The White Rabbit Project

Javier Serrano

CERN BE-CO
Hardware and Timing section

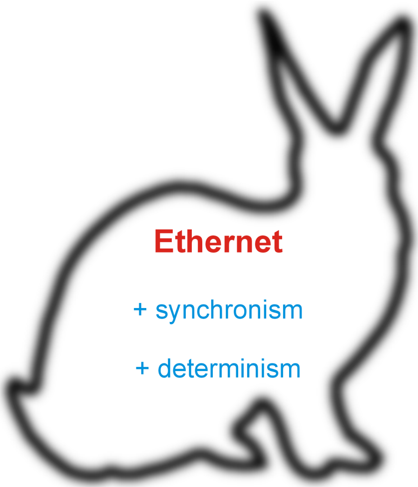
International Beam Instrumentation Conference
Oxford, 19 September 2013

1. Introduction
2. Technology
   - Precision Time Protocol (IEEE 1588)
   - Layer 1 syntonization
   - Phase tracking
3. Hardware and applications
4. Conclusions

Outline

1. Introduction
2. Technology
   - Precision Time Protocol (IEEE 1588)
   - Layer 1 syntonization
   - Phase tracking
3. Hardware and applications
4. Conclusions

What is White Rabbit? 1/2



What is White Rabbit? 2/2

It is also:

What is White Rabbit? 2/2

It is also:

- A multi-company, multi-lab collaboration for the development of Open Source SW and HW solutions for controls and DAQ.
    - Commercial support.
    - Many users: CERN, GSI, LHAASO, cosmic ray detectors, metrology labs. . .

What is White Rabbit? 2/2

It is also:

- A multi-company, multi-lab collaboration for the development of Open Source SW and HW solutions for controls and DAQ.
  - Commercial support.
  - Many users: CERN, GSI, LHAASO, cosmic ray detectors, metrology labs...
- The most accurate solution for synchronisation in Ethernet networks.

What is White Rabbit? 2/2

It is also:

- A multi-company, multi-lab collaboration for the development of Open Source SW and HW solutions for controls and DAQ.
  - Commercial support.
  - Many users: CERN, GSI, LHAASO, cosmic ray detectors, metrology labs...
- The most accurate solution for synchronisation in Ethernet networks.
- A candidate to be standardised under IEEE 1588 (PTP).

Design goals

Design goals

Scalability

Up to 2000 nodes.

Design goals

Scalability

Up to 2000 nodes.

Range

10 km fibre links.

Design goals

Scalability

Up to 2000 nodes.

Range

10 km fibre links.

Accuracy and precision

1 ns time synchronisation accuracy, 20 ps jitter.

Outline

Technologies used in White Rabbit

Sub-nanosecond synchronisation in WR is achieved by using the following three technologies together:

Technologies used in White Rabbit

Sub-nanosecond synchronisation in WR is achieved by using the following three technologies together:

- Precision Time Protocol (IEEE 1588).

Technologies used in White Rabbit

Sub-nanosecond synchronisation in WR is achieved by using the following three technologies together:

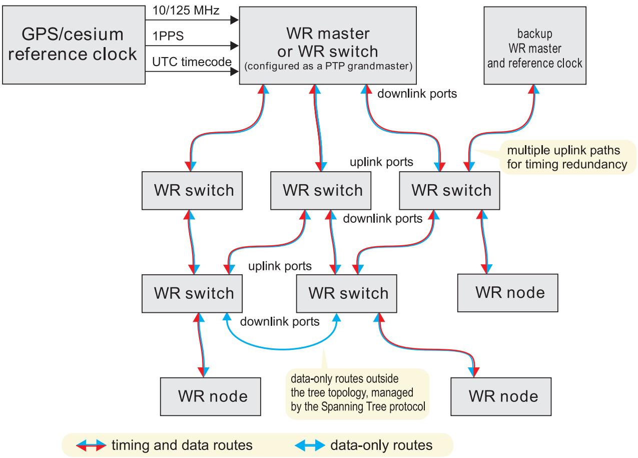
- Precision Time Protocol (IEEE 1588).
- Layer 1 syntonization.

Technologies used in White Rabbit

Sub-nanosecond synchronisation in WR is achieved by using the following three technologies together:

- Precision Time Protocol (IEEE 1588).
- Layer 1 syntonization.
- DMTD phase tracking.

Network topology



Links are 1Gb/s single fibre (TX and RX use different wavelengths).

Precision Time Protocol (IEEE 1588)

Precision Time Protocol (IEEE 1588)

PTP

Synchronises local clock with the master clock by measuring and compensating the delay introduced by the link.

Precision Time Protocol (IEEE 1588)

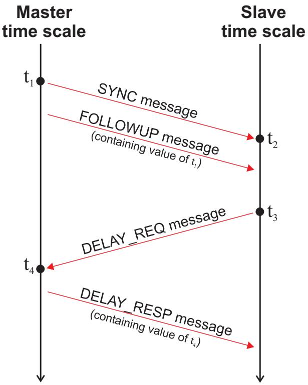
PTP

Synchronises local clock with the master clock by measuring and compensating the delay introduced by the link.

Frame timestamping

Link delay is measured by exchanging frames with precise hardware transmit/receipt timestamps.

Precision Time Protocol (IEEE 1588)



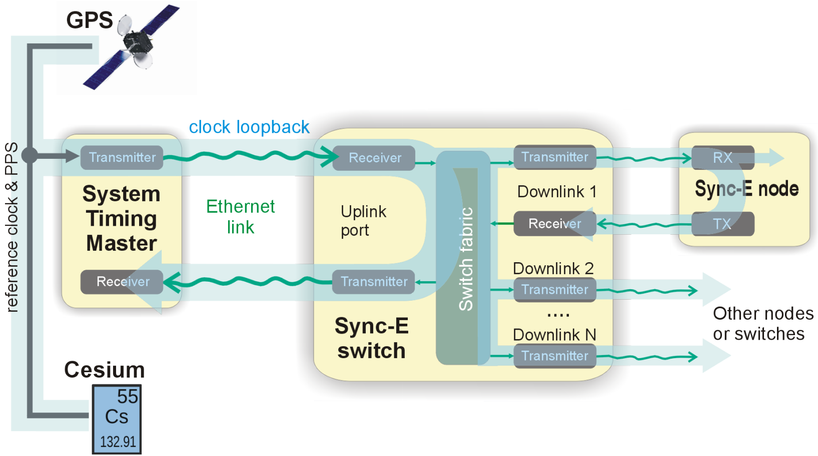
Having values of $t_1 \ldots t_4$, slave can:

- calculate one-way link delay:
  $\delta_{ms} = \frac{(t_4 - t_1) - (t_3 - t_2)}{2}$
- syntonize its clock rate with the master by tracking the value of $t_2 - t_1$
- compute clock offset:
  $offset = t_2 - (t_1 + \delta_{ms})$

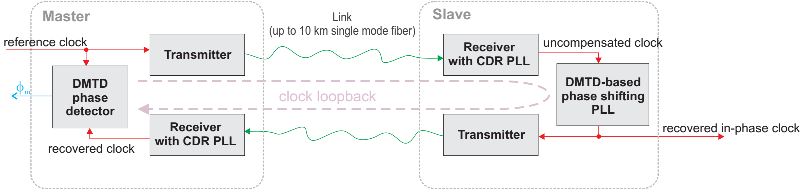
Disadvantages of traditional PTP

- All nodes have free-running oscillators.
- Frequency drift has to be continuously compensated, causing lots of network traffic.
- That doesn't go well with determinism...

Example: Synchronous Ethernet

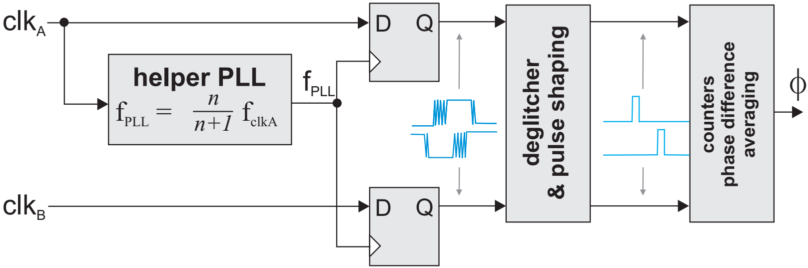


Phase tracking



- Monitor phase of bounced-back clock continuously.
- Phase-locked loop in the slave follows the phase changes measured by the master.

Digital DMTD (Dual Mixer Time Difference)

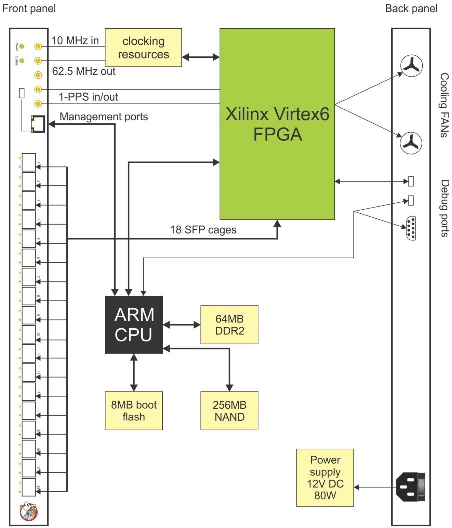


Outline

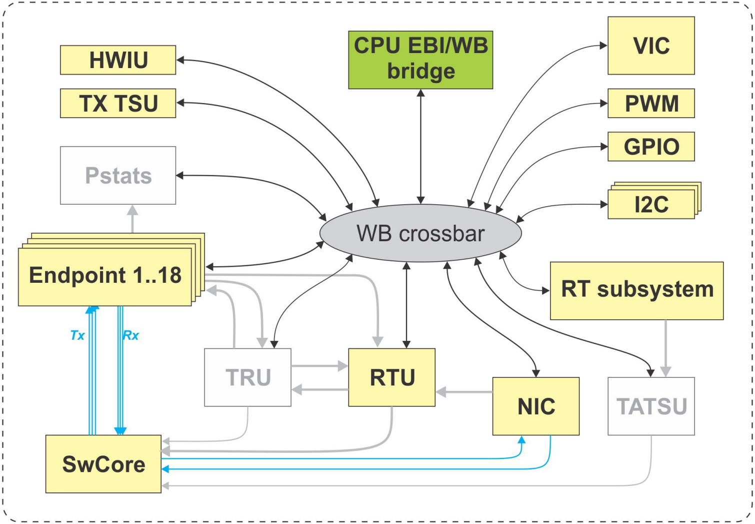
White Rabbit switch v3

Image courtesy of Seven Solutions

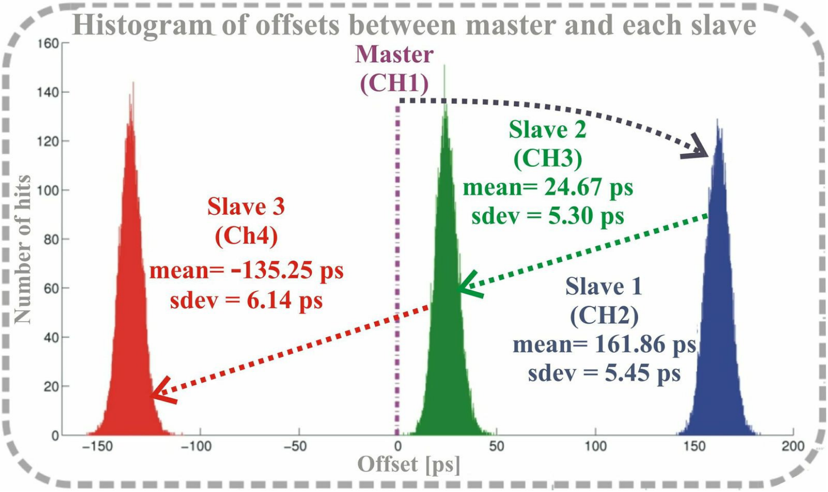
Simplified block diagram of WR switch



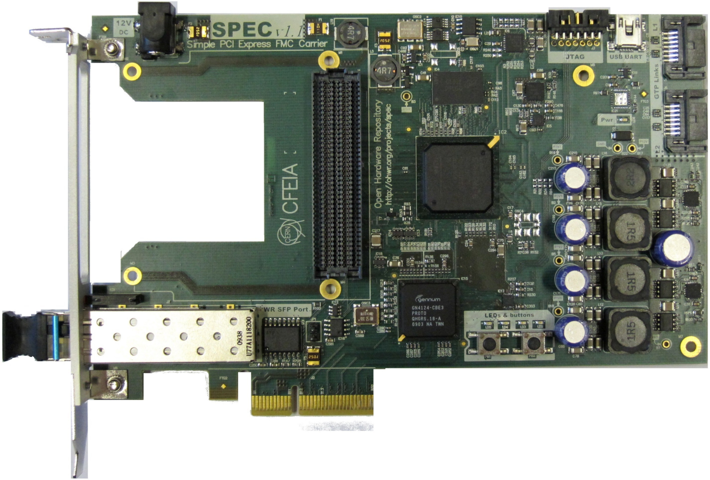
WR switch FPGA block diagram



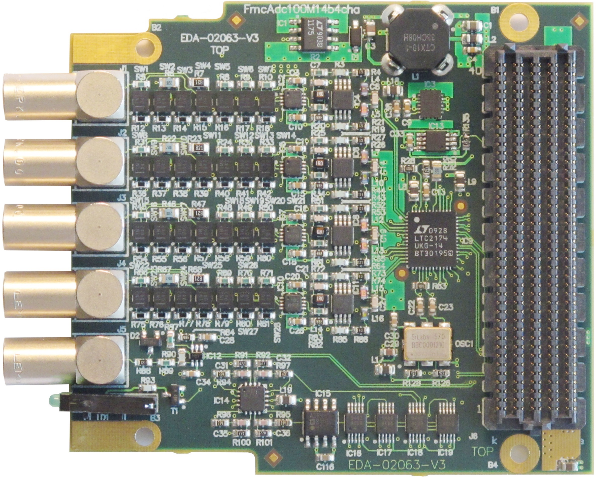
Synchronisation performance



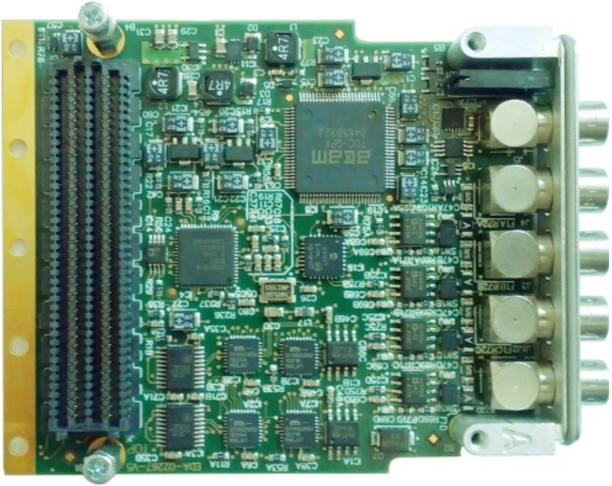
PCIe FMC carrier



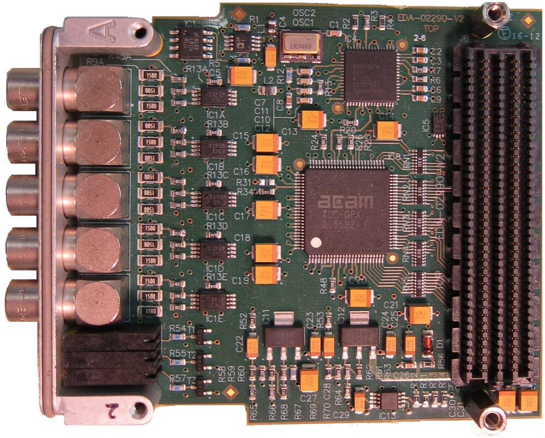
FMC mezzanine: 100 MSPS 14-bit 4-channel ADC



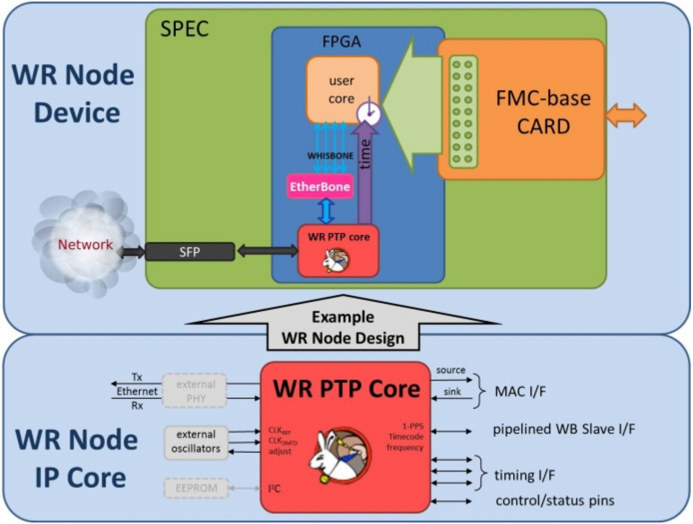
Fine delay generator FMC



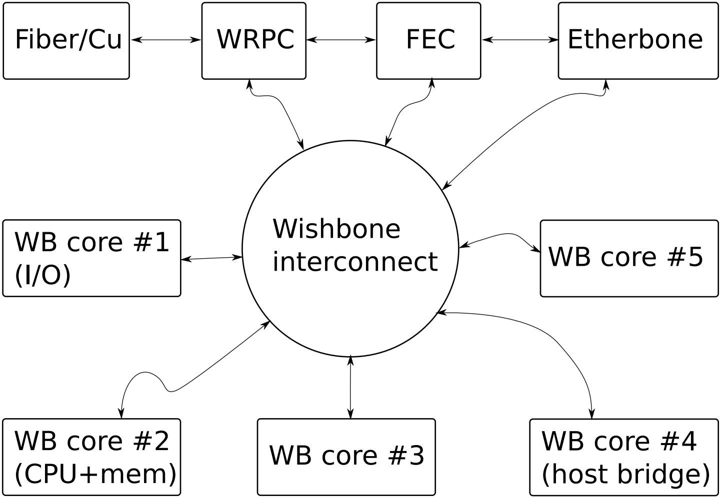
TDC FMC



Simplified block diagram of a WR node



Inside the FPGA of a WR node



Etherbone

Main goals

- Push the customisation layer up by introducing another generic layer on top of WR.
- Very elegant: the whole network is one huge memory map. All messages are reads and writes into some node address space.
- Sits on top of UDP/IP. UDP multi-cast behaves as expected, triggering multiple WB accesses at the same time in many nodes.

Possible applications of White Rabbit

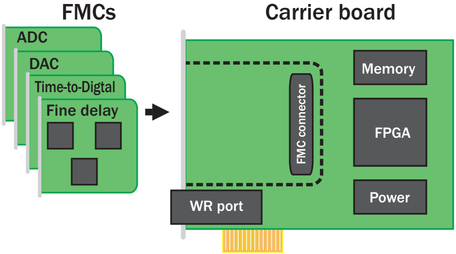
Large-scale data acquisition systems

Precise time tagging

Clock & trigger distribution

Robust event delivery

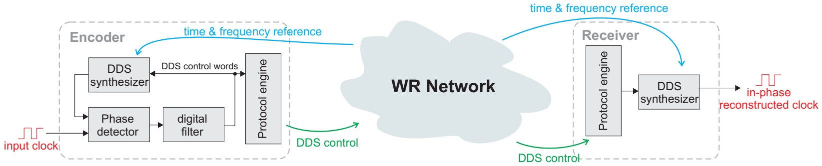
WR in CERN's BE-CO-HT Hardware Kit



CERN's BE-CO-HT FMC-based Hardware Kit:

- FMCs (FPGA Mezzanine Cards) with ADCs, DACs, TDCs, fine delays, digital I/O.
- Carrier boards in PCI-Express and VME64x formats (a µTCA carrier also exists in the OHR).
- All carriers are equipped with a White Rabbit port.

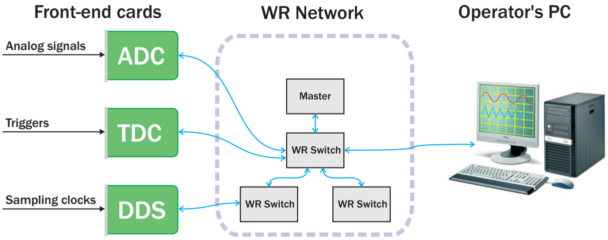
Ethernet Clock distribution a.k.a. Distributed DDS



Distributed Direct Digital Synthesis

- Replaces dozens of cables with a single fibre.
- Works over big distances without degrading signal quality.
- Can provide various clocks (RF of many rings and linacs) with a single, standard link.

Distributed oscilloscope



- Common clock in the entire network: no skew between ADCs.
- Ability to sample with different clocks via Distributed DDS.
- External triggers can be time tagged with a TDC and used to reconstruct the original time base in the operator's PC.

MIMO feedback systems

The highly deterministic nature of WR networks, coupled with the low latency of the WR switch, make WR an ideal platform for MIMO feedback systems, such as the Fast Orbit Feedback system needed in many synchrotrons.

Outline

1. Introduction
2. Technology
   - Precision Time Protocol (IEEE 1588)
   - Layer 1 syntonization
   - Phase tracking
3. Hardware and applications
4. Conclusions

Status and outlook

Status and outlook

- Switches and nodes work and are commercially available.

Status and outlook

- Switches and nodes work and are commercially available.
- Now working on better diagnostics and remote management for the switch.

Status and outlook

- Switches and nodes work and are commercially available.
- Now working on better diagnostics and remote management for the switch.
- IEEE 1588 standardisation effort expected to converge in $\sim$3 years.

Status and outlook

- Switches and nodes work and are commercially available.
- Now working on better diagnostics and remote management for the switch.
- IEEE 1588 standardisation effort expected to converge in $\sim$3 years.
- First operational deployments expected at CERN and elsewhere in 2015.

Summary

Summary

- A novel networking technology allowing precise synchronisation and deterministic data transfer.

Summary

- A novel networking technology allowing precise synchronisation and deterministic data transfer.
- A collaborative distributed effort based on open source hardware and software. Everybody is welcome to join!

Summary

- A novel networking technology allowing precise synchronisation and deterministic data transfer.
- A collaborative distributed effort based on open source hardware and software. Everybody is welcome to join!
- A versatile solution for general control and data acquisition systems.

Summary

- A novel networking technology allowing precise synchronisation and deterministic data transfer.
- A collaborative distributed effort based on open source hardware and software. Everybody is welcome to join!
- A versatile solution for general control and data acquisition systems.

For more information see
http://www.ohwr.org/projects/white-rabbit/wiki