VTT TECHNICAL RESEARCH CENTRE OF FINLAND LTD

MIKES METROLOGY

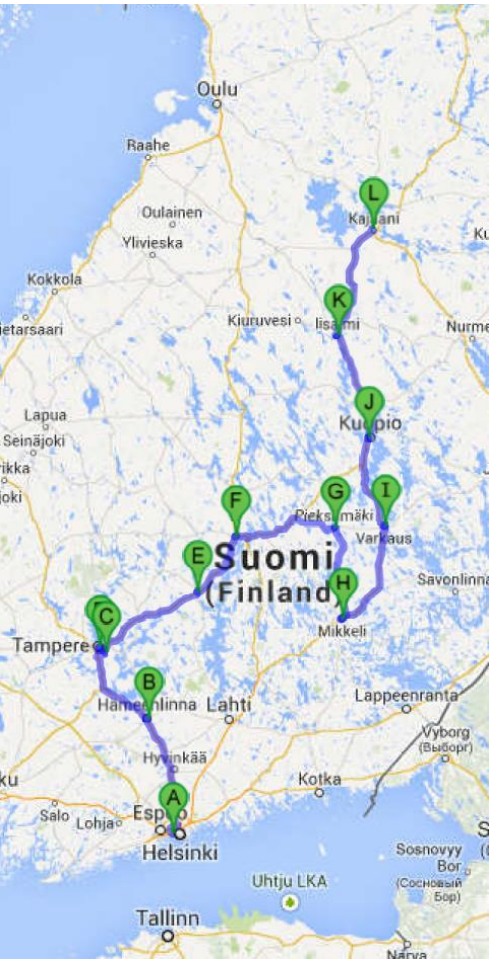
White Rabbit in Time & Frequency Metrology

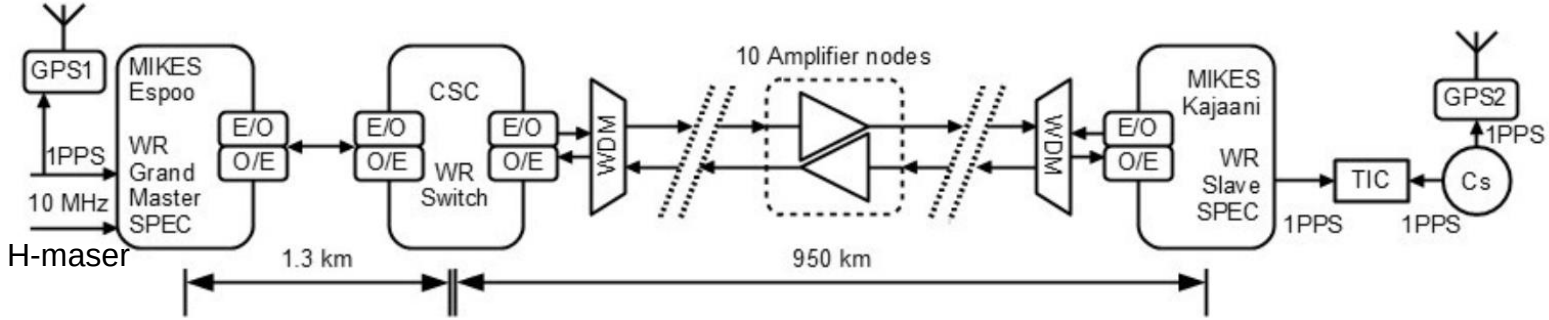
Anders Wallin

White Rabbit Workshop
2016-03-15, Amsterdam

- Long(est?) WR link
- Fiber asymmetry and calibration
- Stability measurements
- Other activities

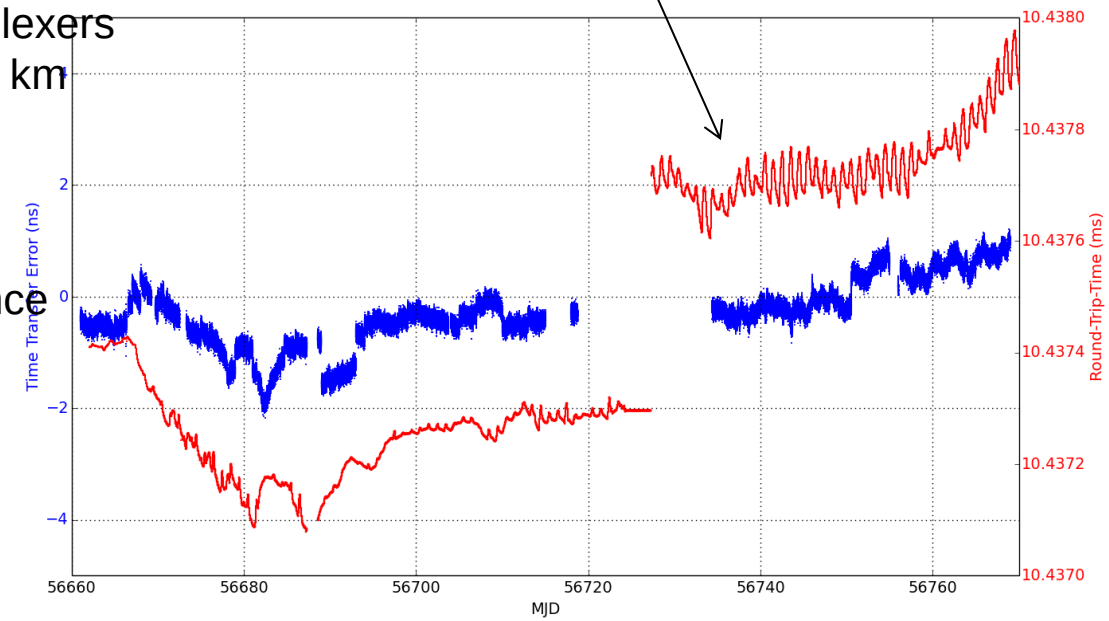
Espoo Kajaani link now permanent for data-transfer and time-transfer





- ~~bidir~~ duplex SFPs and link
- ~~10 km~~ ~1000 km link length
- 10.4 millisecond round trip
- Uplink – downlink = ~4 us
- 12 amplifiers/multiplexers
- Longest span ~140 km

Sergio's comments on servo slew-rate!



Issues:

- Network maintenance changes asymmetry
- Stability limited by Cs-clock and GPS-PPP

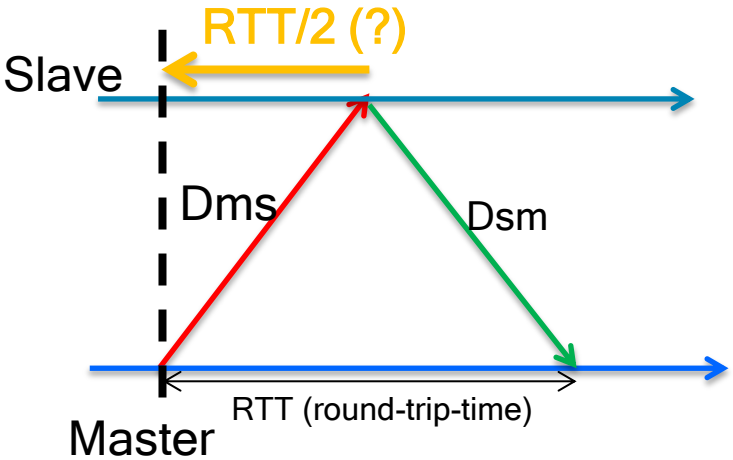
[Dierikx et al. http://dx.doi.org/10.1109/TUFFC.2016.2518122]

10.4 ms RTT ☺

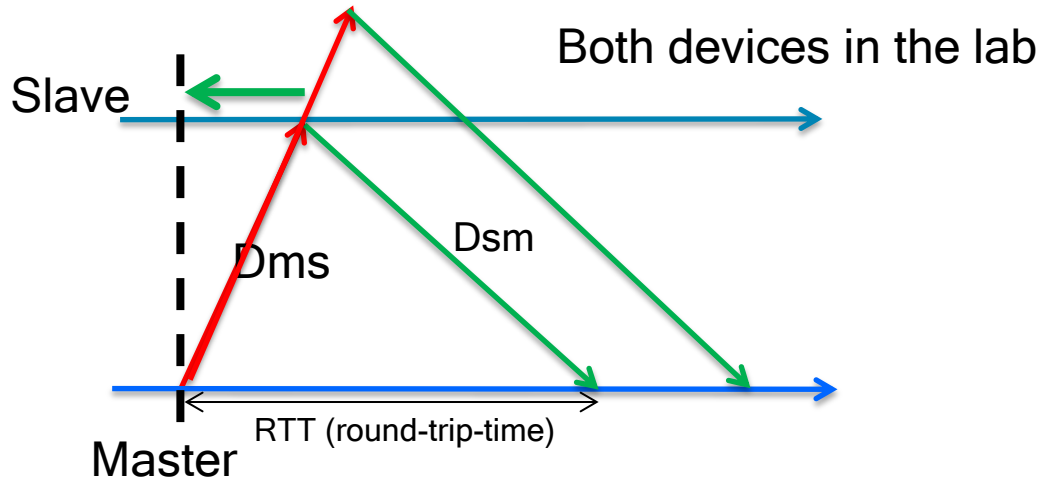
```
WR PTP Core Sync Monitor v 1.0
Esc = exit

TAI Time:                    Fri, Aug 16, 2013, 13:55:37

wru1: Link up   (RX: 4290, TX: 1916), mode: WR Slave   Locked  Calibrated

Synchronization status:

Servo state:                 TRACK_PHASE
Phase tracking:              ON
Synchronization source:      wru1
Aux clock status:            0:disabled

Timing parameters:

Round-trip time (mu):      10445954558 ps
Master-slave delay:        5223650621 ps
Master PHY delays:         TX: 0 ps, RX: 175200 ps
Slave PHY delays:          TX: 46407 ps, RX: 169443 ps
Total link asymmetry:      -1346684 ps
Cable rtt delay:           10445563508 ps
Clock offset:                      0 ps
Phase setpoint:                  235 ps
Skew:                             -4 ps
Manual phase adjustment:           0 ps
Update counter:                  943
--
```

Fiber asymmetry

Remember the Dutch wheel !



http://www.ohwr.org/documents/213



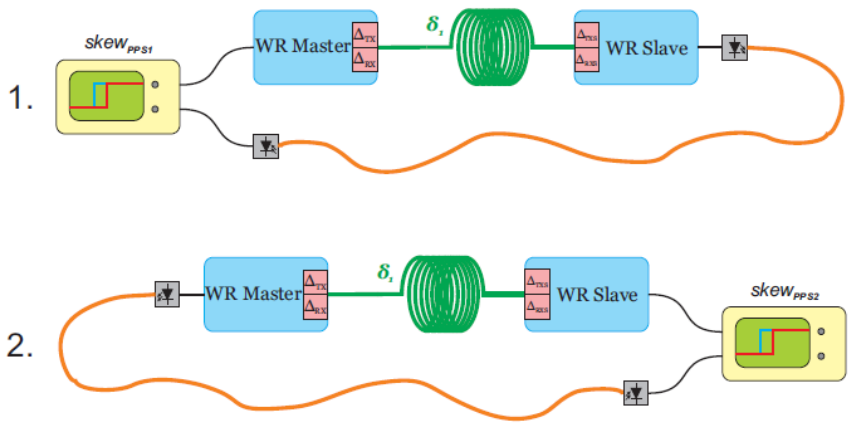


Figure 6: Measuring 1-PPS offset using a loop-back fiber

Alternatives:

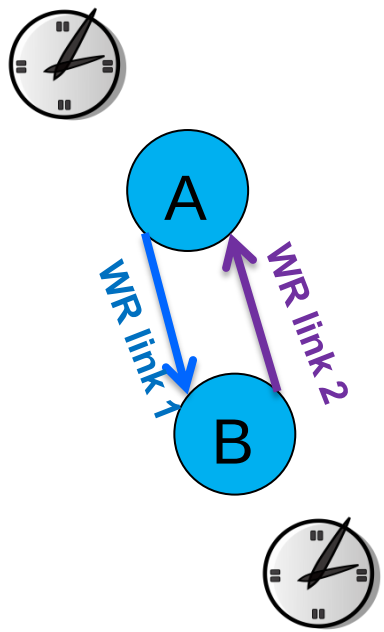
- Transportable clock
- Parallel verification by e.g. GPS-PPP
- Other?

Calibrating an unknown asymmetric link:

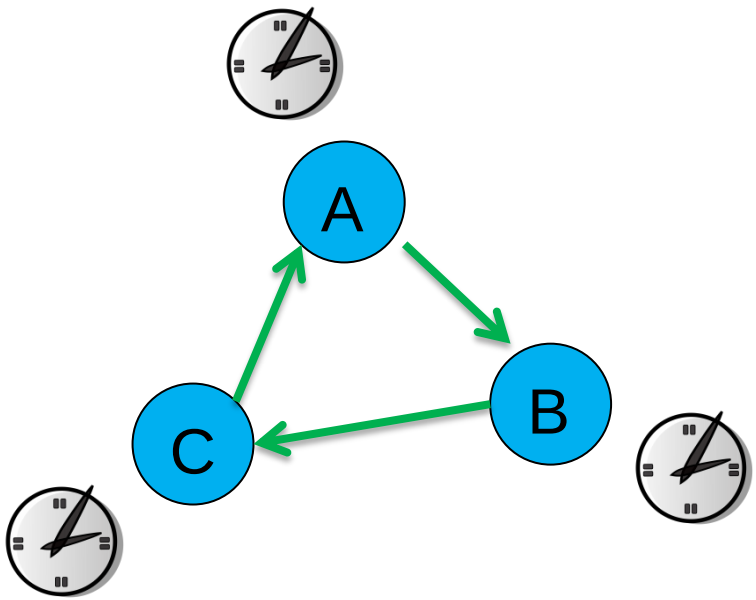
"Let's first assume we have a parallel symmetric link"…!?!

Things that don't work… ☹

Two way?



Triangle closure?

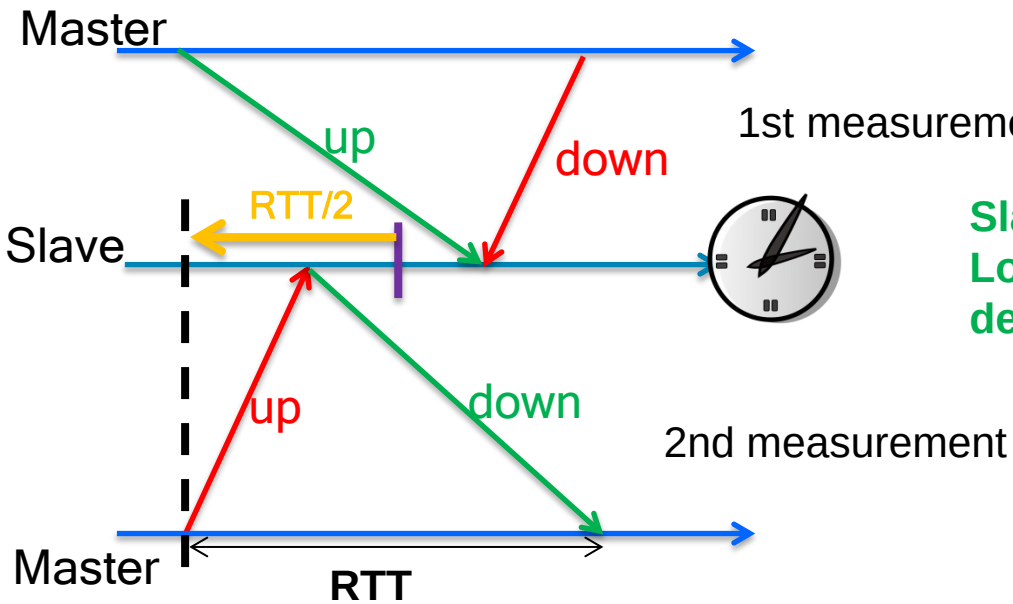


With local measurements Nodes A and B cannot agree on offset btw. Local clocks if link asymmetry Is unknown…

Local measurements only give total error around loop…

[Freris 2011] !?

Fiber or Wavelength Swap! (swap the thing that is causing asymmetry in Tx/Rx)



Slave does two measurements against Local clock -> fiber asymmetry can be determined. [Huang 2013, China Mobile]

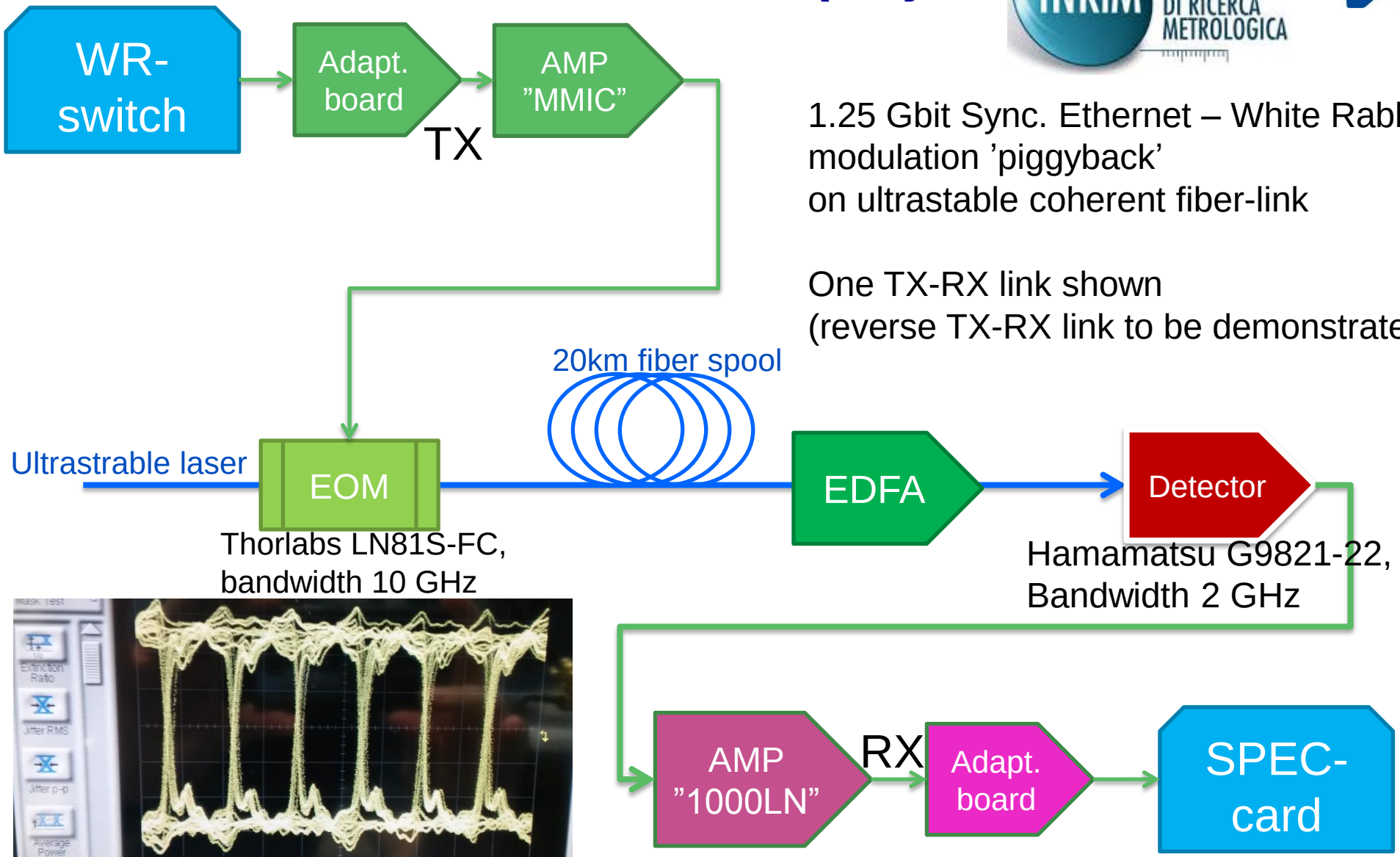
Virtual alpha=zero point At mean of measurements

Bidir links: swap Tx/Rx wavelengths

Duplex links (without amplifiers): swap fibers

or perhaps use tuneable lasers…

White Rabbit in the DEMETRA project

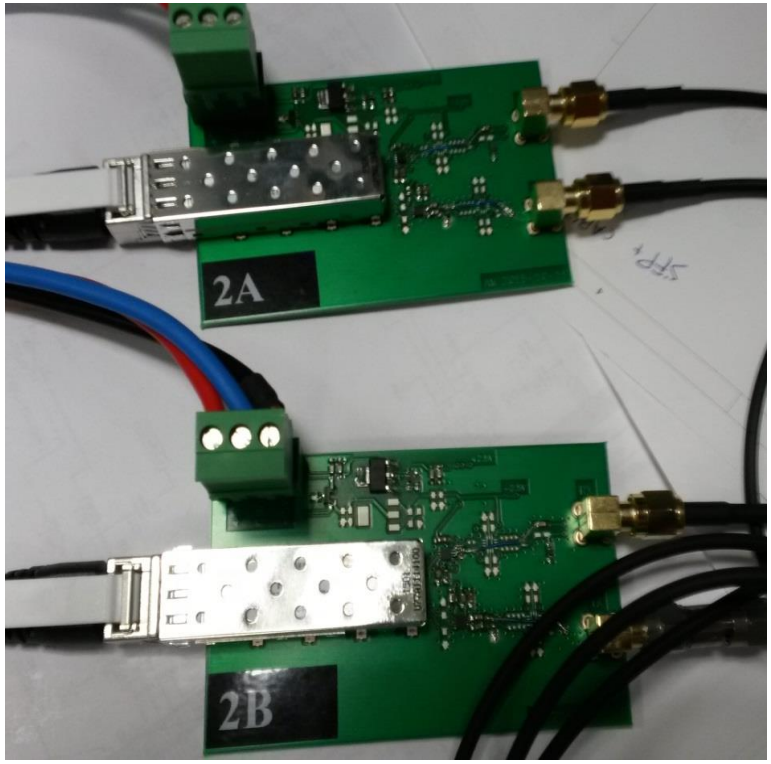


1.25 Gbit Sync. Ethernet – White Rabbit modulation 'piggyback' on ultrastable coherent fiber-link

One TX-RX link shown (reverse TX-RX link to be demonstrated)

White Rabbit in the DEMETRA project

SFP to SMA adaptor board

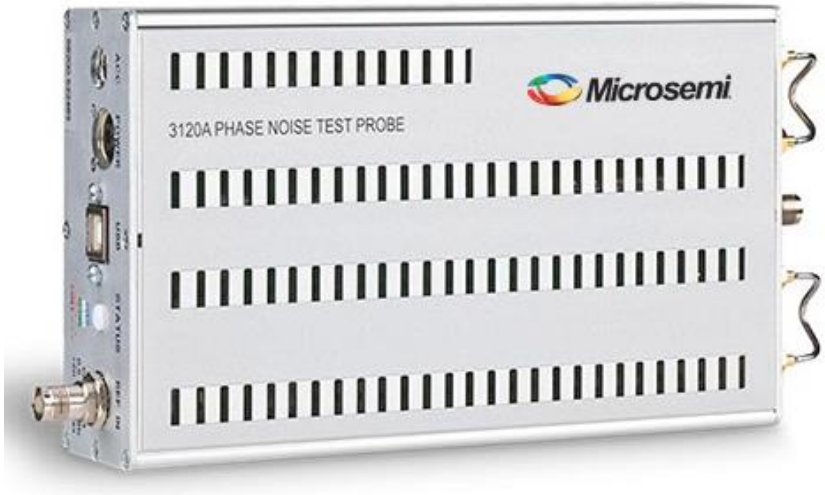


SFP -> SMA(TX), SMA(RX)
using Micrel SY58601U buffer

- Coherent frequency transfer
  + White Rabbit time transfer
- TX+RX in one 100 GHz channel
- Fiber asymmetry ”alpha” zero
  or very small – or perhaps measure
  it by tuning laser?

Stability of WR Switch

Microsemi 3120A DDMTD

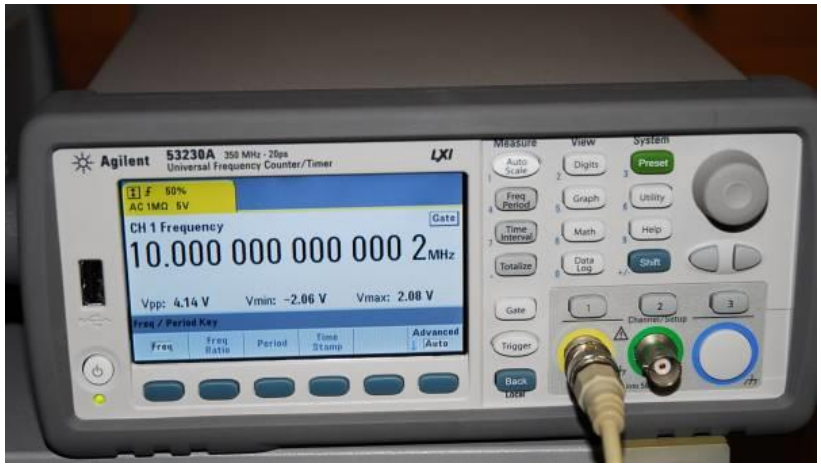


REF, DUT inputs 0.5-30 MHz

ADEV(1s) ~ few * 1e-14

or use WR-switch as phase-meter ☺ ?

53230A (or your favourite counter)

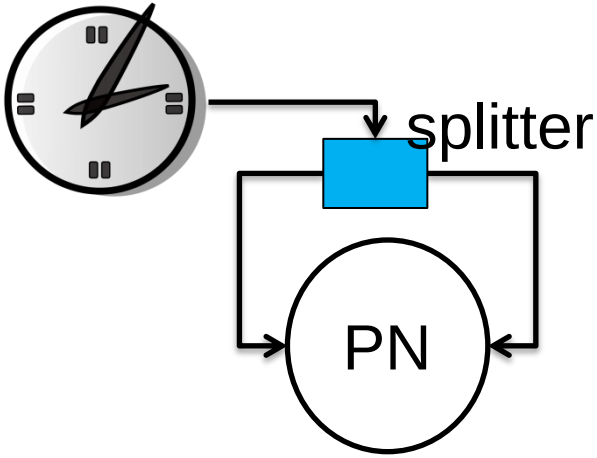


ADEV(1s) ~ few * 1e-11

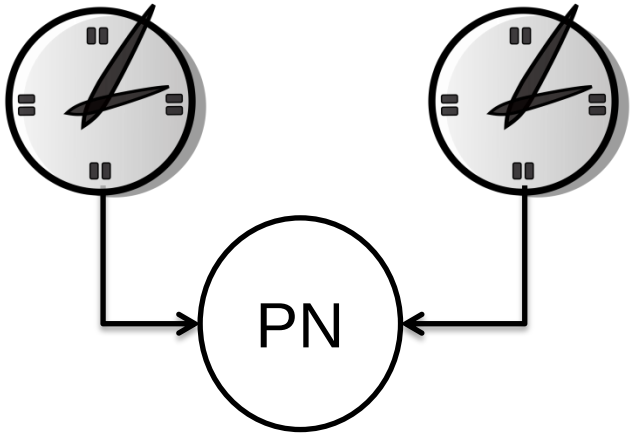
(~9 ps RMS single-shot time stamping)

Latest generation WR-switch 1-PPS stability is at
the same level as time-interval-counter noise (3km, 6km, 9km fibers tested)
need for DMTD or other high resolution measurement on 10 MHz output

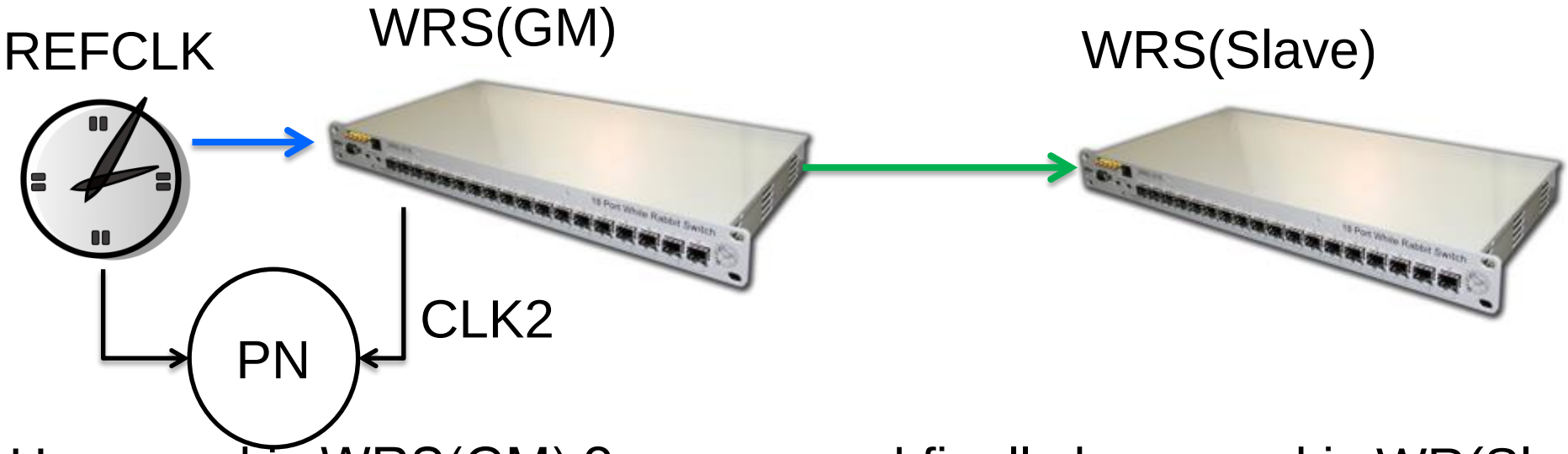
Stability measurement on White Rabbit Switch



How good is my PN-probe?



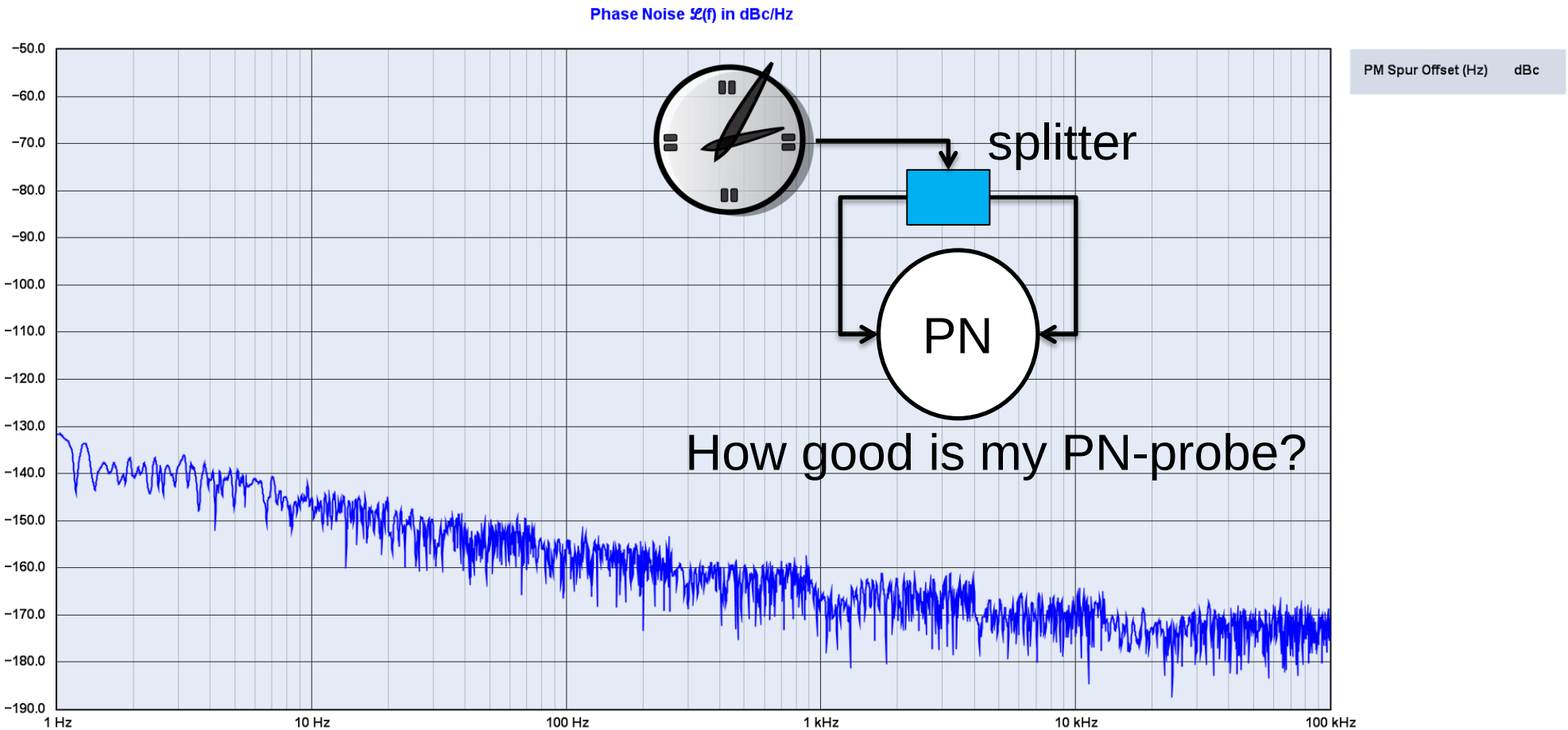
How good are my clocks?



How good is WRS(GM) ?

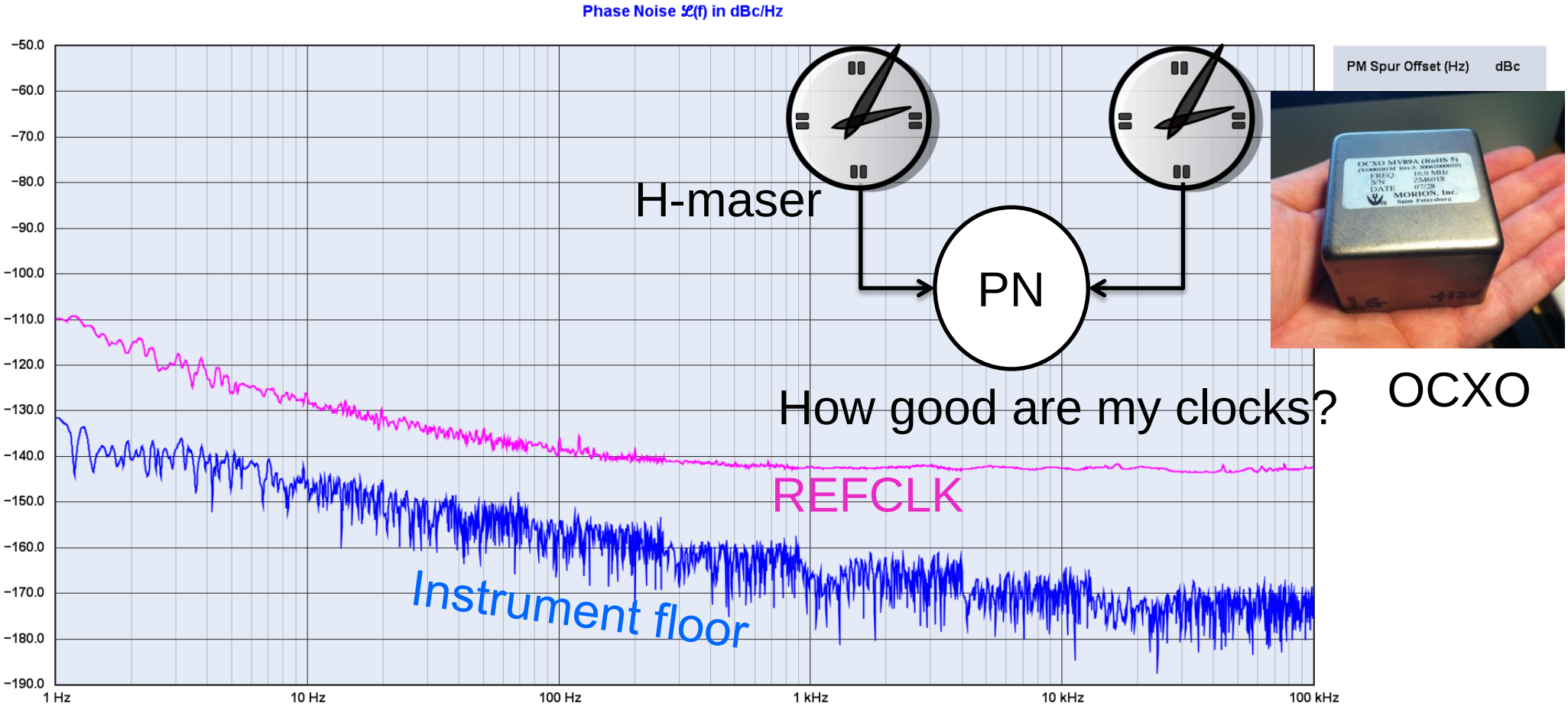
… and finally how good is WR(Slave)?

PN instrument floor



Trace	Notes	DUT Freq	Input Freq	Input Amplitude	Ref Freq	Ref Amplitude	Duration	Acquired	Time/Date	Instrument
3120A noise floor at 10 MHz	AHM3 10MHz thru ZFSC-2-1+	10.000 MHz	10.000 MHz	7.7 dBm	10.000 MHz	7.8 dBm	5m 0s	30000 pts	28.9.2015 14:20:38	Symmetricom 3120A

Clocks (~good)

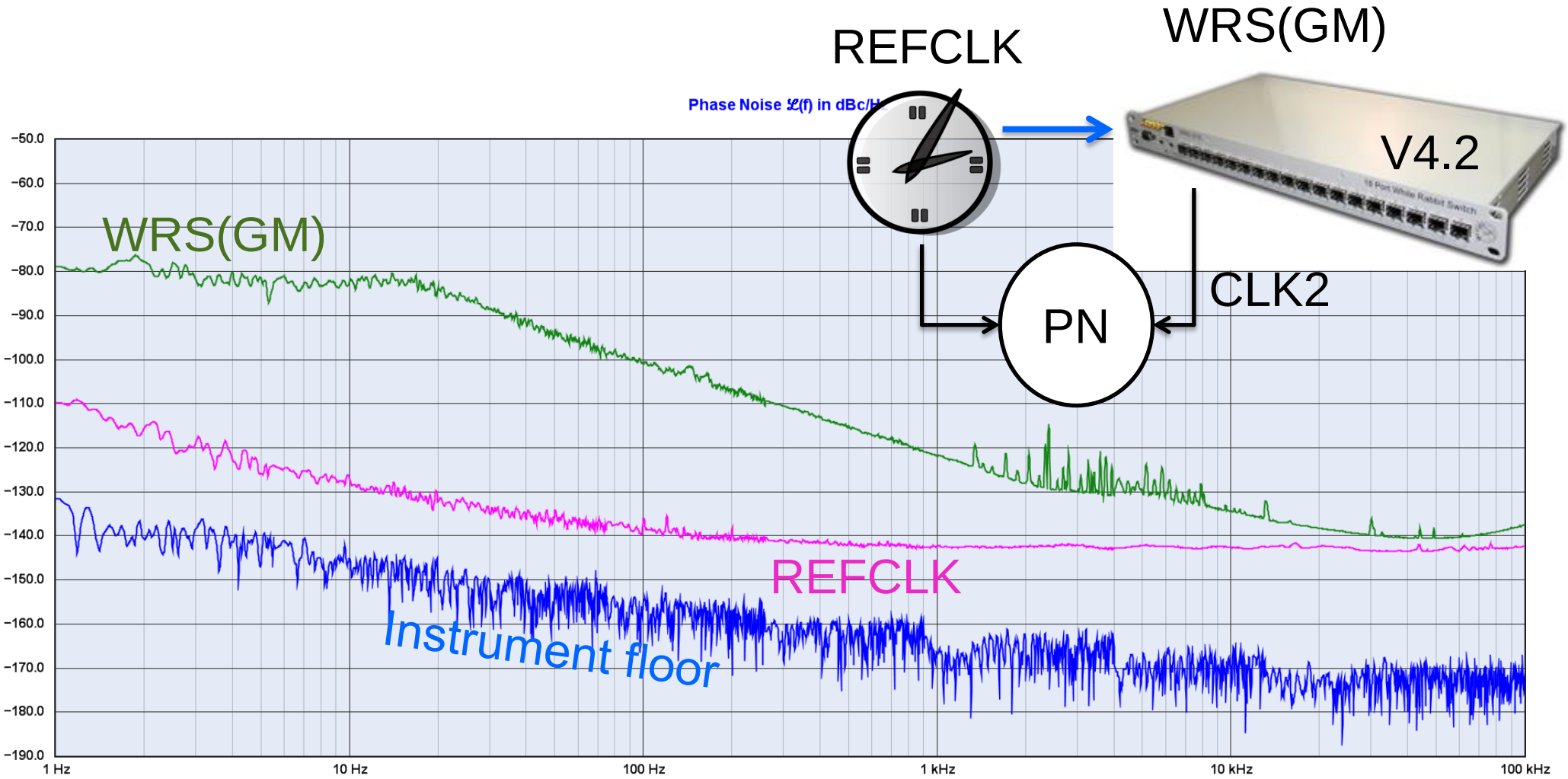


Trace	Notes	DUT Freq	Input Freq	Input Amplitude	Ref Freq	Ref Amplitude	Duration	Acquired	Time/Date	Instrument
3120A noise floor at 10 MHz	AHM3 10MHz thru ZFSC-2-1+	10.000 MHz	10.000 MHz	7.7 dBm	10.000 MHz	7.8 dBm	5m 0s	30000 pts	28.9.2015 14:20:38	Symmetricom 3120A
Morion MV89A "A"	REF=AHM3	10.000 MHz	10.000 MHz	8.5 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 16:20:01	Symmetricom 3120A

Note 1: use a good (measured) distribution amplifier

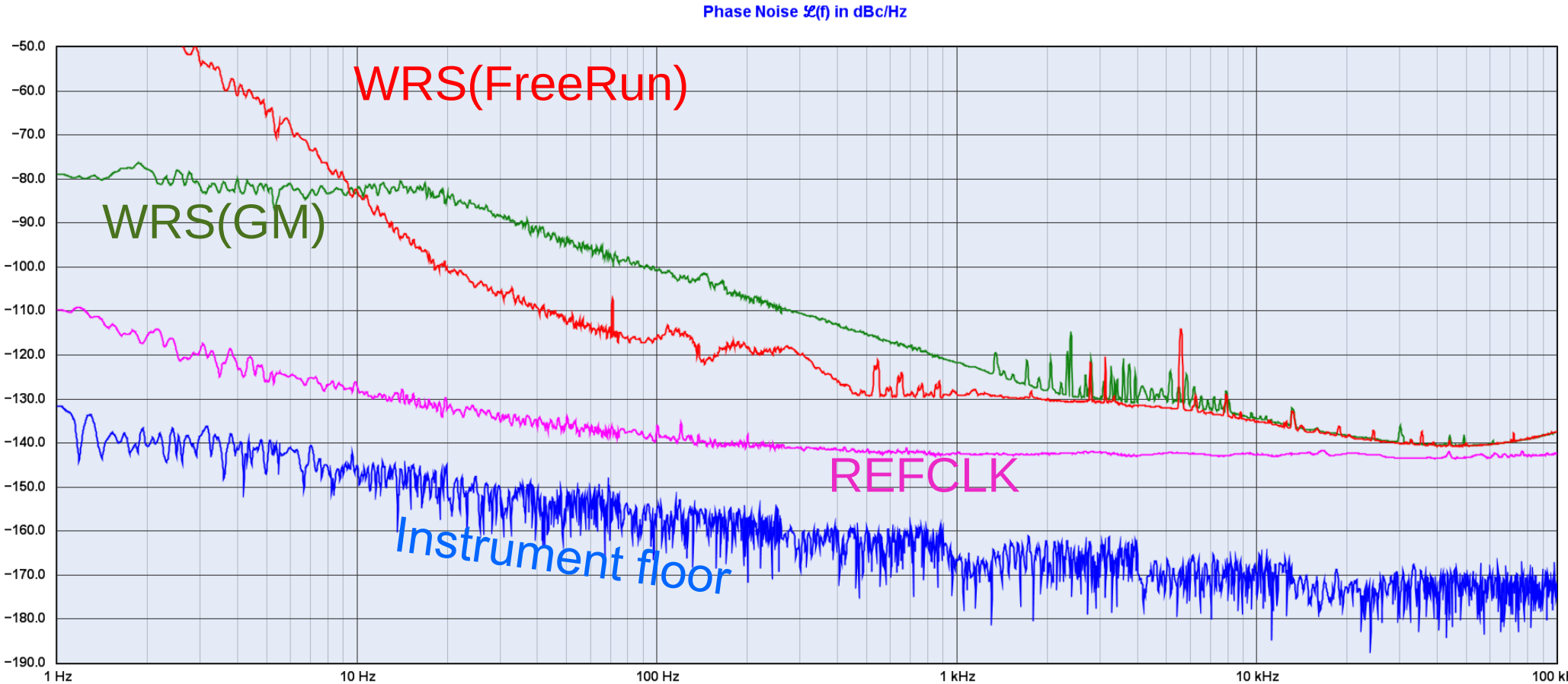
Note 2: no need for H-maser to work on PN, just need good OCXO (50eur/ebay)

WRS(GM) Phase Noise



Trace	Notes	DUT Freq	Input Freq	Input Amplitude	Ref Freq	Ref Amplitude	Duration	Acquired	Time/Date	Instrument
3120A noise floor at 10 MHz	AHM3 10MHz thru ZFSC-2-1+	10.000 MHz	10.000 MHz	7.7 dBm	10.000 MHz	7.8 dBm	5m 0s	30000 pts	28.9.2015 14:20:38	Symmetricom 3120A
Morion MV89A "A"	REF=AHM3	10.000 MHz	10.000 MHz	8.5 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 16:20:01	Symmetricom 3120A
WRS GM (AHM3)	REF=AHM3	10.000 MHz	10.000 MHz	15.1 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 16:29:00	Symmetricom 3120A

And also free running…



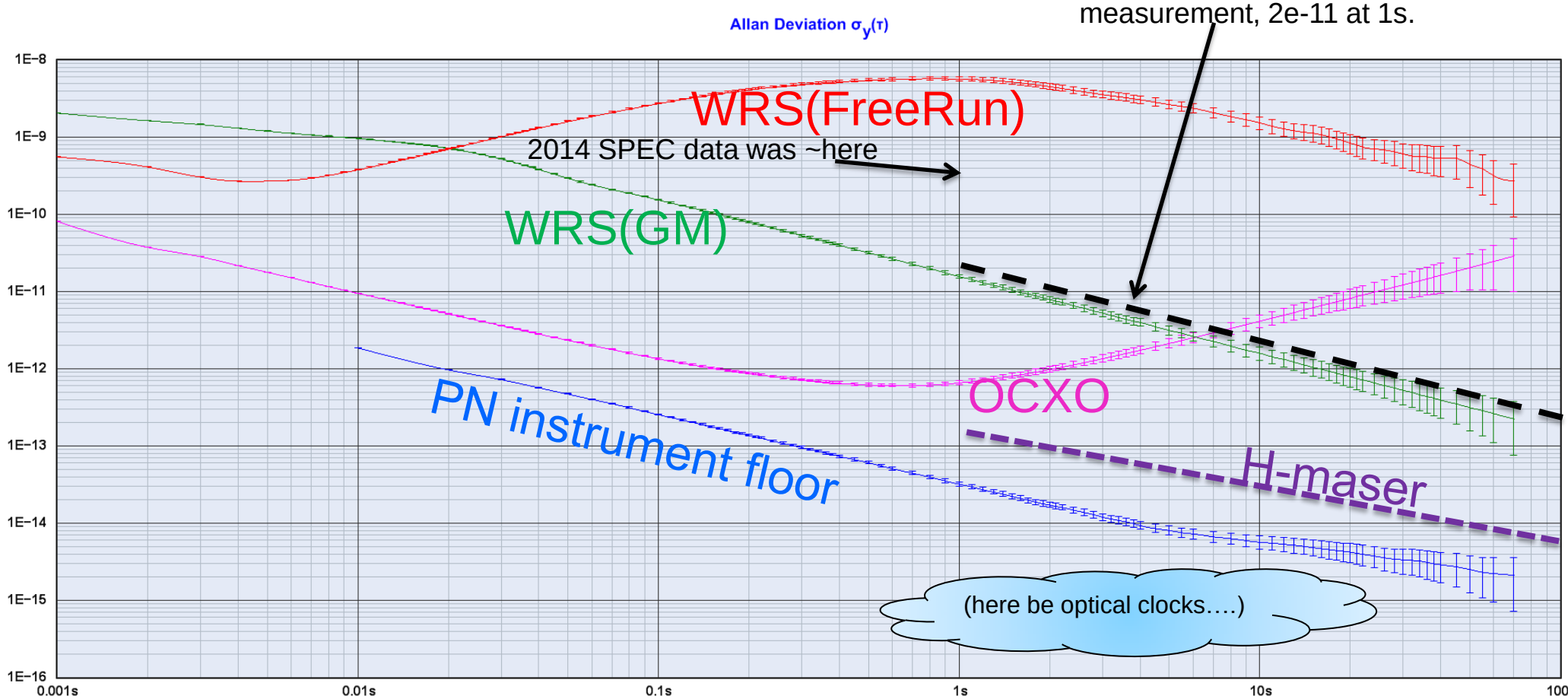
Trace	Notes	DUT Freq	Input Freq	Input Amplitude	Ref Freq	Ref Amplitude	Duration	Acquired	Time/Date	Instrument
3120A noise floor at 10 MHz	AHM3 10MHz thru ZFSC-2-1+	10.000 MHz	10.000 MHz	7.7 dBm	10.000 MHz	7.8 dBm	5m 0s	30000 pts	28.9.2015 14:20:38	Symmetricom 3120A
Morion MV89A "A"	REF=AHM3	10.000 MHz	10.000 MHz	8.5 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 16:20:01	Symmetricom 3120A
WRS GM (AHM3)	REF=AHM3	10.000 MHz	10.000 MHz	15.1 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 16:29:00	Symmetricom 3120A
WRS FreeRun	REF=AHM3	10.000 MHz	10.000 MHz	15.1 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 16:34:46	Symmetricom 3120A

A better PLL should not be that hard?!

”DDS-box” based on Analog Devices dev-kits

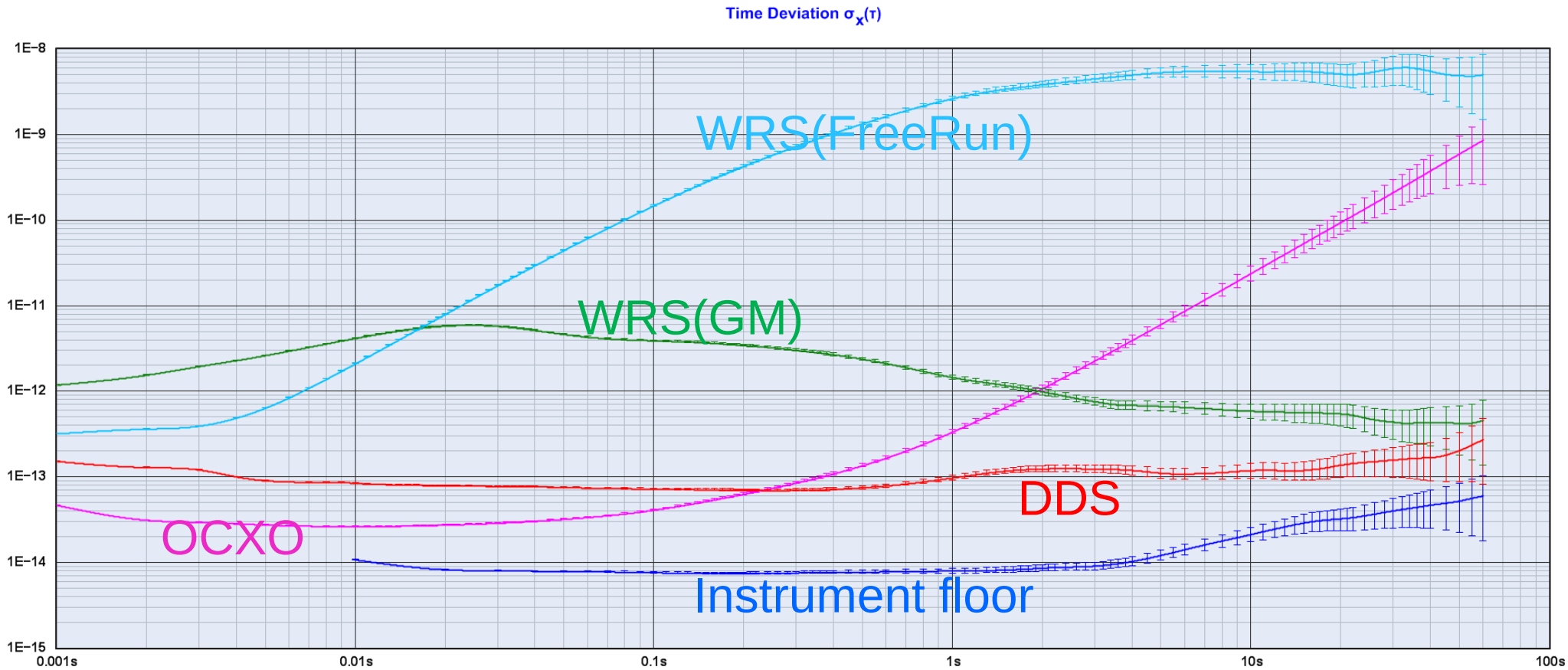
Trace	Notes	DUT Freq	Input Freq	Input Amplitude	Ref Freq	Ref Amplitude	Duration	Acquired	Time/Date	Instrument
3120A noise floor at 10 MHz	AHM3 10MHz thru ZFSC-2-1+	10.000 MHz	10.000 MHz	7.7 dBm	10.000 MHz	7.8 dBm	5m 0s	30000 pts	28.9.2015 14:20:38	Symmetricom 3120A
Morion MV89A "A"	REF=AHM3	10.000 MHz	10.000 MHz	8.5 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 16:20:01	Symmetricom 3120A
WRS GM (AHM3)	REF=AHM3	10.000 MHz	10.000 MHz	15.1 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 16:29:00	Symmetricom 3120A
DDS	REF=AHM3	10.100 MHz	10.100 MHz	−3.7 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 17:07:37	Symmetricom 3120A

Same data as ADEV plot



Trace	Notes	DUT Freq	Input Freq	Input Amplitude	Ref Freq	Ref Amplitude	Duration	Acquired	Time/Date	Instrument
3120A noise floor at 10 MHz	AHM3 10MHz thru ZFSC-2-1+	10.000 MHz	10.000 MHz	7.7 dBm	10.000 MHz	7.8 dBm	5m 0s	30000 pts	28.9.2015 14:20:38	Symmetricom 3120A
Morion MV89A "A"	REF=AHM3	10.000 MHz	10.000 MHz	8.5 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 16:20:01	Symmetricom 3120A
WRS GM (AHM3)	REF=AHM3	10.000 MHz	10.000 MHz	15.1 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 16:29:00	Symmetricom 3120A
WRS FreeRun	REF=AHM3	10.000 MHz	10.000 MHz	15.1 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 16:34:46	Symmetricom 3120A

And TDEV…



Trace	Notes	DUT Freq	Input Freq	Input Amplitude	Ref Freq	Ref Amplitude	Duration	Acquired	Time/Date	Instrument
3120A noise floor at 10 MHz	AHM3 10MHz thru ZFSC-2-1+	10.000 MHz	10.000 MHz	7.7 dBm	10.000 MHz	7.8 dBm	5m 0s	30000 pts	28.9.2015 14:20:38	Symmetricom 3120A
Morion MV89A "A"	REF=AHM3	10.000 MHz	10.000 MHz	8.5 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 16:20:01	Symmetricom 3120A
WRS GM (AHM3)	REF=AHM3	10.000 MHz	10.000 MHz	15.1 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 16:29:00	Symmetricom 3120A
DDS	REF=AHM3	10.100 MHz	10.100 MHz	−3.7 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 17:07:37	Symmetricom 3120A
WRS FreeRun	REF=AHM3	10.000 MHz	10.000 MHz	15.1 dBm	10.000 MHz	11.1 dBm	5m 0s	300000 pts	12.3.2016 16:34:46	Symmetricom 3120A

Other White Rabbit activities

- Time-stamping with FDEL in ’raw’ mode (~100 kStamps/s)
  - https://www.youtube.com/watch?v=g6EF8wWnuaY
  - Photon-correlation test with modulated LED (ZeroMQ+ProtoBuf) https://www.youtube.com/watch?v=lwY1PO4m7gE
- Trusted time source for Time Stamp Authority (TSA) following ITU-R TF.1876 (Finnish TSA = Population Register Centre)
- Tests with Finnish Defence Forces
- Pilot study with Nordic energy industry
  - Synchronization of PMUs
- Metsähovi radio-astronomy observatory
- Interfacing WR with PTPv2 hardware (TAI vs. UTC issues reported 2015/12)

Thank You!

Open-source time & frequency stuff:

- https://github.com/aewallin/allantools/
  python library for Stable32-like statistics: ADEV, MDEV TDEV, etc.
- https://github.com/aewallin/ppp-tools
  helper scripts for GPS Precise Point Positioning (NRCAN gpsppp, ESA gLAB, rtklib, GPSTk?)