Improving performances of White Rabbit

presenter: Paul-Eric Pottie
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- Context and motivations
- Focus on
  - Low noise local oscillators
  - Low-noise WR devices
- Outlook
Context and motivations

WR performances <2016
ADEV = 10^{-11} @ 1 second
integration time in 500 Hz
bandwidth of measurement

Aims :
1. Upgrade the performance of White Rabbit devices to a level suitable for most demanding scientific applications (high performance industrial clock, discipline of remote oscillators on H-Maser)
2. Compatibility with other protocols and standards

Related work :
Mattia Rizzi -
https://ohwr.org/project/wrs-low-jitter/wikis/home
doi: 10.1109/ISPCS.2016.7579514 (2016)
Asterics : https://www.asterics2020.eu/
PhD thesis : Namneet Kaur (OP), Miguel Jiménez López (UGR)
Synopsis of a WR engine

- Improve the WR board: better digital components and better portability
- Improve the analog blocks: local oscillator (as input) and the PPS output
- Improve compatibility with other standards and make the WR devices interoperable
Local oscillator

- OCXO (OP, NIKHEF): manufactured by Morion
- MV 341: $<5 \times 10^{-13}$, 1s-100s
- MV 216, MV336

![Frequency stability comparison](image)

- Measurement bandwidth = 50 Hz (parts JA688 and JA674)
## Local oscillator: MV341 phase evolution

<table>
<thead>
<tr>
<th>relative frequency</th>
<th>MV341-1</th>
<th>MV341 -2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean offset</td>
<td>-3.9e-8</td>
<td>+1.3e-8</td>
</tr>
<tr>
<td>Drift rate (s^{-1})</td>
<td>-3.7e-16</td>
<td>-2.9e-16</td>
</tr>
<tr>
<td>Quadratic rate (s^{-2})</td>
<td>1.6e-22</td>
<td>7.3e-23</td>
</tr>
</tbody>
</table>

Offset, drift and quad. removed

![Graph showing time errors (ns) vs MJD (Modified Julian Date)](image-url)
Local oscillator implementation

- Track 1: Low jitter daughterboard, + improved LO (embedded in the board): NIKHEF, SevenSol
- Track 2: Extract/generate an error signal and feedback to an external oscillator: OP

See also:
Low-jitter daughter board at CERN
https://ohwr.org/project/wrs-low-jitter/wikis/home
SPEC7 (NIKHEF)

- Excellent Phase noise external oscillator
- Add 10 MHz phase align
- Re-clock outputs with fast flip-flops

https://www.ohwr.org/project/spec7/wikis/home
SPEC7: phase noise measurements

125 MHz Phase Noise

-150 dBc/Hz

Offset[Hz]

10 MHz Phase Noise

-100 dBc/Hz

Offset[Hz]

As compared to <2016:
10 MHz Phase noise at 1 Hz offset of the carrier is improved by ~15-20 dB

limited by WR PLL BW
Need better loop tuning

Very low-phase noise above 2 kHz Fourier frequency

https://ohwr.org/project/spec7/wikis/home
HPSEC (NIKHEF)

- Ultra-stable 10MHz OCXO (MV336)
- 10 MHz/1 GHz sine wave reference input - 1-PPS input
- Outputs: 10 MHz Sine wave, 100 MHz LVPECL, differential LVPECL 125/62.5 MHz, 1 GHz
- Arbitrary frequency available on N connector (J25)
- PPS output LVPECL SMA front panel connectors (J10, J11)
- Clean-up circuitry for differential 10MHz and PPS outputs
- 10/100 Mb Ethernet interface (RJ45), mini-USB
- Uninterruptible Power Supply (UPS)

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Measurements on-going ... stay tuned!

https://ohwr.org/project/hpsec/wikis/home
Redesign and manufacture White Rabbit Switch with Mattia Rizzi’s clocking enhancements

Pilot working in a Japan Accelerator Facilities

Development of a Holdover expansion board with different oscillators fingerprints

I-PPS measurements

WRS SCB Low-jitter board

WRS WRITE Holdover exp. board
Phase noise < -100 dBc/Hz at all Fourier frequencies

RMS jitter equals 900 fs over the whole analyzed band

- Phase noise < -100 dBc/Hz at all Fourier frequencies
- RMS jitter equals 900 fs over the whole analyzed band
**WR-disciplined approach**

1. A frequency counter (dead-time free) measures the frequency difference (WR vs OCXO)
2. Correction is calculated (digital PID)
3. An analog correction is applied to the external local oscillator
   This approach is equivalent to filter the WR signal with an ultra-low noise LO.

See also work at OPNT
Compatibility with other protocols and standards

- Review of PTP profiles used on the different markets
- Analyses of the WR PPSI stack interoperability with these standards
- Evaluate the performance of mixed solutions (WR devices interfacing with devices compliant with different PTP profiles)

More will be presented during the presentation this afternoon (14:30)
- review of legacy devices for the telecom and industry domains
- interoperability evaluation and results of WR with legacy telecom and industrial equipment.

Related work:

See also efforts towards 10Gb/s WR:
Conclusions - Take away messages

- Important role of the local oscillators, as embedded master oscillator on board, or as cleaners
- We show improved White Rabbit devices for users asking for better than $1 \times 10^{-11}$ at 1 s
- SPEC7, HPSEC: https://www.ohwr.org/project/spec7/wikis/home
- Low-jitter and daughterboards commercially available
- Alternative approach with an external oscillator
- Work ahead:
  - More flexible soft PLL optimisation
  - Supervision (see WP2 presentation)
Thank you for your attention!

Special thanks to CERN and the WR community

https://ohwr.org/project/white-rabbit