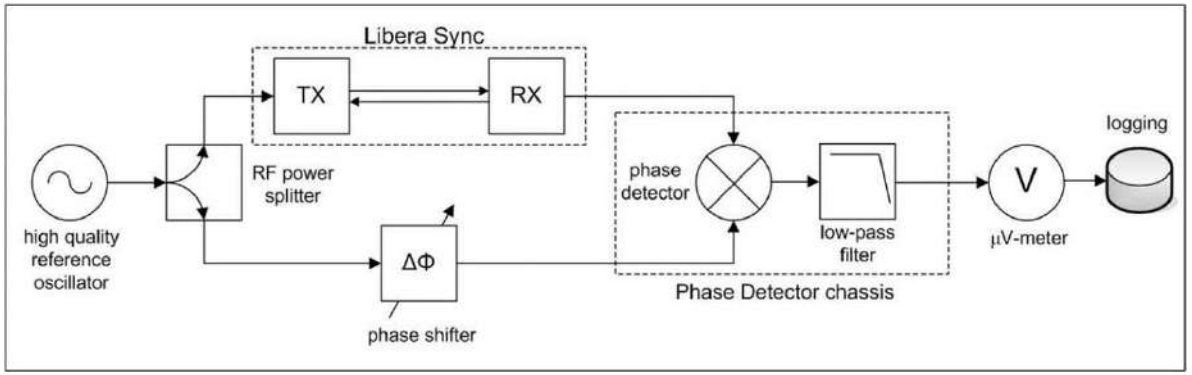
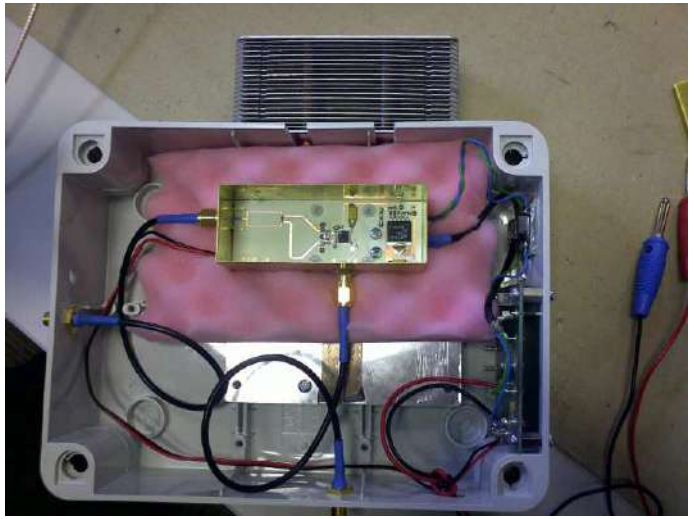
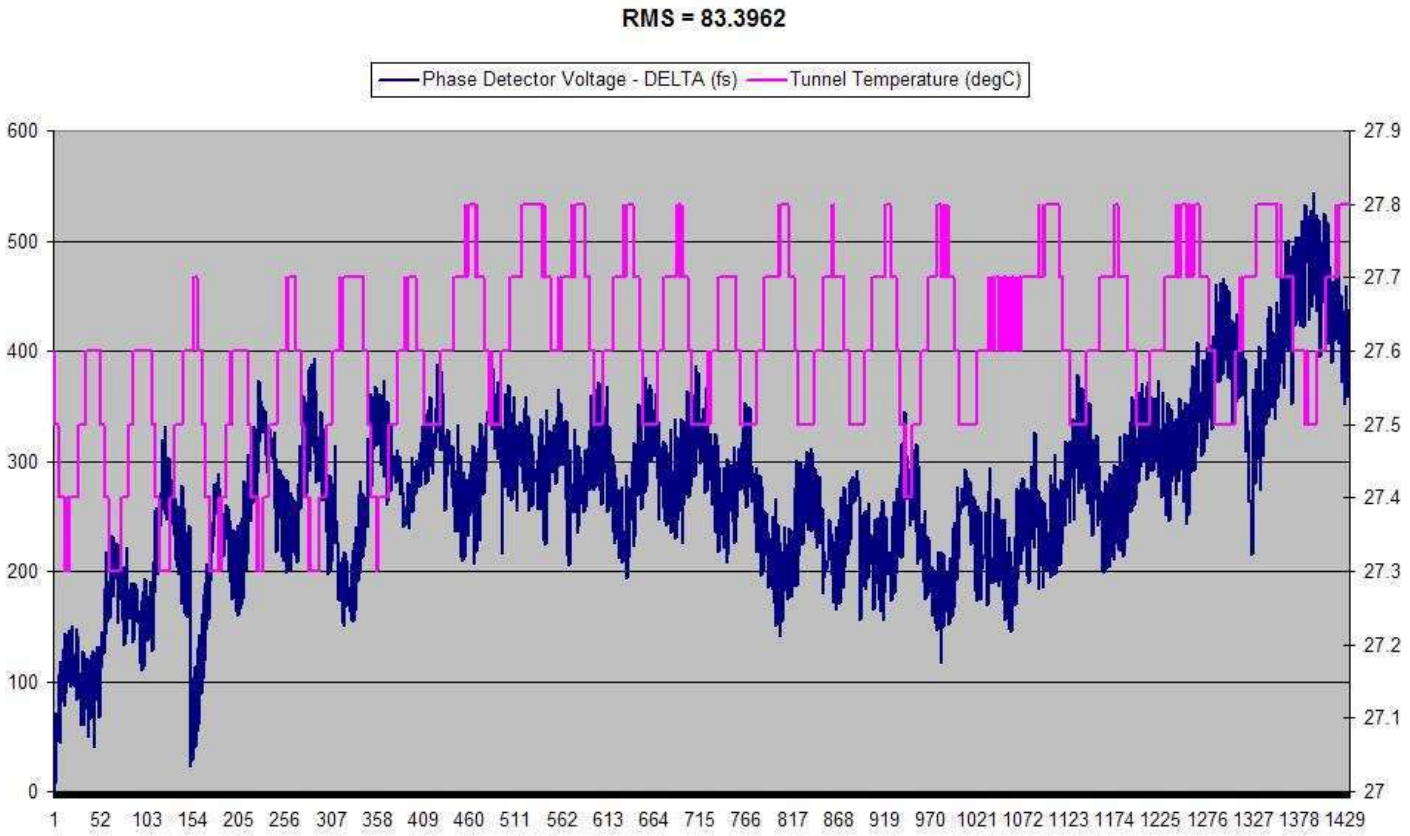
Measuring setup





First results



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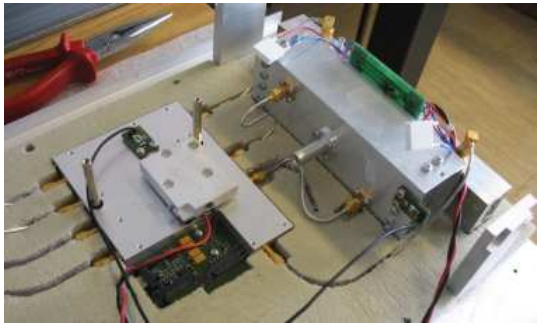
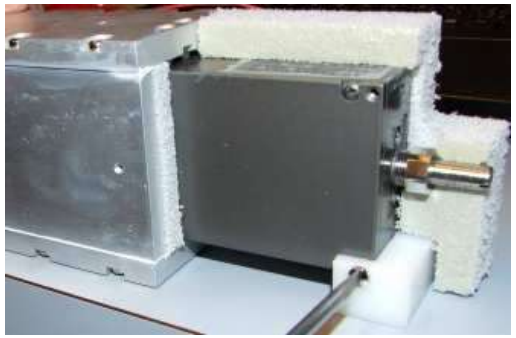
2010 Industrialization of prototype (Libera Sync)

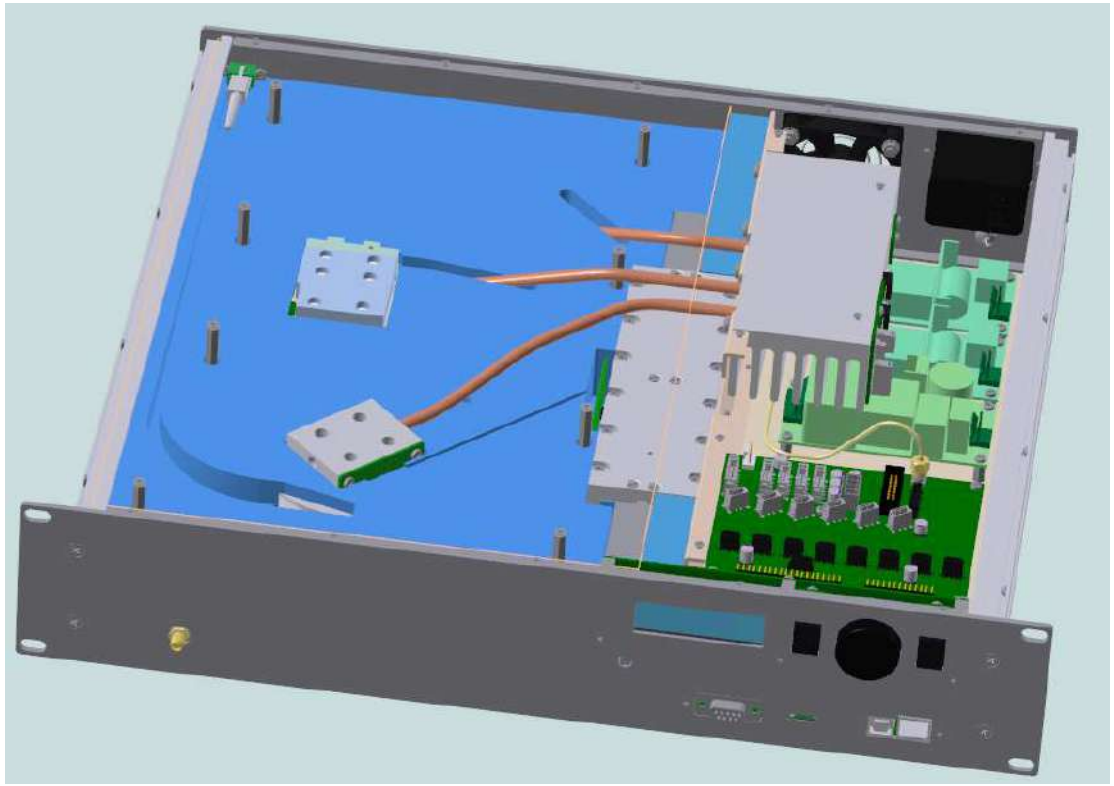
- Reduced number of modules
- Connectorized cabling
- Temperature stabilization of all crucial components

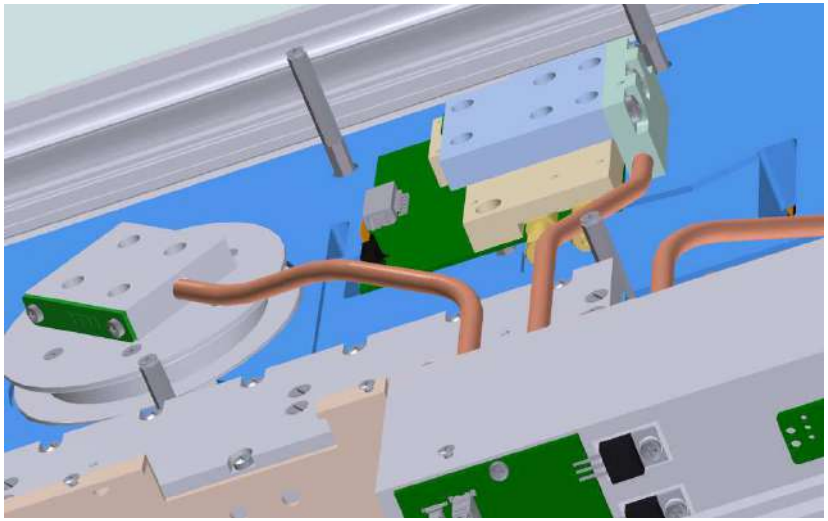




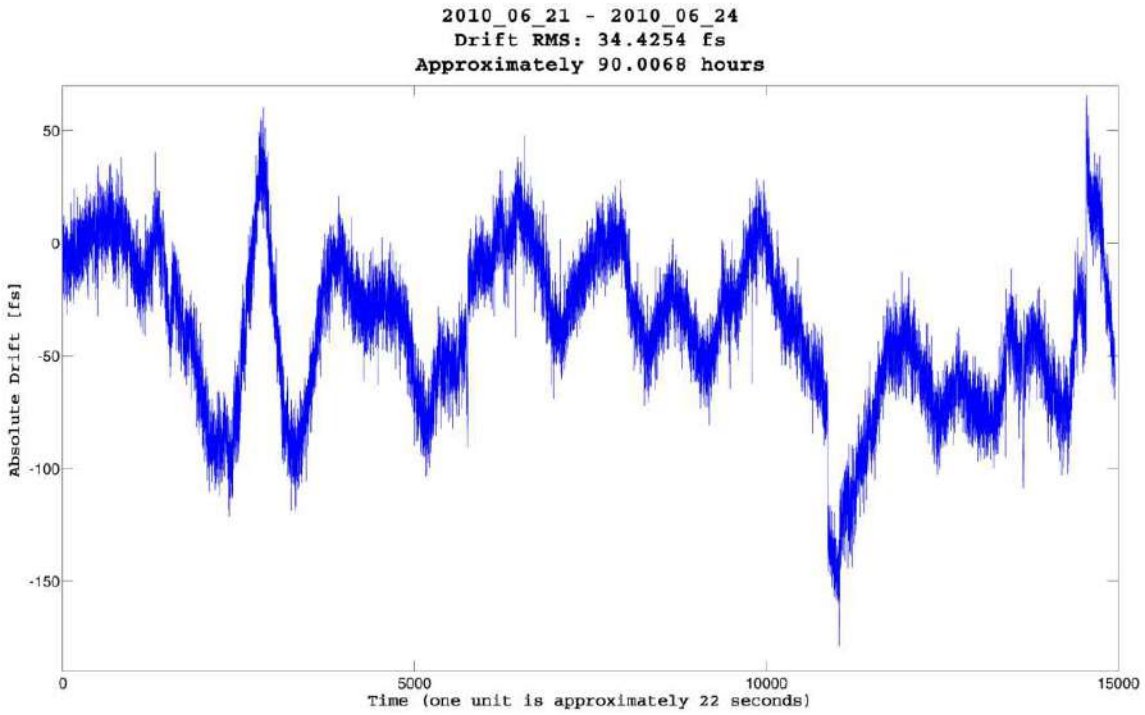
Instrumentation Technologies

CAD mechanical design

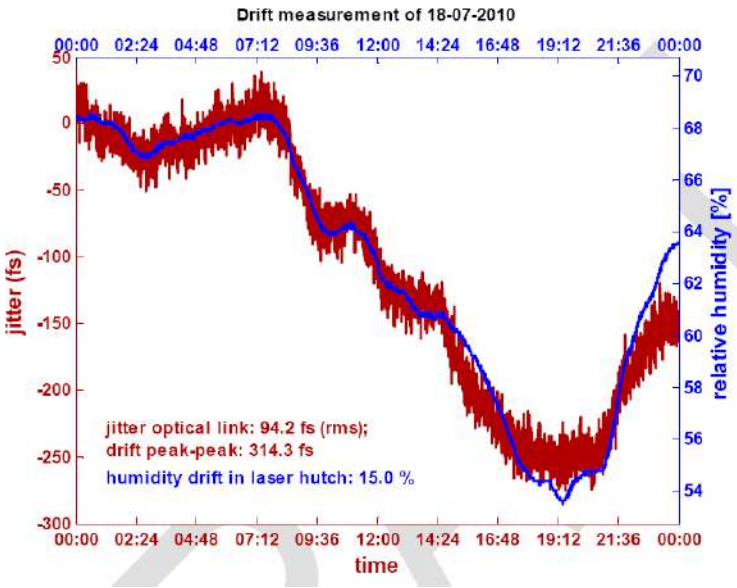




First testing results at Paul Scherrer Institute (PSI)



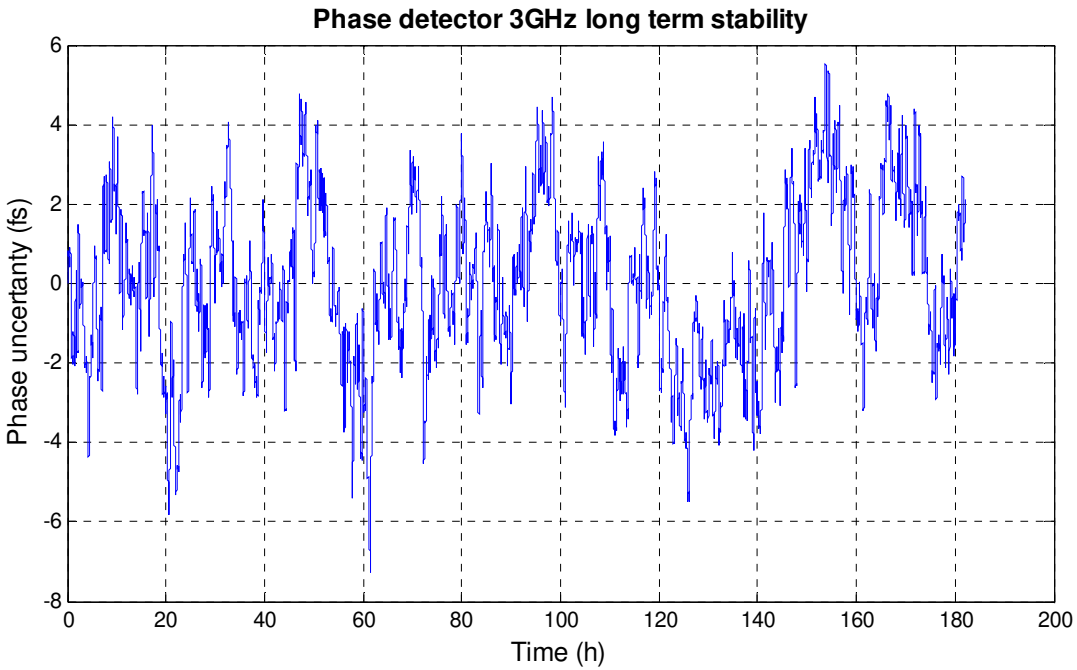
- High phase unstability
- Too high added phase noise



2011 Libera Sync 352 and 500 MHz

- 2 optical fibers
- 1U chasis (45 mm)
- Increased module integration
- Relaxed specifications for long-term stability and added phase noise

2011 Phase detector PhD1



www.i-tech.si

Testing period: 7 days

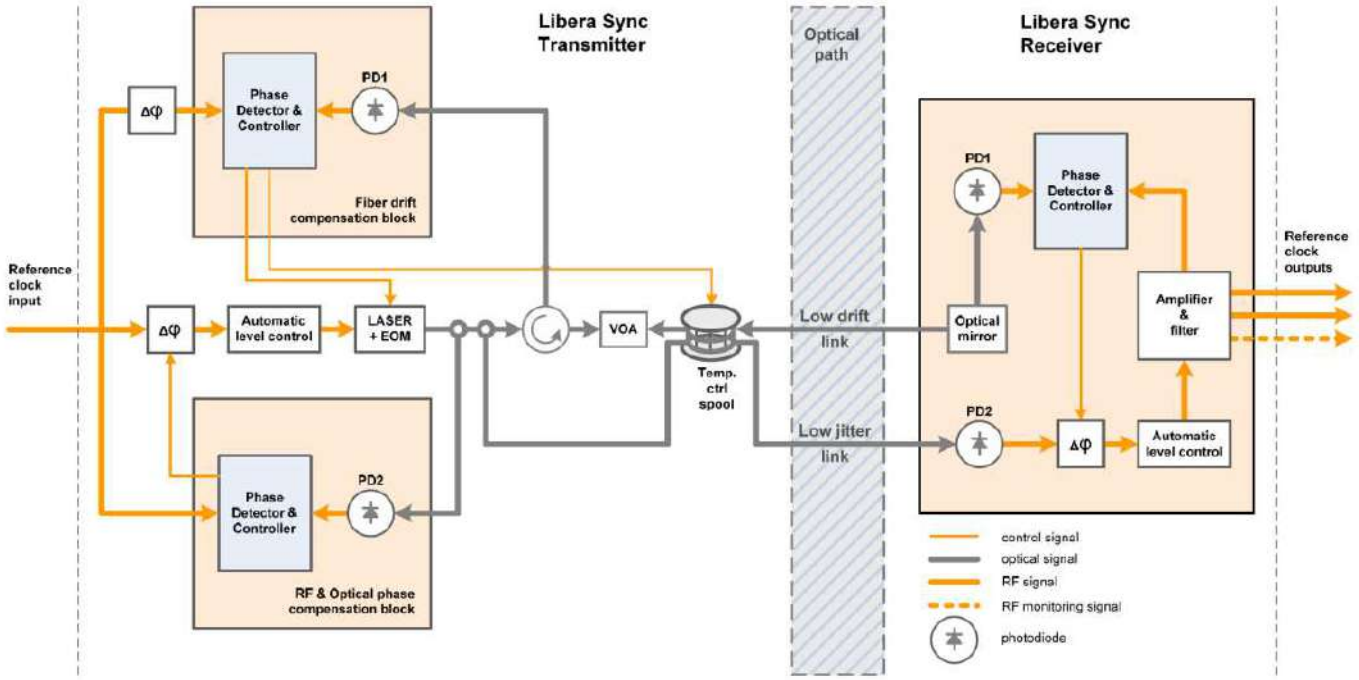
Frequency: 0.2 - 3GHz

12 fs pp (filtered signal)

2.1 fs RMS (filtered signal)

Instrumentation Technologies

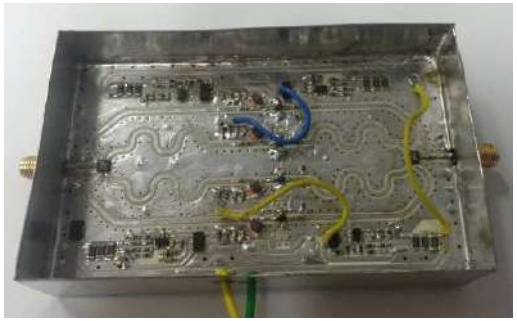
2012 In collaboration with PSI the development of Libera Sync 3 has started

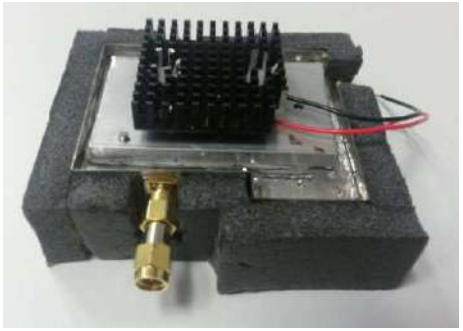


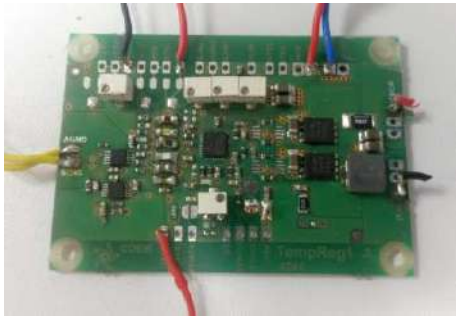
- Operational frequencies
  2998.8 MHz
  2856 MHZ
- Tx: RF input power
  +15 dBm ± 1 dBm
- Rx: RF output power
  +15 dBm ± 0.5 dBm
- Optical link length: 1.5km

Instrumentation Technologies

Prototyping phase







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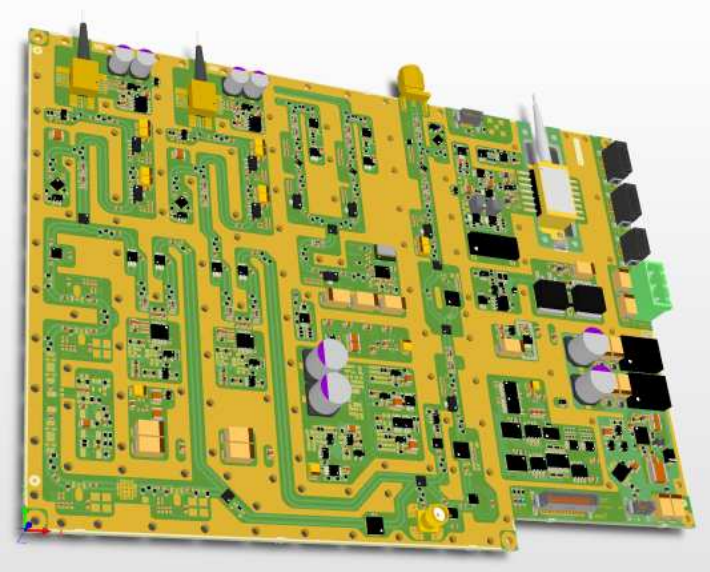
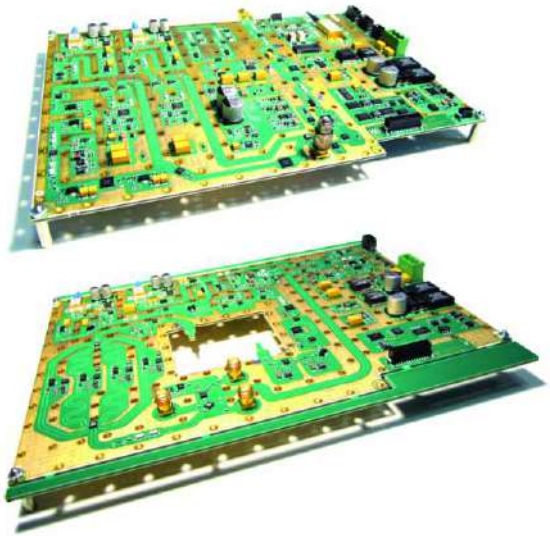
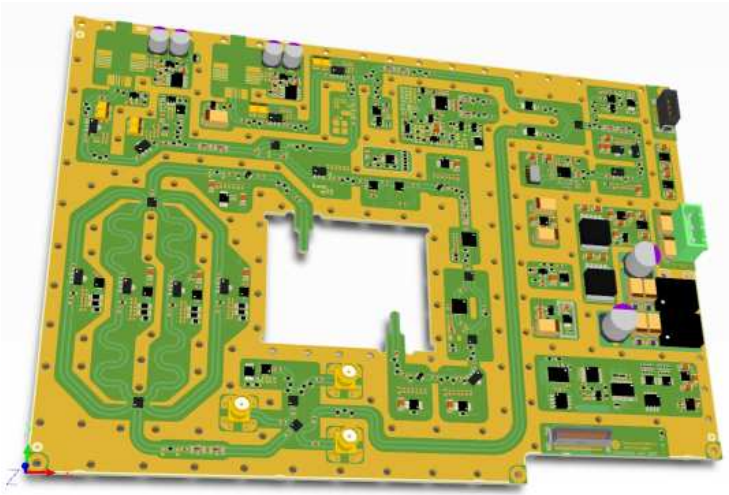
Integration of all RF and control electronics on single PCB (Single board solution)







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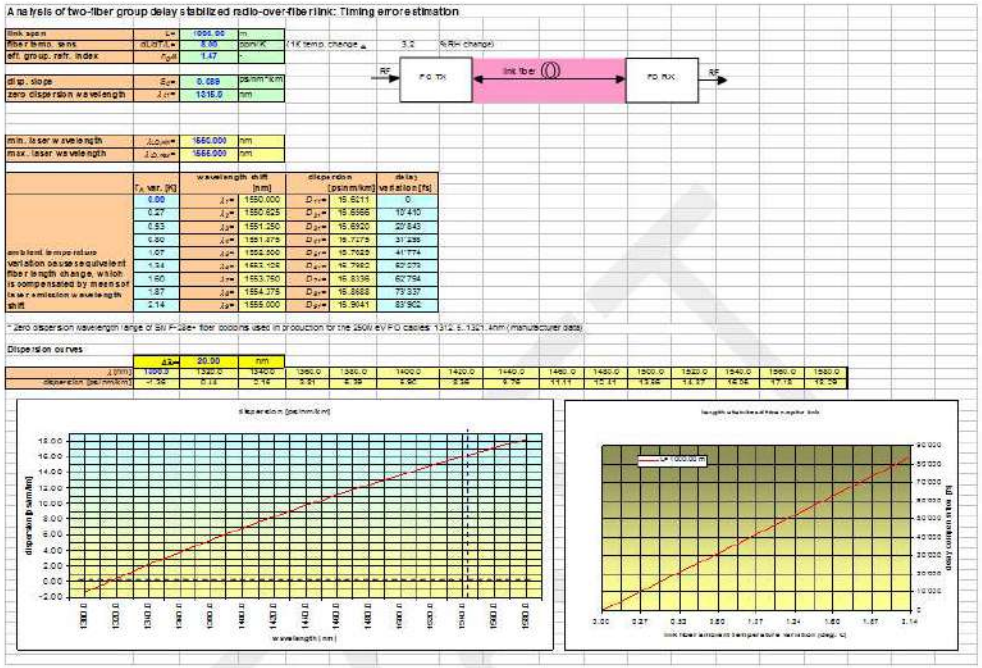
Design of optics at PSI

PAUL SCHERRER INSTITUT



PAUL SCHERRER INSTITUT

Delay variation in SSMF using wavelength tuning

fiber 2nd order dispersion coefficient, D=	17.00	ps/nm/km
fiber temp. dependent el. length variation, dL/dT_A=	8.00	ppm/°C
eff. fiber group refractive index, n_{gr}=	1.47	-
laser temp. tuning coefficient, $d\lambda_{laser}/dT$=	0.09	nm/°C

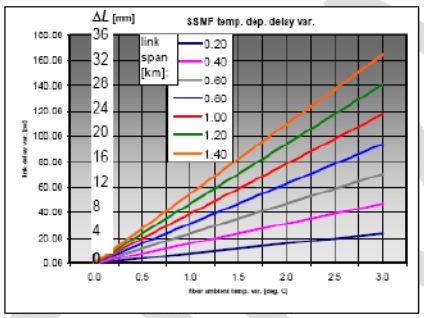
link delay variation [ps]:

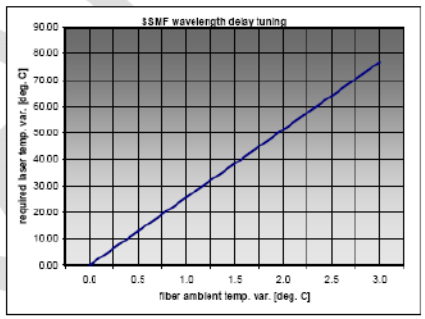
ambient temp. var. [°C] → / ↑ link span [km]	0.0	0.5	1.0	1.5	2.0	2.5	3.0
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.20	0.00	3.92	7.84	11.76	15.68	19.60	23.52
0.40	0.00	7.84	15.68	23.52	31.36	39.20	47.04
0.60	0.00	11.76	23.52	35.28	47.04	58.80	70.56
0.80	0.00	15.68	31.36	47.04	62.72	78.40	94.08
1.00	0.00	19.60	39.20	58.80	78.40	98.00	117.60
1.20	0.00	23.52	47.04	70.56	94.08	117.60	141.12
1.40	0.00	27.44	54.88	82.32	109.76	137.20	164.64

	ambient temp. var. [°C]						
	0.0	0.5	1.0	1.5	2.0	2.5	3.0
req. ΔT_{laser} [°C]:	0.00	12.81	25.62	38.43	51.24	64.05	76.86

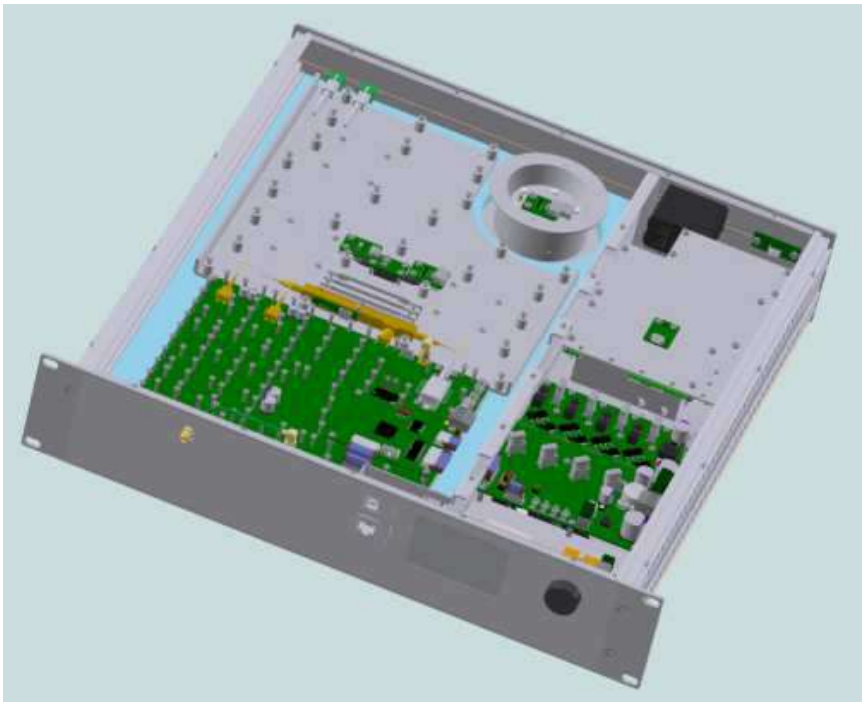
$\Delta T_{laser}/\Delta T_A$= 25.62

	ambient temp. var. [°C]						
	0.0	0.5	1.0	1.5	2.0	2.5	3.0
req. $\Delta\lambda_{laser}$ [nm]:	0.00	1.15	2.31	3.46	4.61	5.76	6.92





Unified mechanical construction for Tx in Rx units



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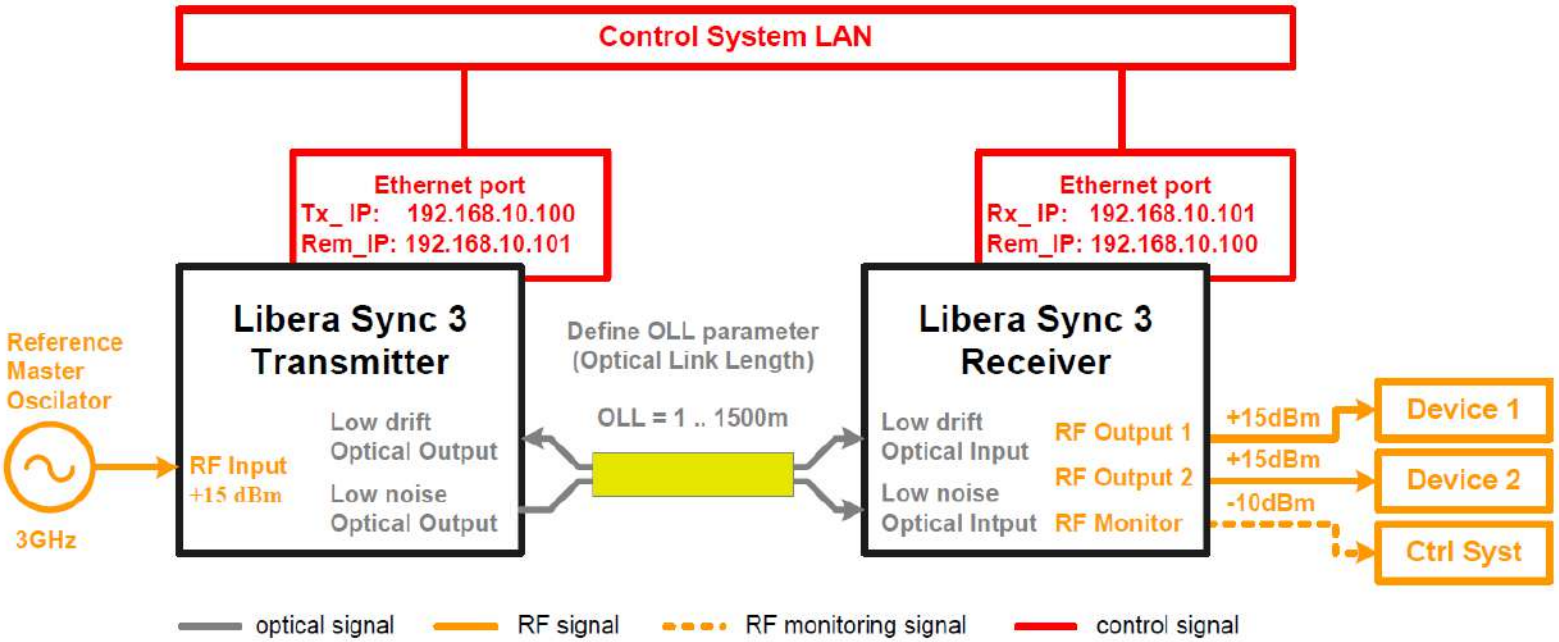
Libera Sync 3

3 GHz Transmitter

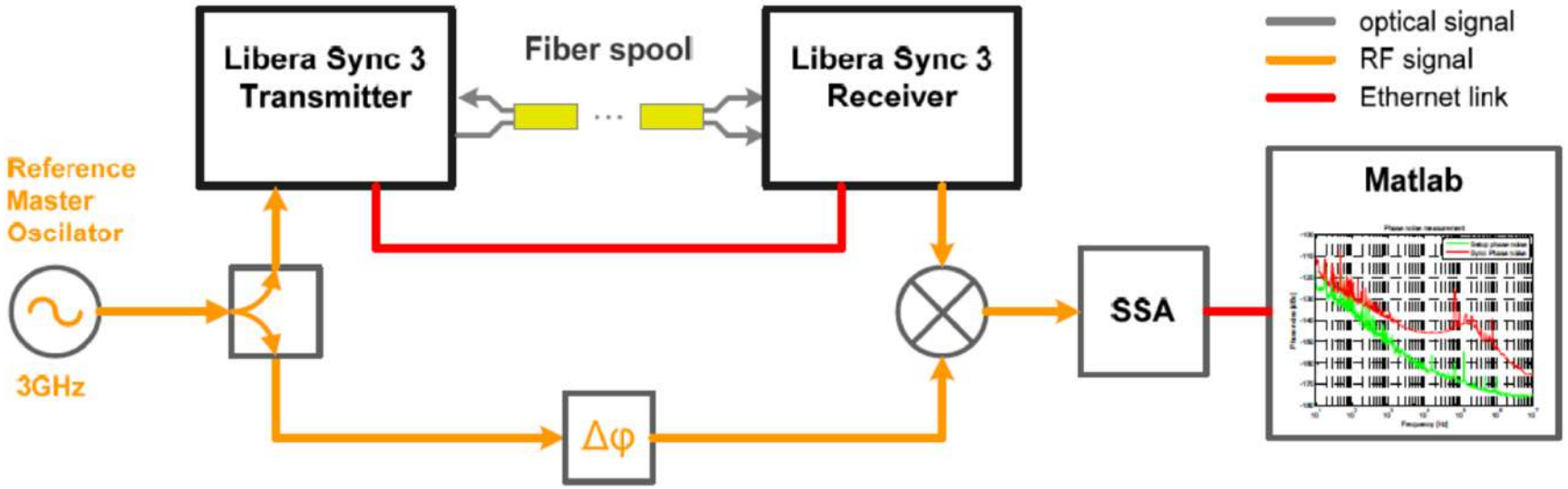
3 GHz Receiver

Libera Sync 3 configuration



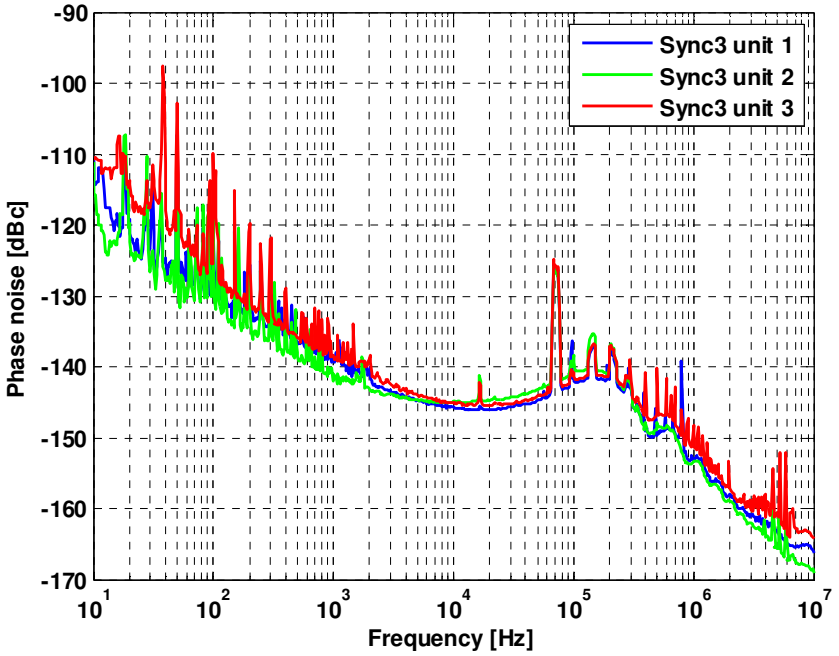
Instrumentation Technologies

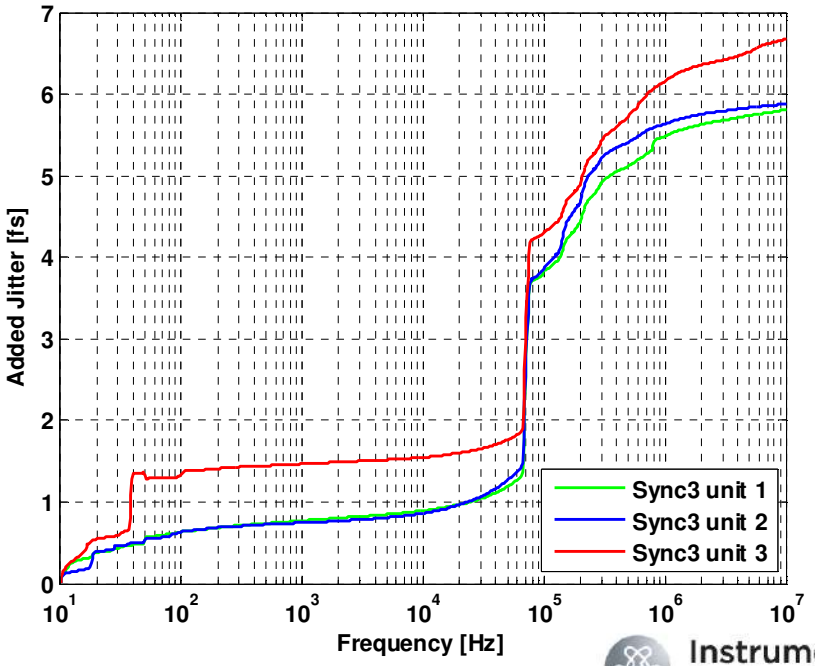
Added jitter and phase noise measuring setup



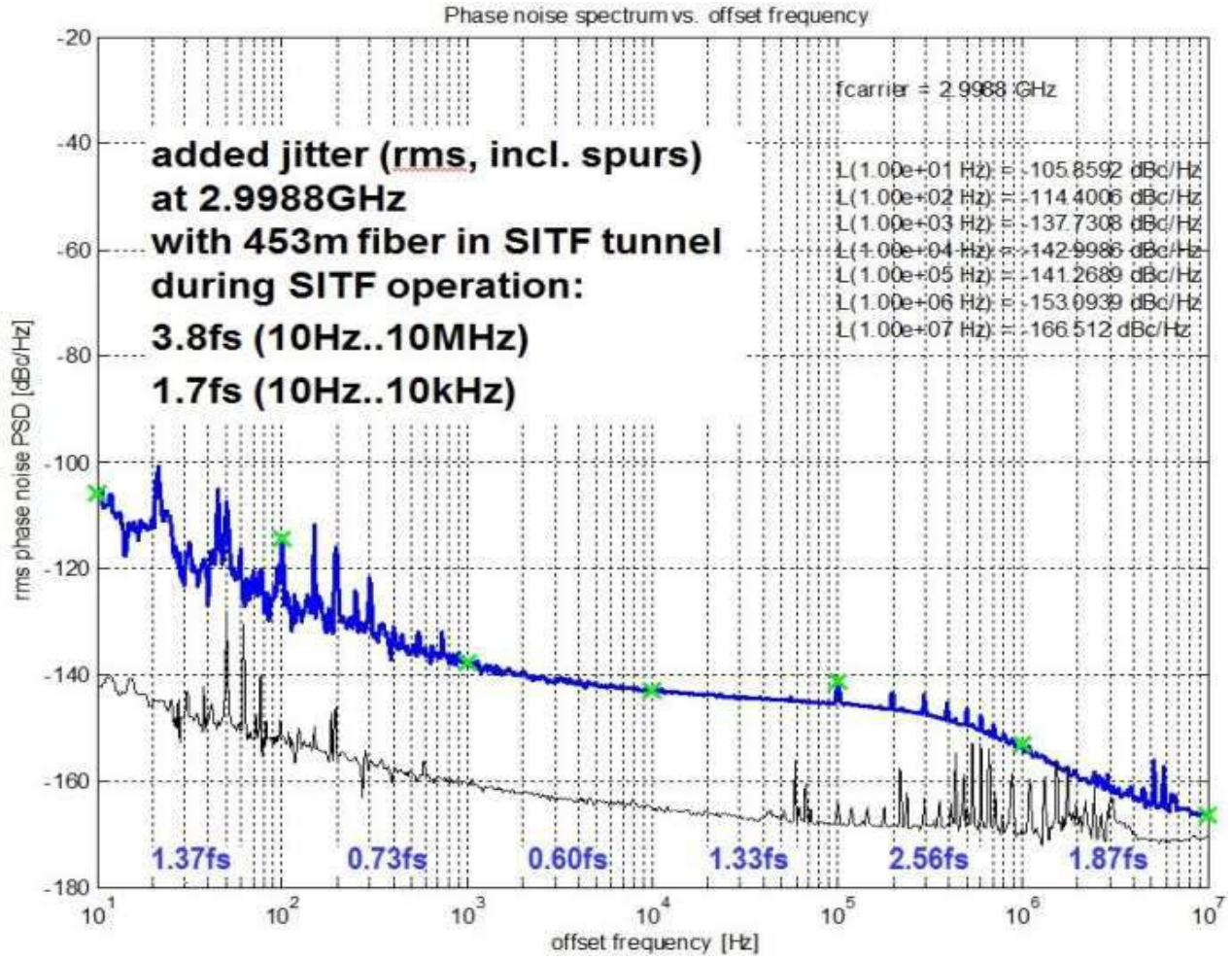
Instrumentation Technologies

Instrumentation Technologies – phase noise and added jitter measurement results





Instrumentation Technologies



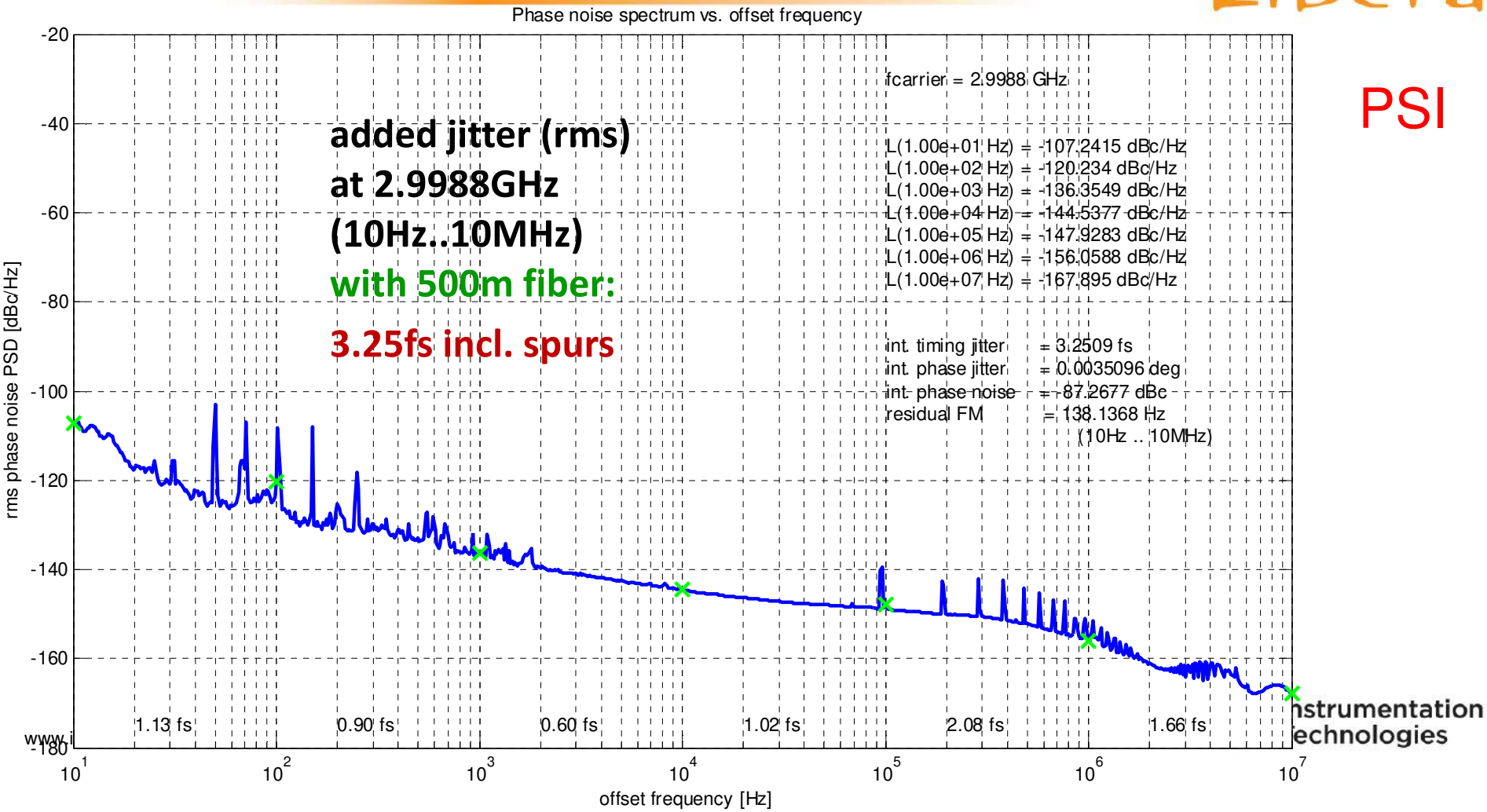
PSI SwissFEL measurement

Libera Sync 3 measured phase noise and jitter at 2998.8MHz.
The thin black curve shows the limit of the setup (mixer Pulsar ML-04-LC, SSA Agilent E5052B baseband)

Instrumentation Technologies

Libera

PSI



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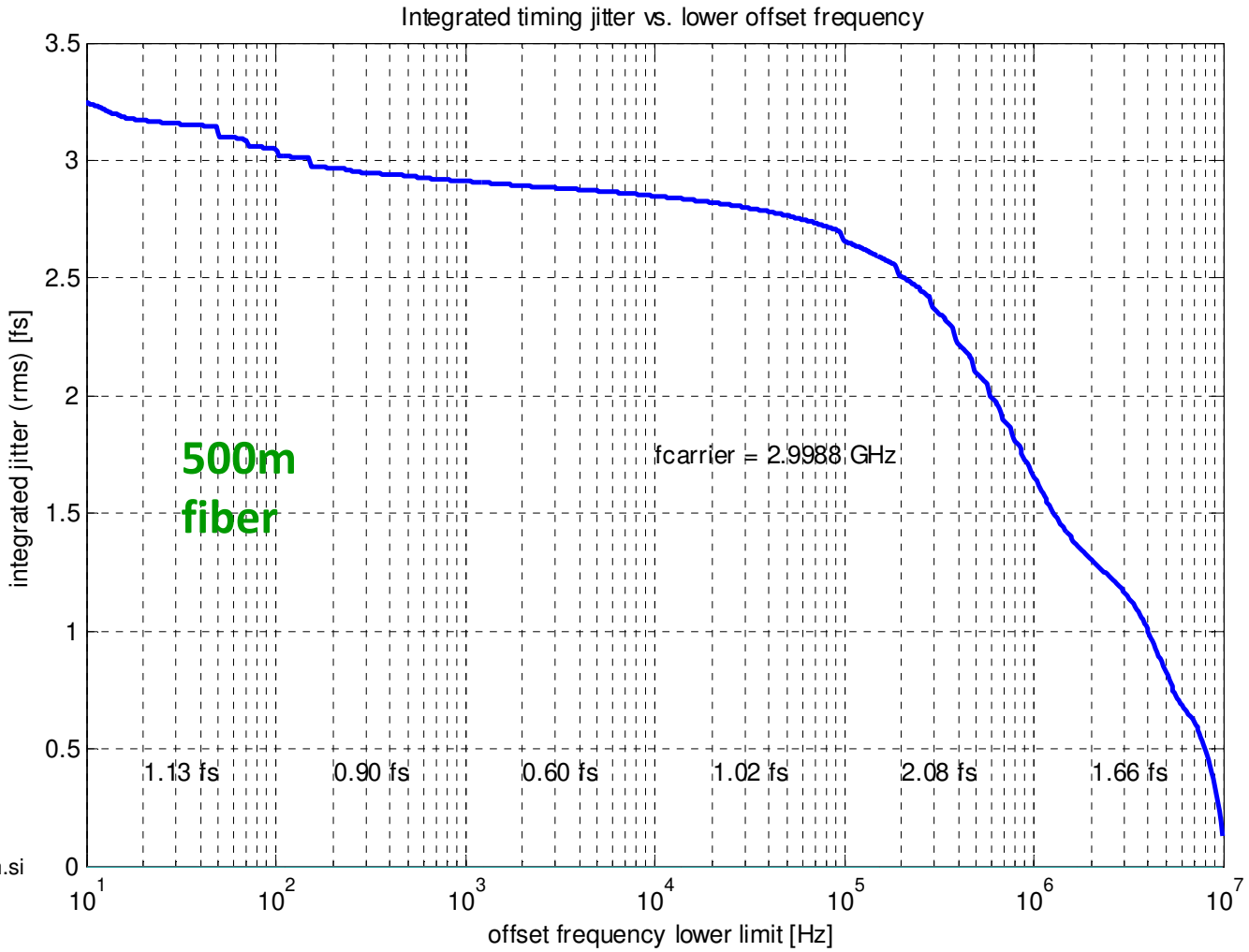
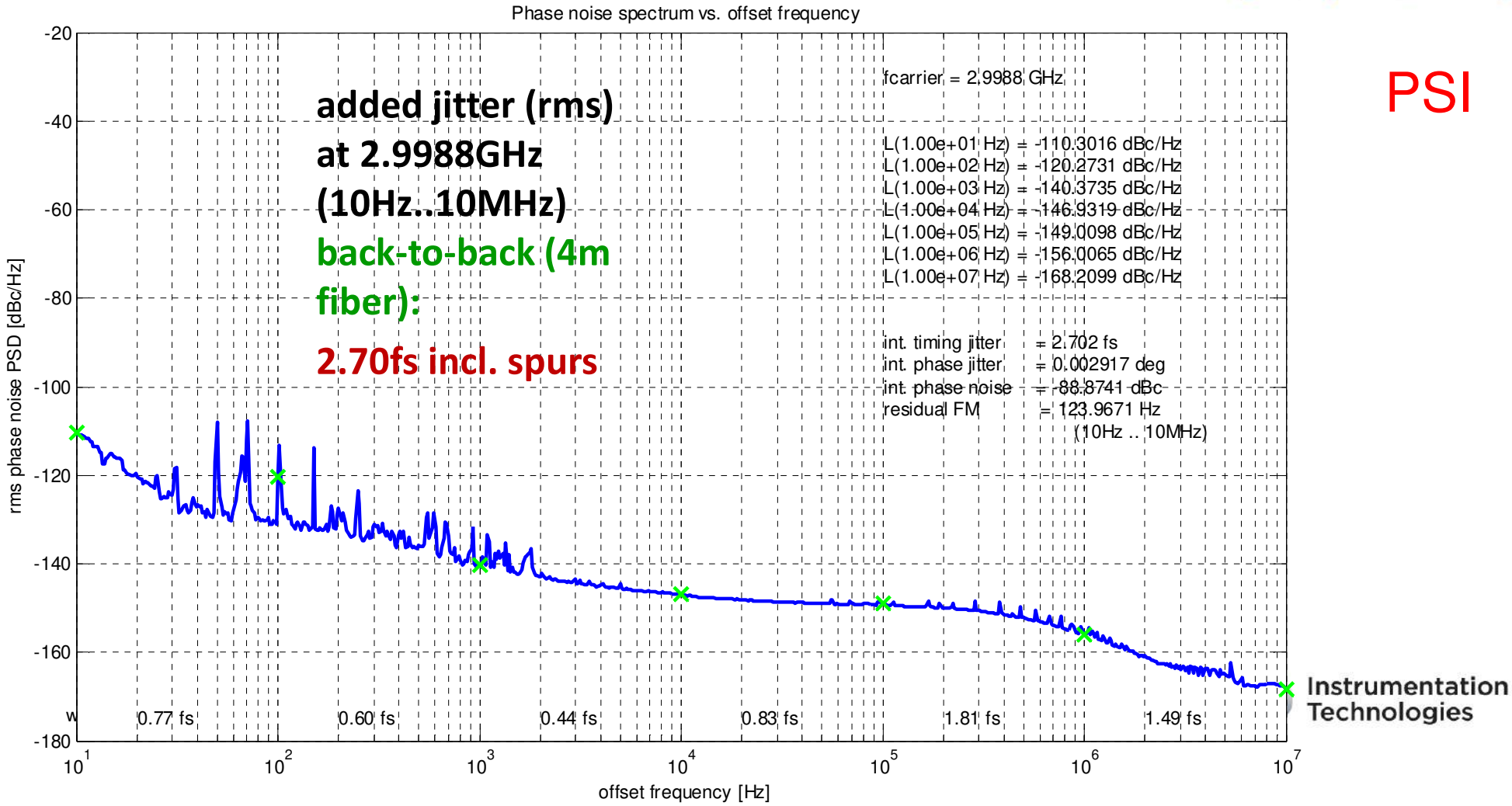
PSI



Instrumentation Technologies

Libera

PSI



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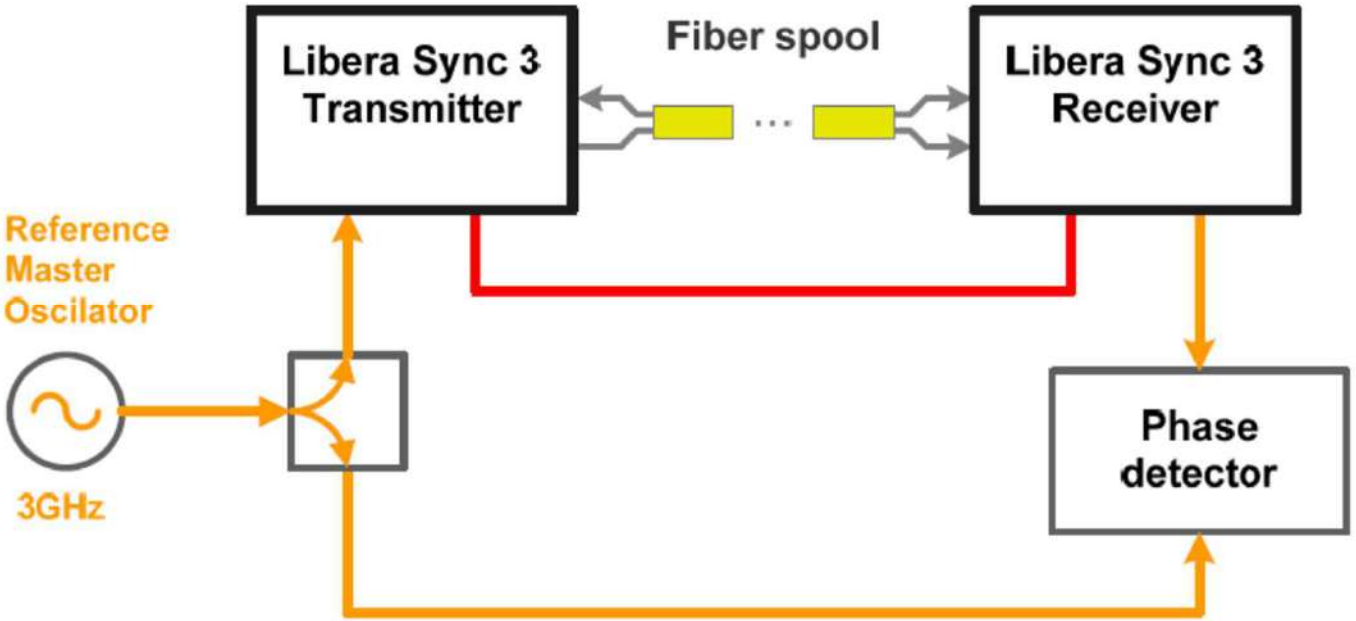
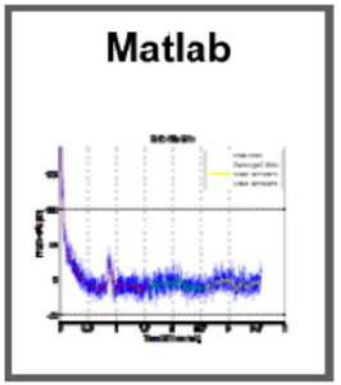
Long-term stability measurements



optical signal
RF signal
Ethernet link



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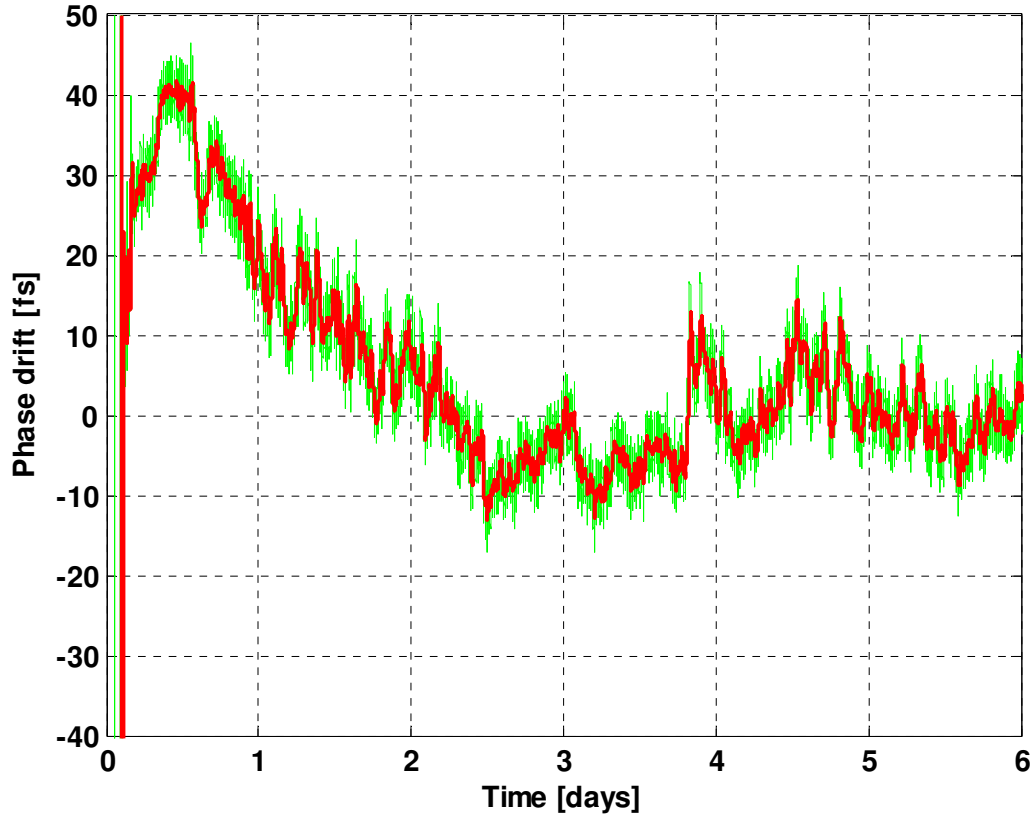
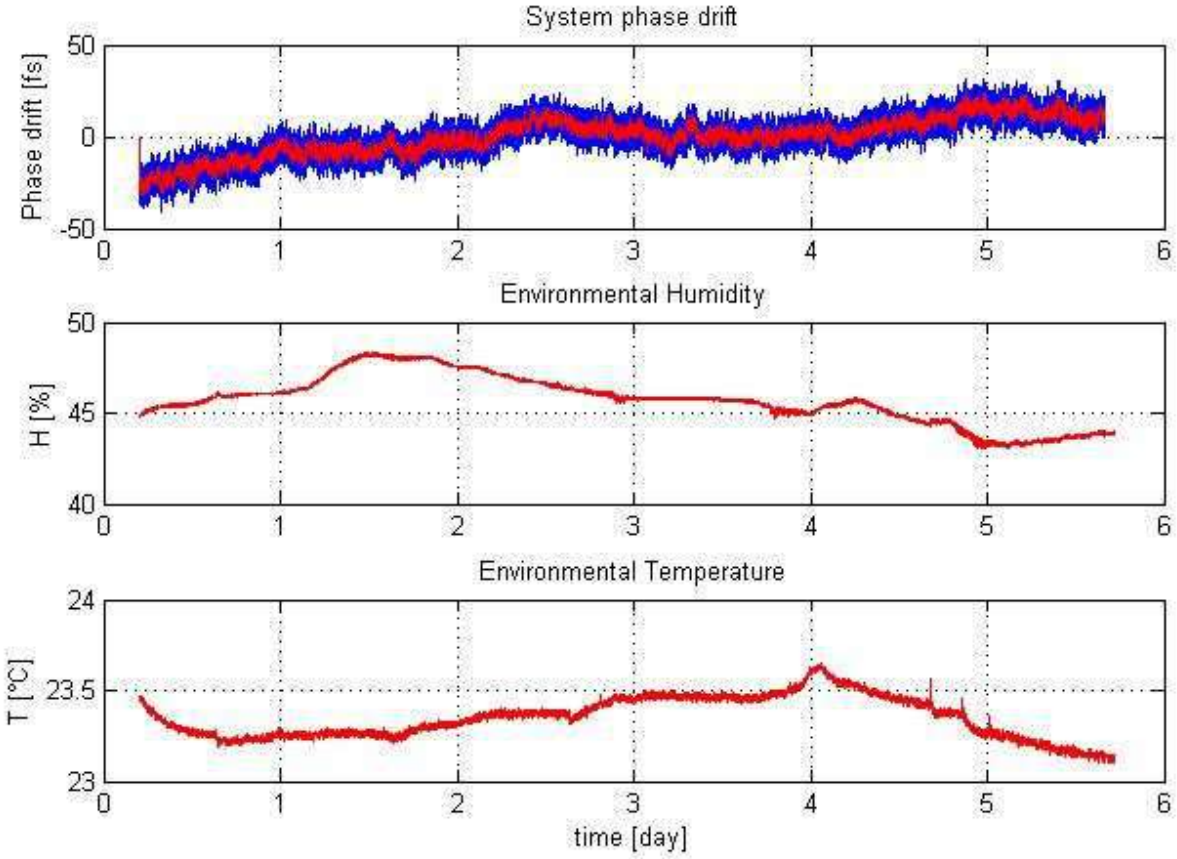
Long-term stability measurements of Libera Sync 3 prototype



Phase drift < 40 fs_{pp} over 4 days

Instrumentation Technologies

Libera Sync 3 Phase drift and environmental conditions



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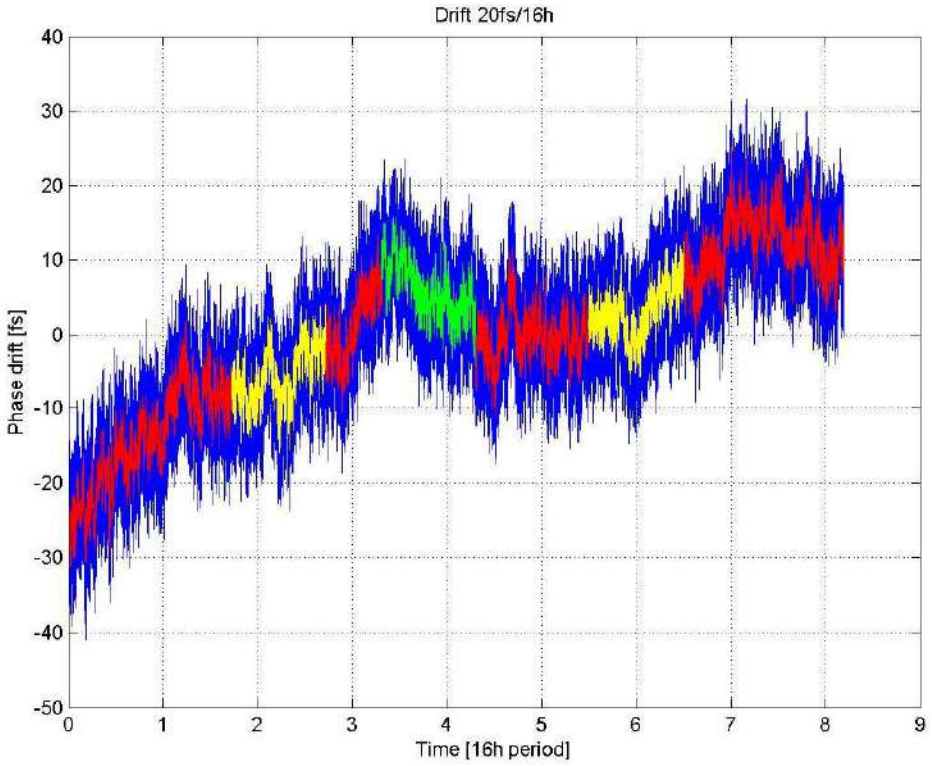
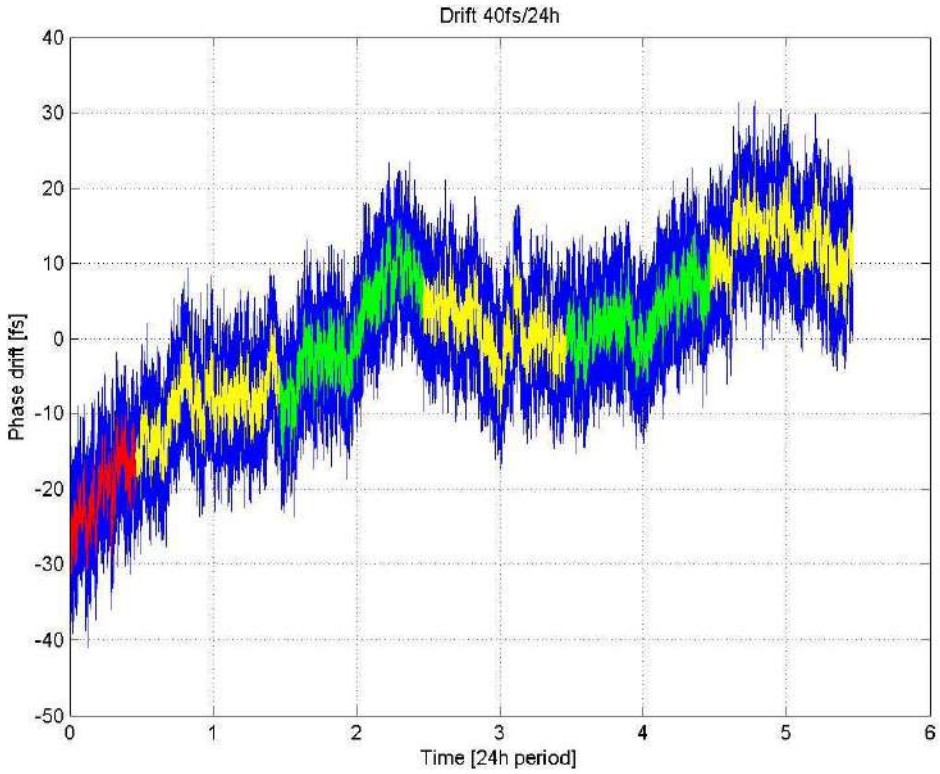
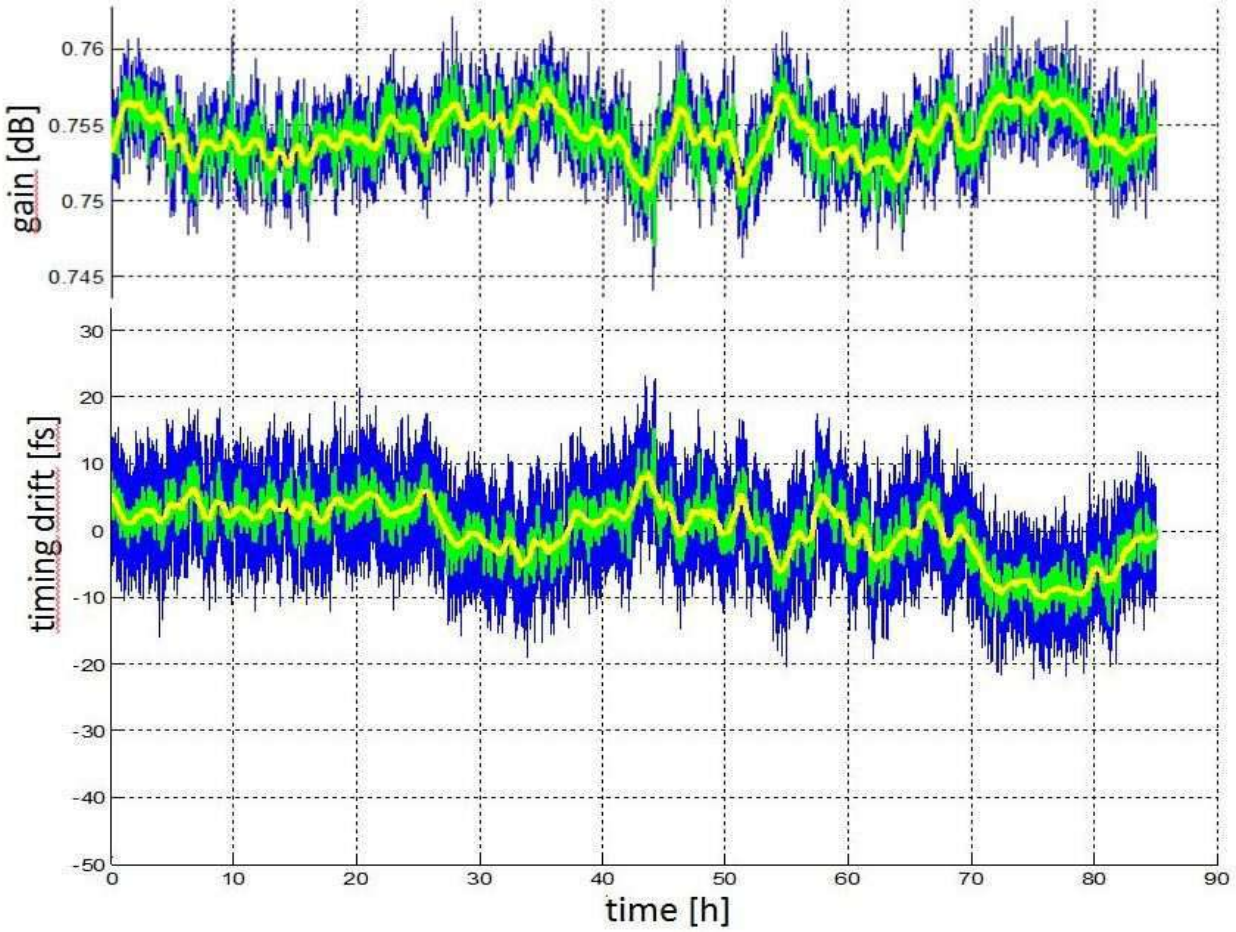
$20fs_{pp}/16h$ and $40fs_{pp}/24h$ segments







PSI SwissFEL measurement

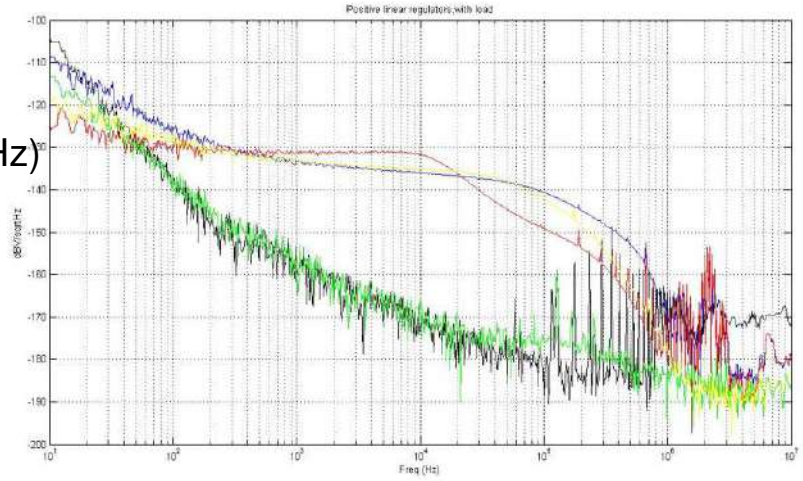
Libera Sync 3 phase/gain drift over 85h (453m link in SITF tunnel, f=2998.8MHz):
Gain detector (top), phase detector (bottom).
Blue: raw data (2.2s sampling period); green: averaging over 2.2min; yellow: averaging over 1h.
Timing/gain drift:
$29.5fs_{pp}/0.013dB_{pp}$ (2.2min avg.),
$18.6fs_{pp}/0.007dB_{pp}$ (1h avg.).

Instrumentation Technologies

Libera Sync 3

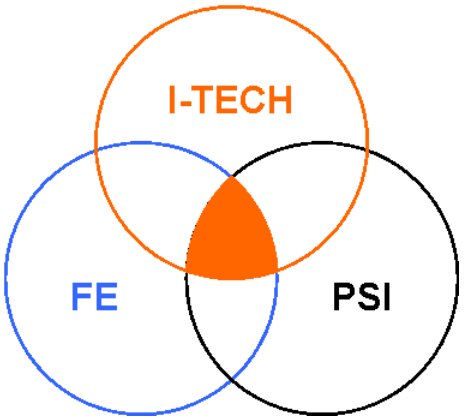
- Reliable long-term performance
- Extremely low added jitter
- Easy instalation
- Automatized self tuning start-up procedure
- Robust operation (after instalation no further tuning is needed)
- Remote monitoring and control
- Design for manufacturing, design for performance, only quality components used

Used technologies



- Low-noise power supply (noise < -100 dBV/√Hz 10Hz – 10MHz)
- Extremely low phase noise RF electronics
- Temperature stabilization in the range of a few m°C
- CAD mechanical design
- 8-layer PCB 2x Rogers core, IMS (Insulated Metal Substrate)
- Embeded control module ARM Cortex M3 + firmware
- In-house assembly of optics (including polarization dependent optical fibers)
- Integration of all stated technologies in one standard 2U chasis (smal form factor)

Development team



- Colaboration of research, development and user sphere

Acknowledgment

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Paul Scherrer Institute (PSI), Switzerland: dr. Stephan Hunziker, dr. Volker Schlott, Maik Kaiser

Instrumentation Technologies d.d.: Peter Orel, Žarko Lestan, Črt Valentinčič, Luka Rahne, dr. Dejan Tinta, mag. Primož Lemut, mag. Borut Repič, Borut Baričevič, Mateja Lampe Rupnik, Rok Mesar, Rok Uršič, Rok Hrovatin, Zdravko Rijavec, Miha Leskovec