The White Rabbit Project
Technical introduction and status report

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Outline

1. Introduction
2. Technology overview
   - Precision Time Protocol (IEEE1588)
   - Synchronous Ethernet
   - Phase tracking
   - White Rabbit Switch
3. Applications
   - WR in CERN’s BE-CO-HT Hardware Kit
4. Planning
   - Current status
   - Development plans for 2011
BE-CO-HT mission

Provide HW kit for equipment groups at CERN
Based on carriers (VME64x, PCIe...) and FMC (VITA 57) mezzanines.

Act as knowledge hub for hardware design
FPGA designs based on Wishbone bus, ADC, DAC, TDC, fine delay generators...

Provide low-level software support for the HW kit
Linux device drivers and libraries, production testing environment...

Design and operate CERN’s General Machine Timing system
Based on the HW and SW technologies the section develops. We eat our own dog food!
## Why we use Open Hardware

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<th>Why we use Open Hardware</th>
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<tr>
<td><strong>Get a design just the way we want it</strong></td>
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<td>We fully specify the design.</td>
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<td><strong>Peer review</strong></td>
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<td>Get your design reviewed by experts all around the world, including companies!</td>
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<td><strong>Design re-use</strong></td>
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<td>When it’s Open, people are more likely to re-use it.</td>
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<td><strong>Healthier relationship with companies</strong></td>
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<td>No vendor-locked situations. Companies selected solely on the basis of technical excellence, good support and price.</td>
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Example of a carrier: the SPEC board

- Low-cost PCI-Express Carrier
- Spartan-6 FPGA (XC6SLX45T), 256 MB DDR3 RAM
- White Rabbit Ethernet port
Example of a mezzanine: 4-channel 100MS/s ADC

- 105 MSa/s, 14 bits (11.7 ENOB)
- 3 input ranges (±5 V, ±0.5 V, ±50 mV)
- Flexible triggering: (external, internal or via White Rabbit)
Development model

- Developed in the frame of CERN’s (and GSI’s) renovation projects.
- Open source design done in collaboration with industry.
- Commercial production and support.
What is White Rabbit?

- Ethernet
  - synchronism
  - determinism
What is White Rabbit?

An extension to Ethernet which provides:

- **Synchronous mode** (Sync-E) - common clock for physical layer in entire network, allowing for precise time and frequency transfer.

- **Deterministic routing** latency - a guarantee that packet transmission delay between two stations will never exceed a certain boundary.
Design goals

**Precision**
1 ns time synchronization accuracy, 20 ps jitter

**Range**
10 km fiber links

**Scalability**
Up to 2000 nodes
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Sub-nanosecond synchronization in WR is achieved by using the following three technologies together:

- Precision Time Protocol (IEEE1588)
- Synchronous Ethernet
- DMTD phase tracking
Network topology

GPS/cesium reference clock

10/125 MHz
1PPS
UTC timecode

WR master or WR switch (configured as a PTP grandmaster)

downlink ports

backup WR master and reference clock

multiple uplink paths for timing redundancy

uplink ports

downlink ports

downlink ports

data-only routes outside the tree topology, managed by the Spanning Tree protocol

timing and data routes
PTP Protocol (IEEE1588)

**PTP**
Synchronizes local clock with the master clock by measuring and compensating the delay introduced by the link.

**Packet timestamping**
Link delay is measured by exchanging packets with precise hardware transmit/receive timestamps.
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...
Synchronous Ethernet

- **GPS**
  - reference clock & PPS

- **System Timing Master**
  - Transmitter
  - Receiver

- **Sync-E switch**
  - Uplink port
  - Switch fabric
  - Receiver
  - Transmitter
  - Downlink 1
  - Receiver
  - Transmitter
  - Downlink 2
  - Receiver
  - Transmitter
  - Downlink N
  - Receiver
  - Transmitter

- **Sync-E node**
  - RX
  - TX

- **Ethemet link**
- **Clock loopback**

- **Cesium**
  - 55 Cs
  - 132.91
Monitor phase of bounced-back clock continuously.

Phase-locked loop in the slave follows the phase changes measured by the master.
White Rabbit Switch

- Central element of WR network
- Fully custom design, done from scratch at CERN
- Ten 1000Base-X ports, may drive 10+ km of SM fiber
- 200 ps synchronization accuracy
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Possible applications of White Rabbit

- Large-scale data acquisition systems
- Clock & trigger distribution
- Precise time tagging
- 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, VME and uTCA formats.
- All carriers are equipped with a White Rabbit port.
Distributed oscilloscope

- Common clock: 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
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WR Switch development status

**Switch hardware**
- Working and debugged V2 hardware prototype
- Tested on 10-km fiber links
- Interoperates with standard Ethernet gear

**Switch software**
- Done the Hardware Abstraction Layer and PTP daemon
- Sub-nanosecond accuracy over PTP has been achieved
- Verified interoperability with other PTP devices on ISPCS 2010 Plug Fest
Already achieved...

According to ISPCS Plug Fest results ...

... White Rabbit is the most accurate PTP implementation in the world!
## Foreseen milestones

### WR Switch
- Basic functionality of HDL and software achieved, code cleanup underway
- V3 prototype (18 ports): Q4 2011
- Commercial product: Q2 2012
  Estimated COTS price: ≈2500€

### WR Ecosystem commercial availability
- PCIe carrier available now, VME Q2 2012
- WR timing node in VME and PCIe: Q2 2012
- Mezzanines: Full set of cards Q2 2012
# Summary

## A deterministic timing and data link
- 1 ns accuracy and 20 ps jitter
- 10 km fiber links
- Up to 2000 nodes

## A successful open collaboration
- Fully open development
- Involving institutes and companies
- Full system commercially available mid-2012

For more information, [http://www.ohwr.org/projects/white-rabbit/wiki](http://www.ohwr.org/projects/white-rabbit/wiki)