White Rabbit

Sub-Nanosecond timing over Ethernet

"Oh dear! Oh dear!
I shall be too late!" [1)]

[1)] Alice in Wonderland, Lewis Carroll (1865)

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H.Z. Peek ...

... on behalf of the White Rabbit collaboration

Outline

- What is White Rabbit
- Network
- Building blocks
- Measurement results
- Applications
- Conclusion

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What is White Rabbit

- Networking and timing
- Based on well-known technologies / standards
- Open Hardware and Open Software
- International collaboration
- Main features:
  - Transparent, **high-accuracy** time distribution,
  - Low-latency, **deterministic** data delivery,
  - Designed for **high reliability**,
  - Plug & play.

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Timing over Ethernet History

- 1985

  NTP (RFC 1305) sub **milli**-second
- 2002

  PTP (IEEE 1588) sub **micro**-second
- 2012

  White Rabbit (?) sub **nano**-second

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White Rabbit timing distribution

- Synchronization with **sub-ns** accuracy over fiber
- A combination of:
  - Synchronous Ethernet (**SyncE**) syntonization
  - Digital Dual-Mixer Time Difference (**DDMTD**) phase detection (φ)
  - Precision Timing Protocol (**PTP**) synchronization

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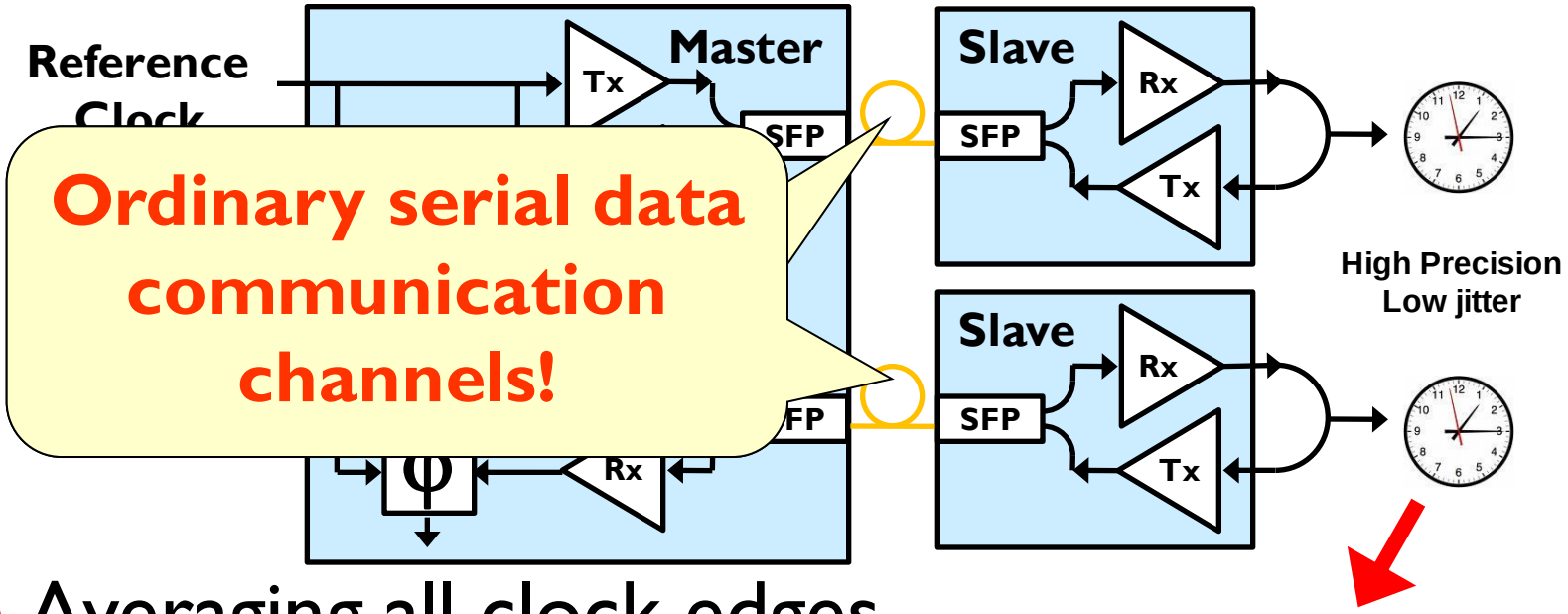
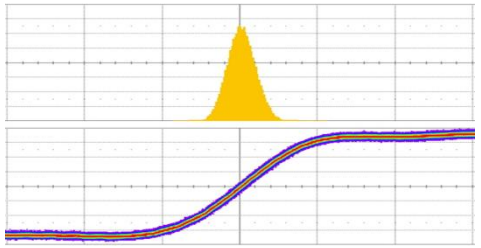
Timing distribution



- Averaging all clock edges
  - "mean phase"
- Syntonization
  - "The adjustment of two electronic circuits or devices in terms of frequency"



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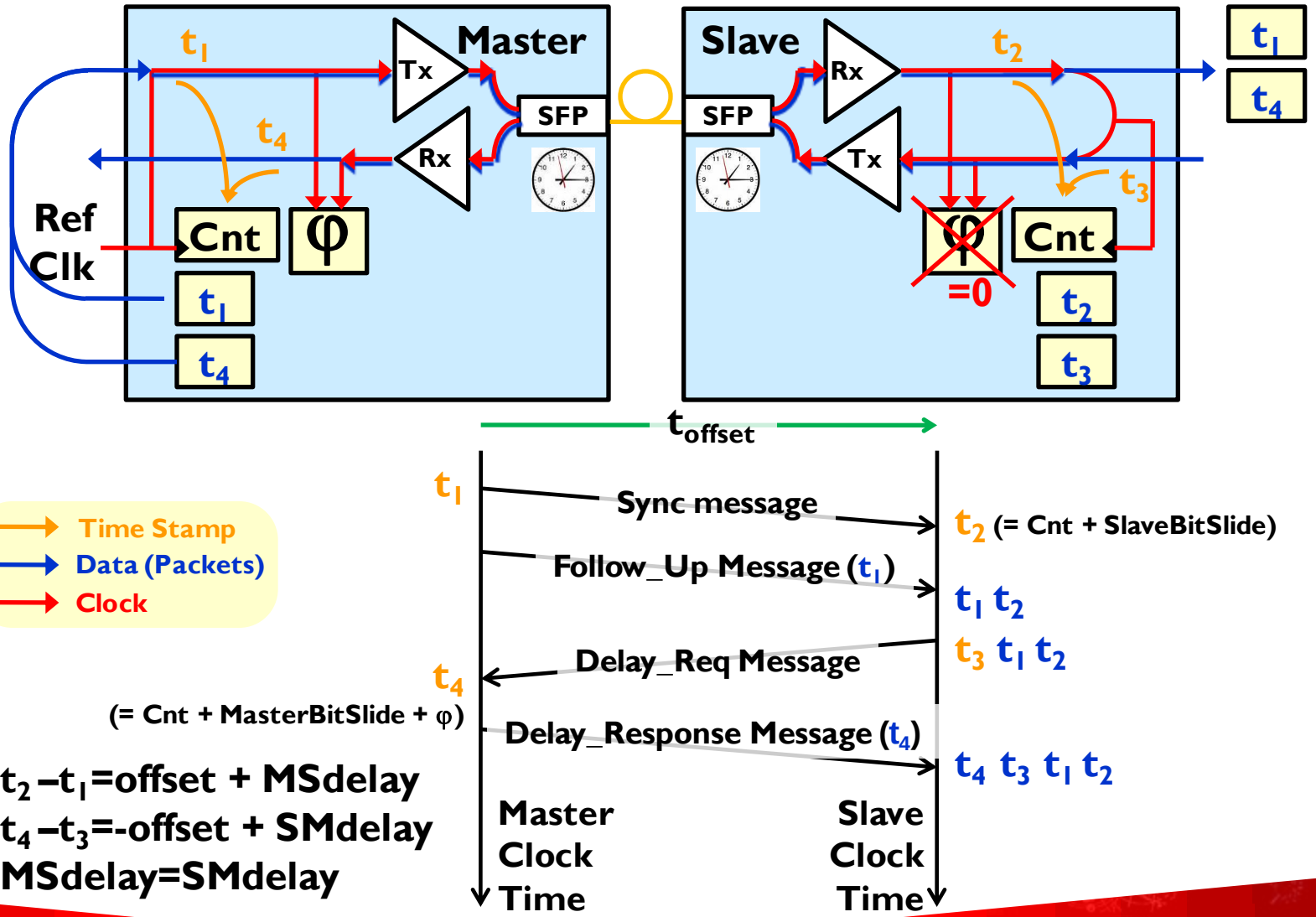
PTP (IEEE1588)



1. $t_2 - t_1$ = offset + MSdelay
2. $t_4 - t_3$ = -offset + SMdelay
3. MSdelay = SMdelay

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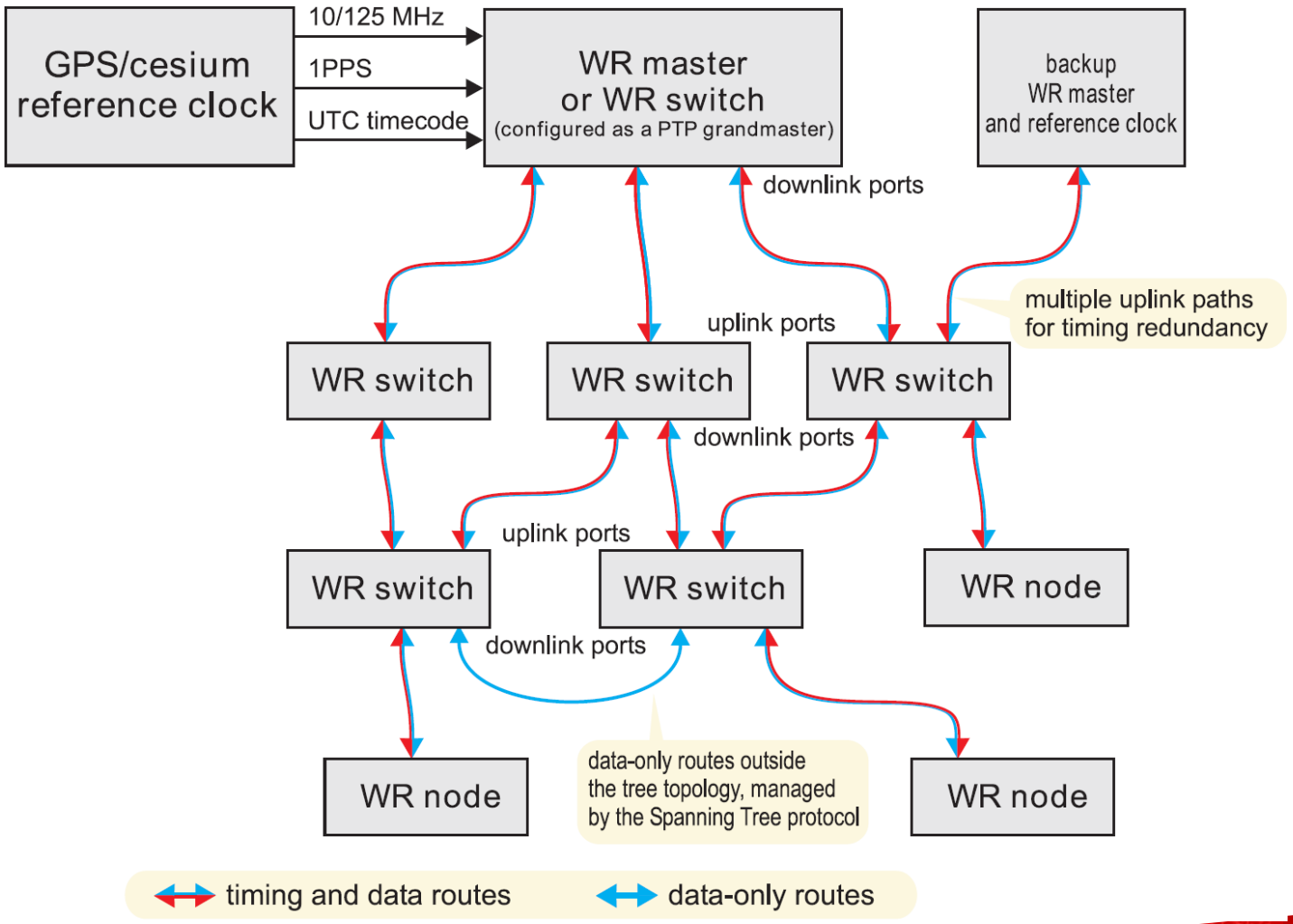
White Rabbit network



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White Rabbit Switch V2

- Central element of White Rabbit network
- Fully custom design, designed from scratch
- 10 SFP ports (1000Base-LX)
- Capable of driving long distance Single Mode fiber

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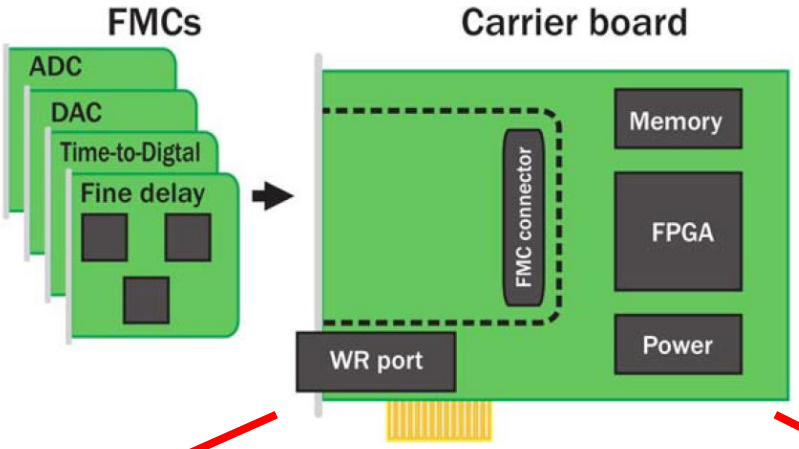
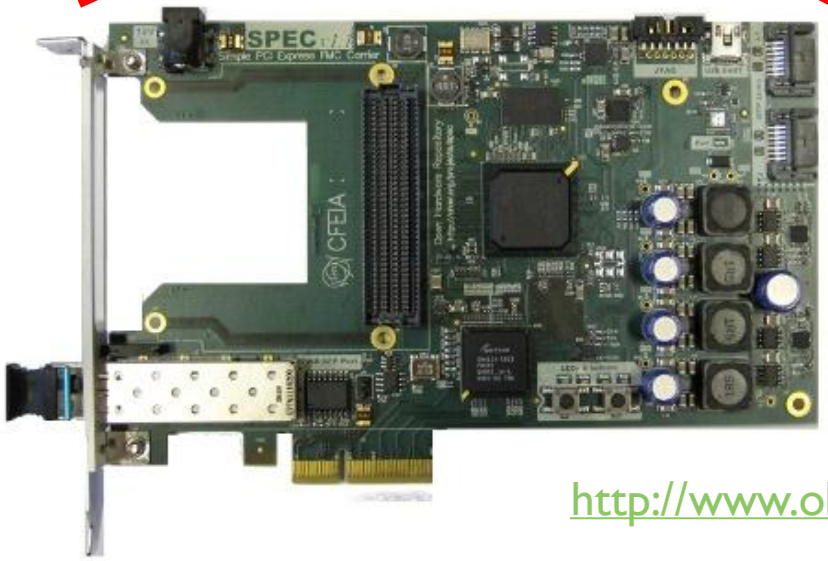
White Rabbit Node



- Simple PCIe FMC Carrier (SPEC)
- Currently available



http://www.ohwr.org/projects/spec/wiki

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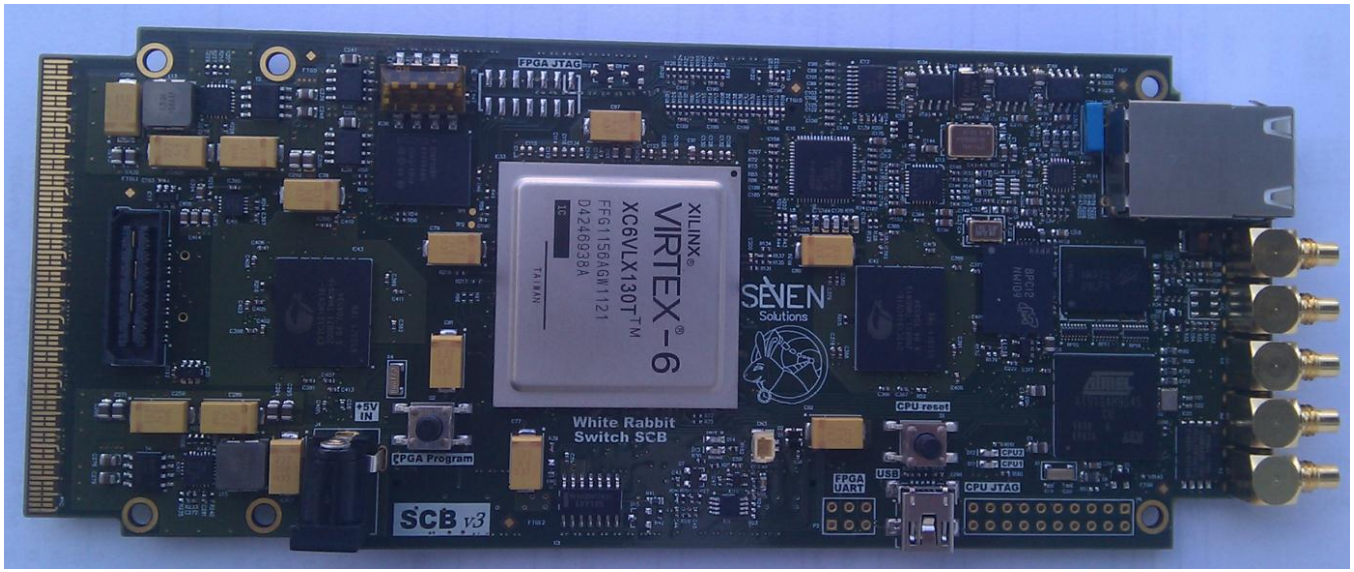
White Rabbit Switch V3



- 2 uplink ports, 16 downlink ports
- Hardware just assembled.
- Hardware & Software currently being tested.
- Production expected Q1-2012

http://www.ohwr.org/attachments/741/White_Rabbit_Technical_Spec_05.pdf

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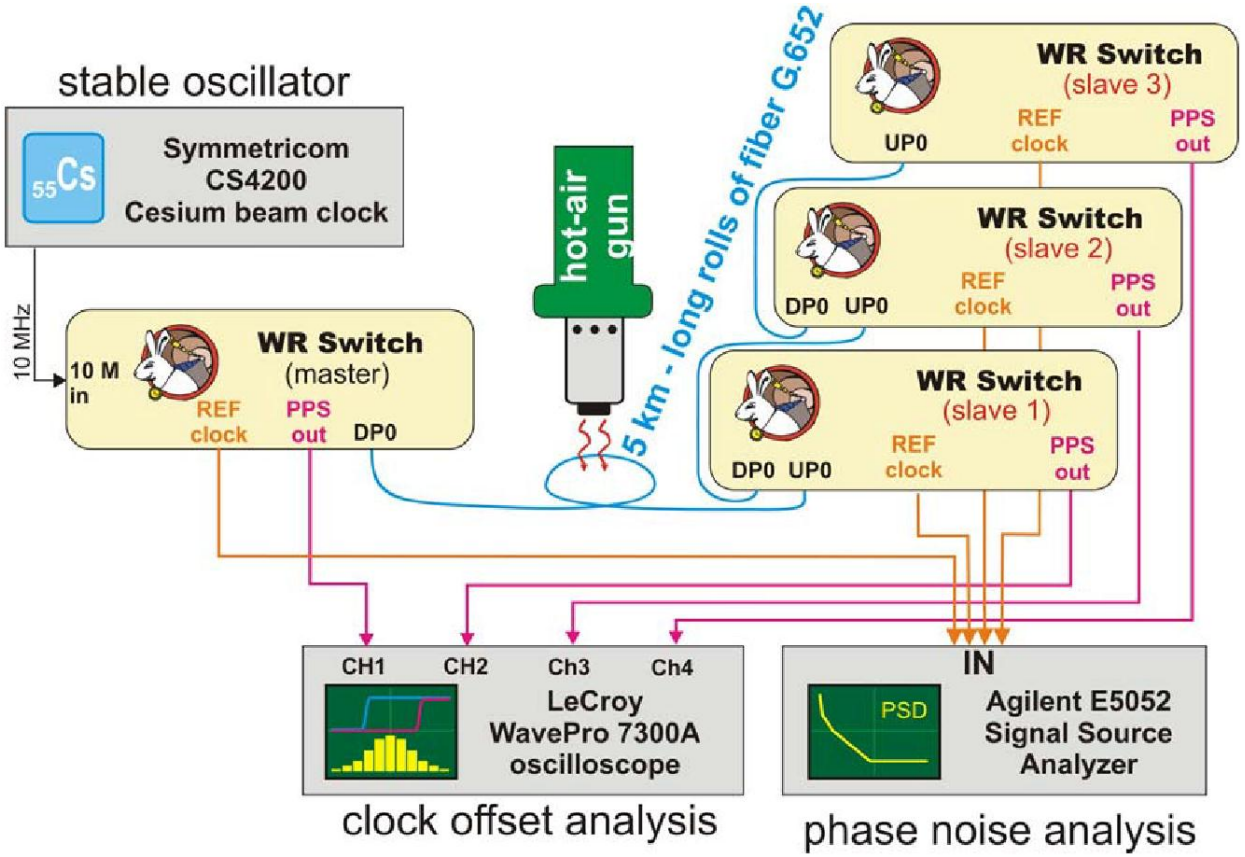
Measurement test setup



Hot-air gun demo:

http://www.youtube.com/watch?v=ZSRQEExbdq8

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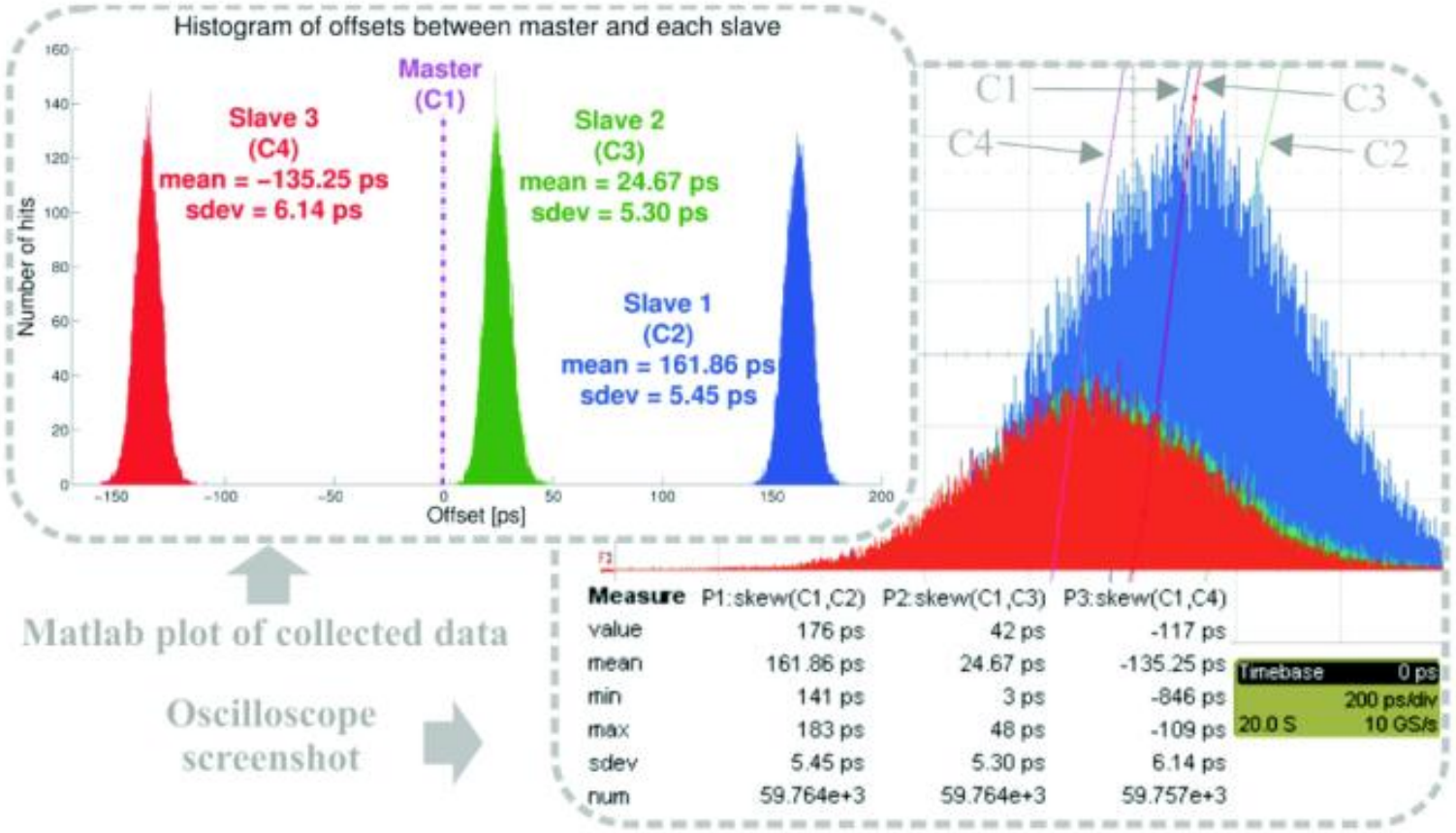
Measurement results



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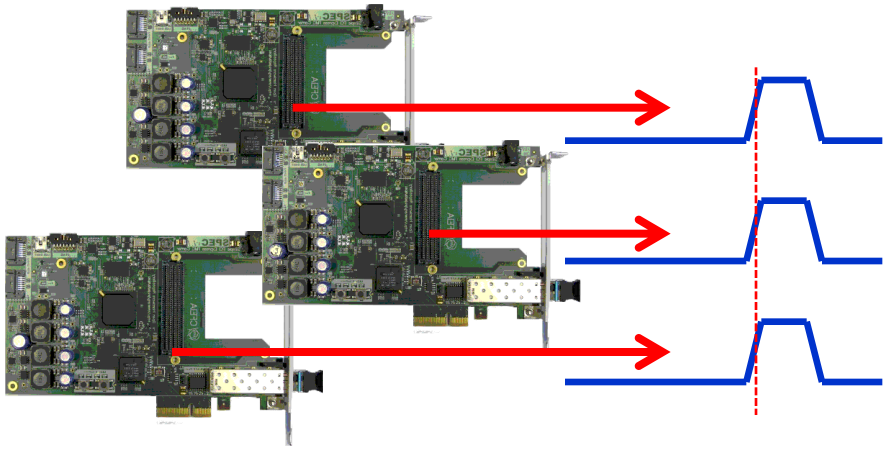
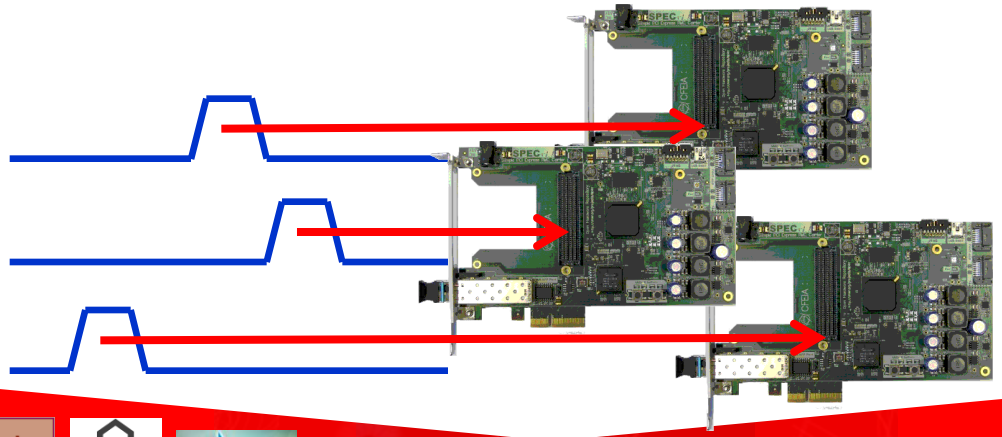
Applications

- Digital to Time Converter (DTC) = Alarm Clock



- Time to Digital Converter (TDC) = Time stamping



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Conclusions

- White Rabbit enables measurement and control applications which are using distributed system technologies.
- Such applications may be spread over large distances.
- Data transmission delay changes are continuously measured and compensated.
- System timing of White Rabbit nodes are synchronized with high precision.

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White Rabbit

a multi-laboratory, multi-company effort

Coming Soon!

Thank you

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How do we know the time offset between Master and Slave?

- T_{offset} = Total delay$_{(Master>Slave>Master)}$ / 2
- Can we measure propagation delay using existing serial communication channels?

Serial Communication Coding Properties:

1. Clock & Data coded into one stream
2. DC-Balance
3. Special code-groups / Word Alignment

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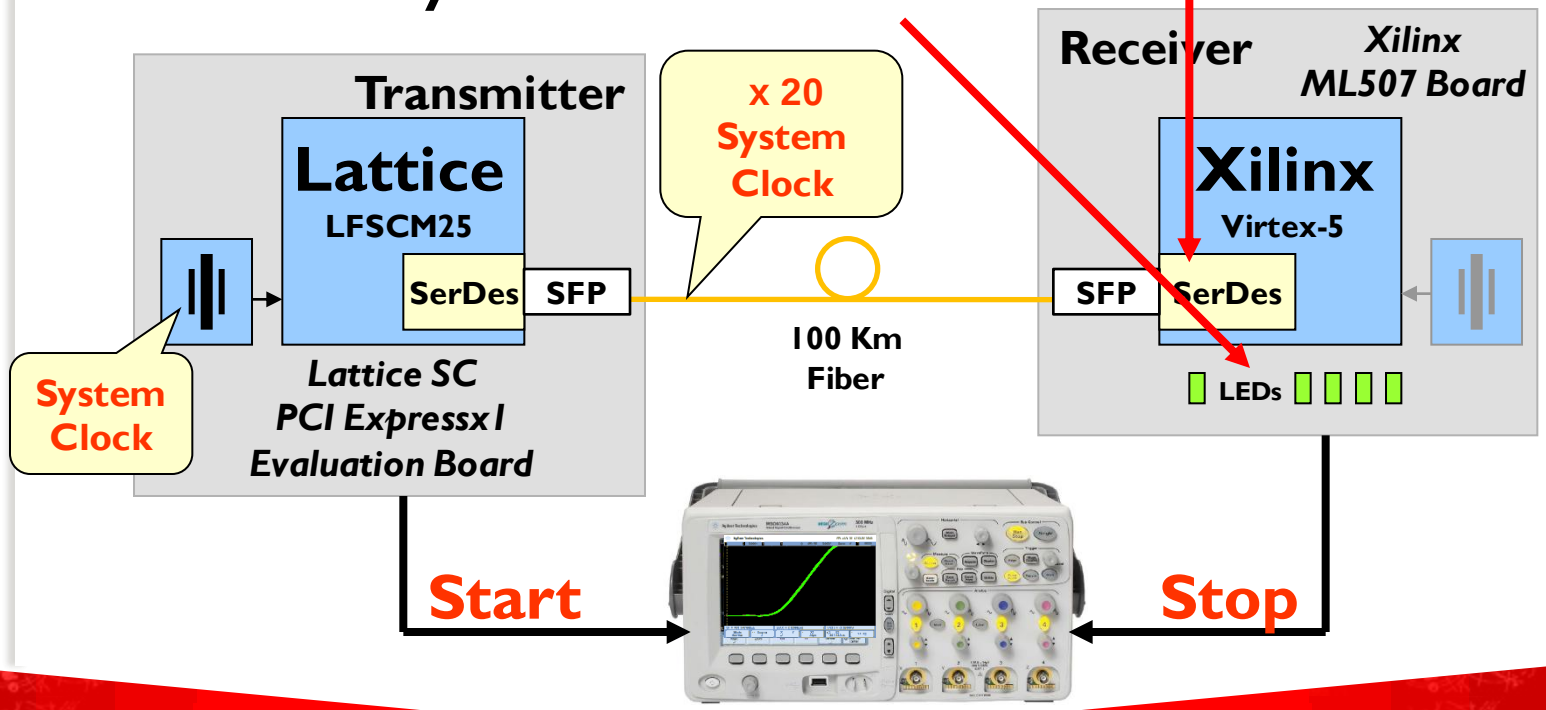
Measure propagation delay using FPGA SerDes technology

1. Regenerate system clock at the receiver
3. Using a barrel shifter for word alignment

⇨ delay known with bit clock resolution



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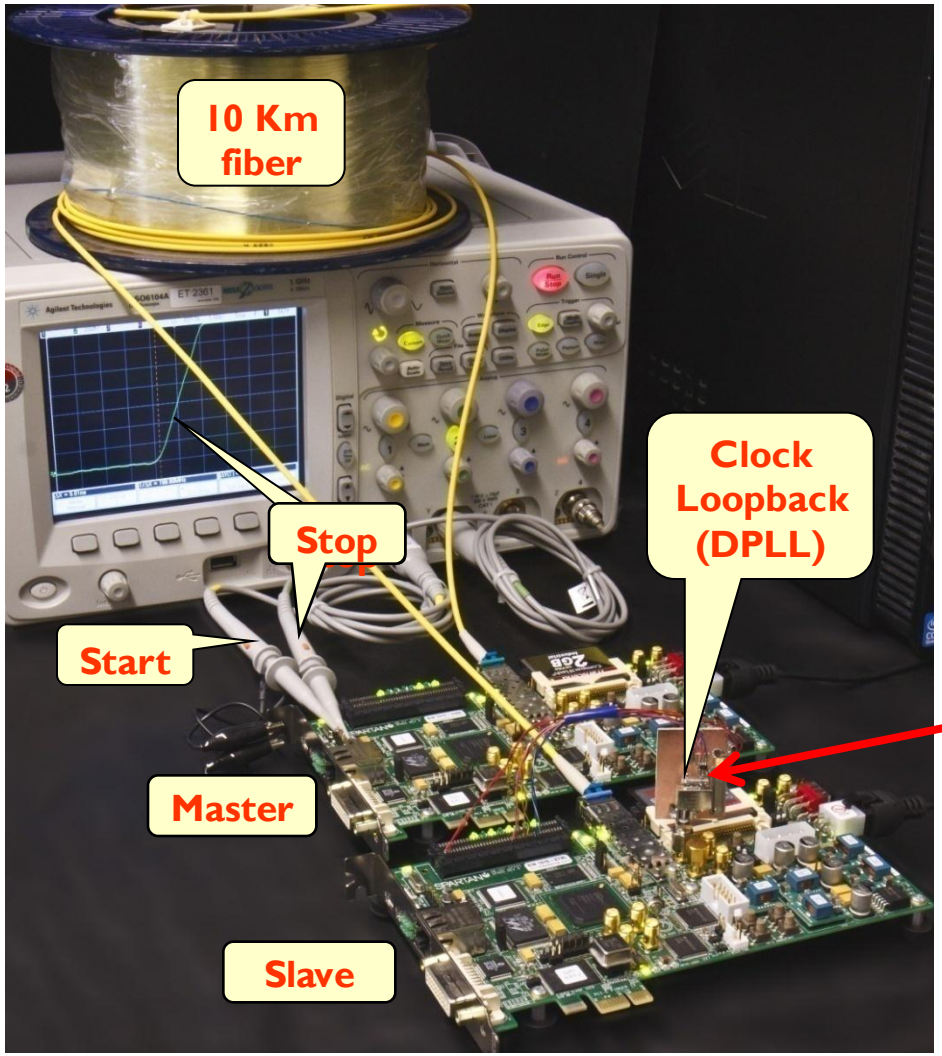
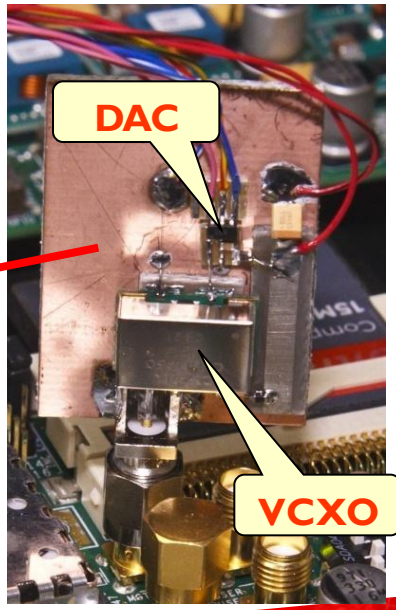
Time offset measurement test setup



Loopback the recovered clock with a Voltage Controled Xtal Oscillator



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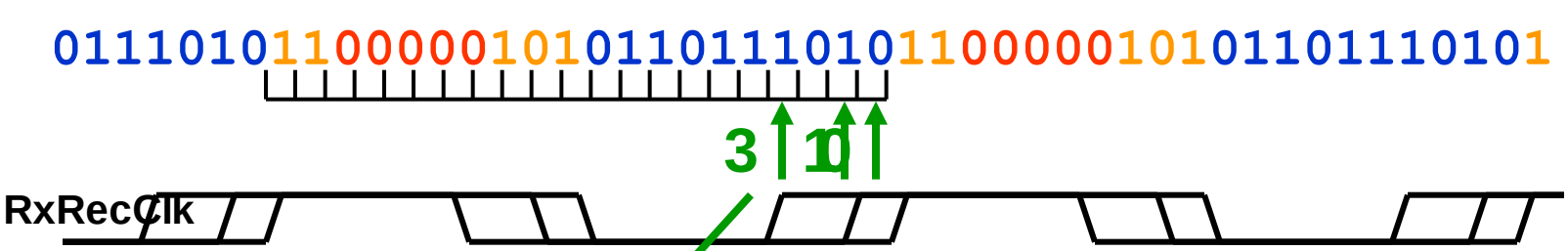
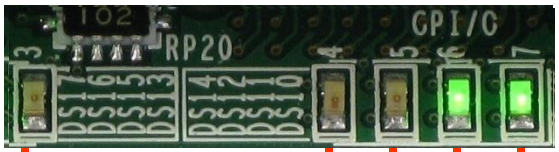
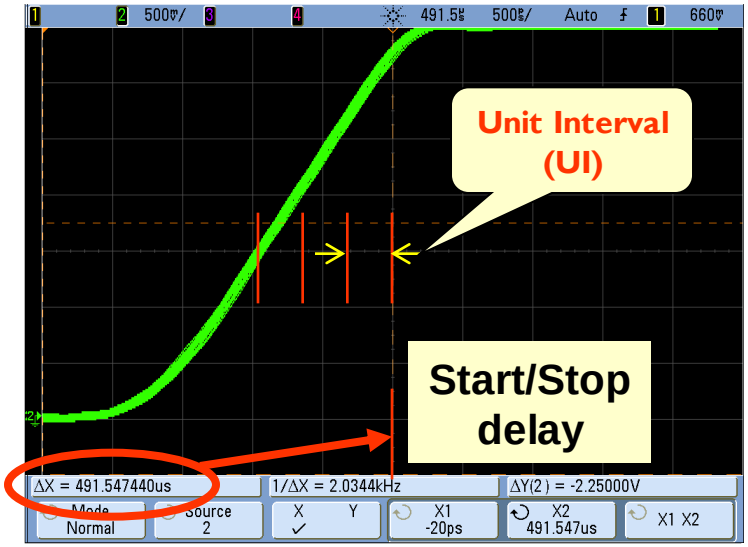
Resynchronization + Barrel shifting action



BitSlide(4:0)



0 0 0 1 1 = 3



Algorithm:

Propagation Delay = "Start-Stop" Delay + "LED Value" * UI

Details : VLVnT09, October 15, 2009 in Athens

- Presentation: http://www.nestor.noa.gr/vlvnt09/pres/Jansweijer_MeauringPropagationDelay.ppt
- Paper: http://dx.doi.org/10.1016/j.nima.2010.04.126

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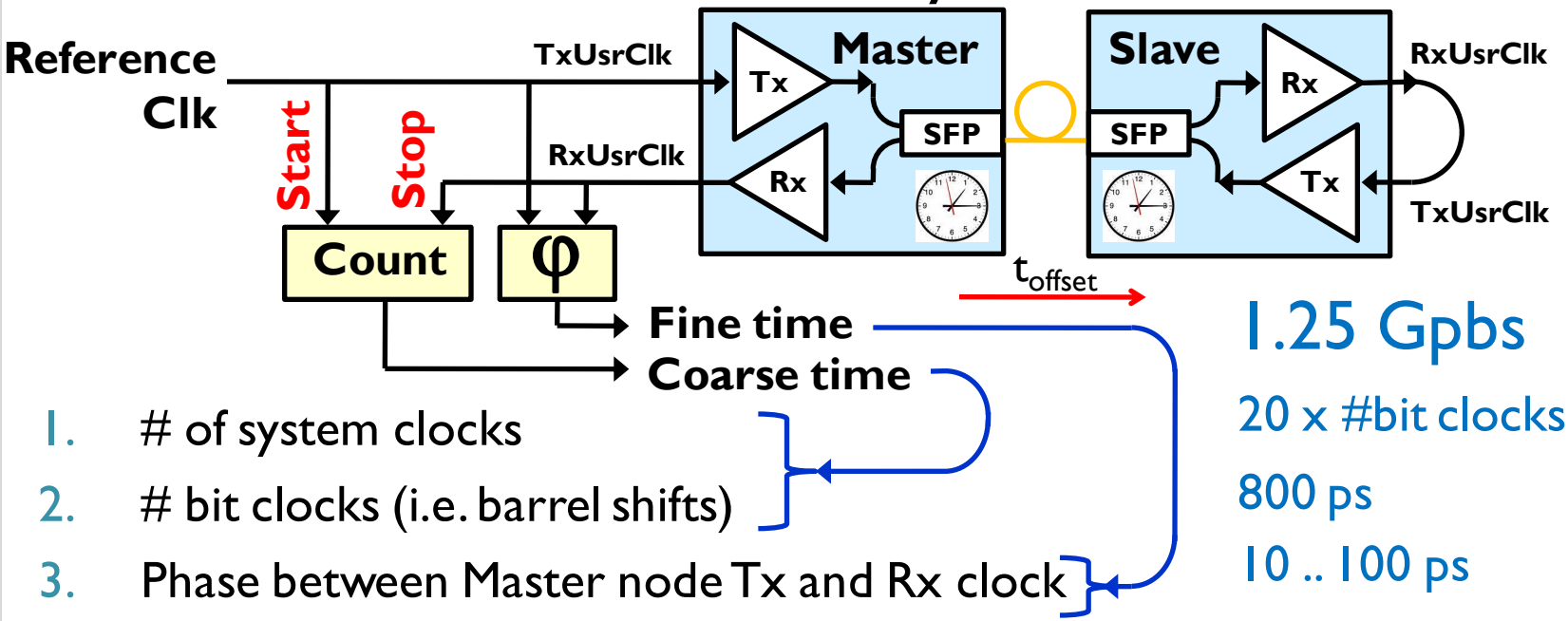
Measure time offset

- Bidirectional + Loopback the recovered clock
- 1.25 Gbps (IEEE802.3 1000BASE-X = Gigabit Ethernet)
- Time offset is determined by:



For details please see Technical Report "ETR2010-01":

http://www.nikhef.nl/pub/services/biblio/technicalreports/ETR2010-01.pdf

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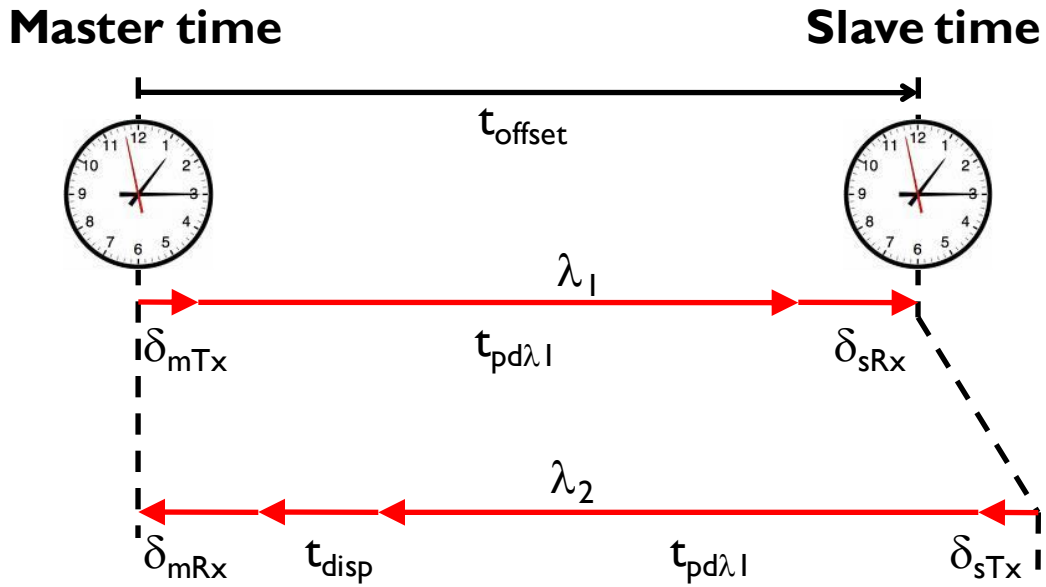
Time offset and fibre dispersion



$$t_{offset} \approx \frac{P}{2 + V_{\lambda 1} \cdot \int_{\lambda_1}^{\lambda_2} D d\lambda} \approx \frac{P}{2 + \frac{1416}{4.9.10^6}} \approx \frac{P}{2.000289}$$

(t_{disp} = 15150 ps over 10.7 km => D(λ) = 1416 ps/km)

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