Long Distance Synchronization Using White Rabbit

White Rabbit (WR) provides sub-nanosecond accuracy and picosecond-precision for synchronization of large distributed data acquisition systems using Synchronous Ethernet. A WR network enables high-precision time-tagging of measured data and allows for triggered data capture in large installations [1]. The technique can be used to synchronize digitizers over long distances and in this paper, we describe how to achieve this using WR hardware from Seven Solutions together with high-performance digitizers from Teledyne SP Devices (TSPD).

Digitizers spread over long distances require a common clock in order to perform synchronized sampling and make it possible to relate samples between different digitizers. Such high-resolution distribution typically contains three parts:

- A common clock reference clock, typically 10 MHz.
- A 1 Pulse Per Second (PPS) signal indicating the first clock edge each second.
- Time of day, date and time.

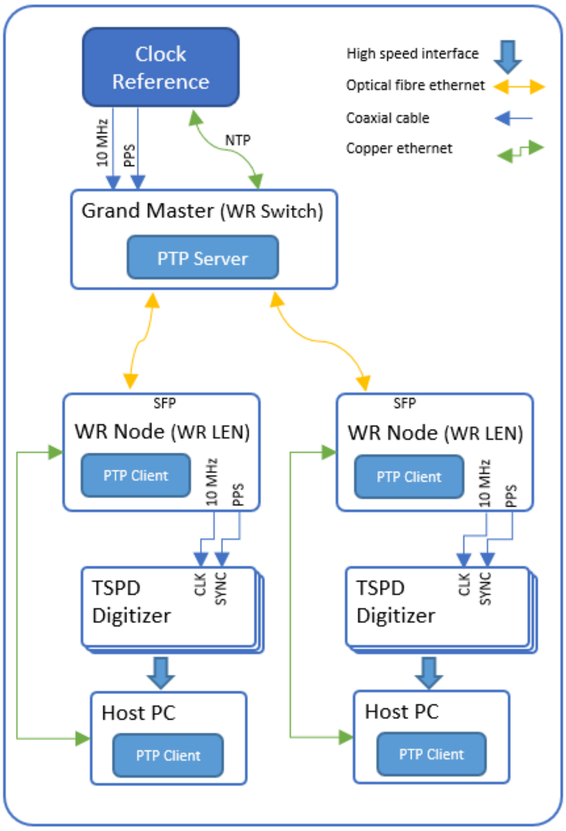

Figure 1 Proposed network structure.

White Rabbit connect nodes trough optical fibre cables. The cables can be several kilometres long and the nodes could be configured in a daisy chain. Each node has 10 MHz clock and 1 PPS output signals whereas time of day is distributed using PTP.

The proposed method is only using commercially available hardware and well-known techniques. The WR network is primarily used for clock distribution and cannot be used to transfer a large amount of data from the digitizers.

Each digitizer or cluster of digitizers needs a host PC as shown in Figure 1.

Synchronizing Digitizers

Each data record captured by TSPD digitizers is timestamped with a high-resolution timestamp in a local time base. To be able to compare timestamps between different digitizers, we need to find the relation between this local time base and White Rabbit time. Our proposed method is to reset digitizer timestamp at a known time instance, *t_zero*, using the 10 MHz clock and the 1 PPS signal.

Each host PC connected to the digitizers need to have their time and date synchronized with the WR network via PTP. The digitizers are synchronized by connecting the 10 MHz reference clock and the PPS signal to the SYNC and CLK inputs.

Synchronization is performed in the following way:

1. Connect the WR node slave outputs to the digitizer clock reference and sync inputs.
2. Synchronize the clock of the host PC to White Rabbit using PTP.
3. Reset the digitizer timestamp on PPS synchronized to the 10 MHz clock.
4. Sample and round the computer clock to the nearest second (*t_zero*).

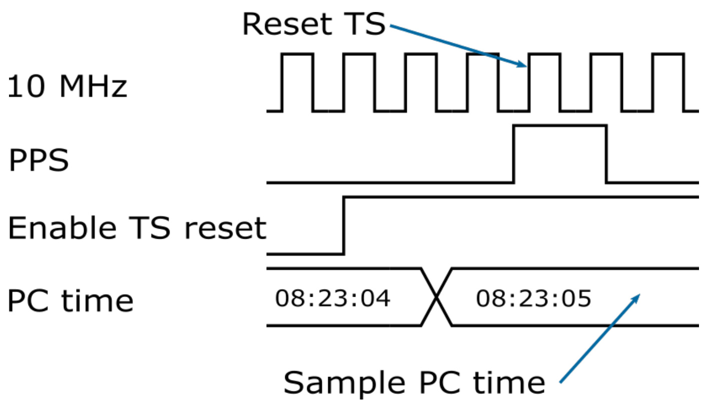

Figure 2 Digitizer timestamp reset.

An example of the procedure is shown in Figure 2. The host PC initiates a timestamp reset and waits until the reset is completed. The PC time is then sampled and rounded to the nearest second. The method described in this application note can be used with the following digitizer models:

- ADQ14
- ADQ7 (precision limited to 400 ps)
- ADQ8

Chassis with Multiple Digitizers

The WR nodes in Figure 1 can also consist of a set of digitizers hosted in a PXIe- or MTCA.4-format chassis or a PC hosting either multiple PCIe plug-in boards or external USB box digitizers. One PC and one WR module would then serve a number of digitizers.

The tests in this application note have been performed using front panel connections on stand-alone USB devices and PCIe plug-in boards. For PXIe and MTCA.4, it may be of interest to use backplane signaling instead to avoid front panel cabling. Suitable backplane signals clock and PXI TRIG for PXIe and TCLK and MLVDS bus for MTCA.4. This remains to be explored further.

Data Capture

After synchronization, data can be triggered and acquired in a normal manner. Thanks to the synchronization procedure previously described there is a known relation between digitizer timestamps and absolute time. Conversion between timestamp and absolute time is done by adding *t_zero* to the timestamp.

Timing Performance Test

Synchronization performance was measured using the setup described in Figure 1. In this test, two ADQ14 digitizers were used together with a signal generator connected to the trigger input on each digitizer.

A timing performance measure was defined as the absolute time difference between the trigger timestamps in the two digitizers. Both cards were connected with equally long cables to the trigger source and under ideal conditions, the trigger timestamp difference should not vary between two measurements.

Synchronization between the digitizers was measured by capturing 100 records and calculate the average timestamp difference and both the WR nodes and digitizers were restarted between each measurement. Figure 3 shows the resulting histogram.

These measurements show a synchronization precision (standard deviation) of 18 picoseconds and an accuracy (offset) of 225 picoseconds. These results are well-aligned with results shown in other literature, for example [2], with similar accuracy but slightly worse precision due to jitter introduced by the digitizer. The offset was constant between restarts and could therefore be calibrated.

Hardware configuration used for the test (see also Figure 4):

- 2 pcs ADQ14 digitizers (Teledyne SP Devices) https://www.spdevices.com/products/hardware/14-bit-digitizers/adq14
- 1 pcs WR Switch (Seven Solutions) https://sevensols.com/index.php/index/timing-products/white-rabbit-switch/
- 2 pcs WR LEN (Seven Solutions) https://sevensols.com/index.php/index/timing-products/wr-len/
- 2 pcs 1Gb SFP RJ45 Module
- Optical fibre and coaxial cables
- Signal generator
- Splitter

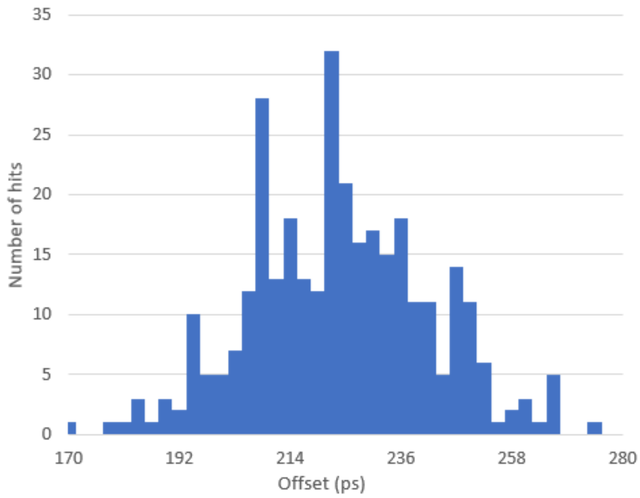

Figure 3 Histogram of offset between digitizers.

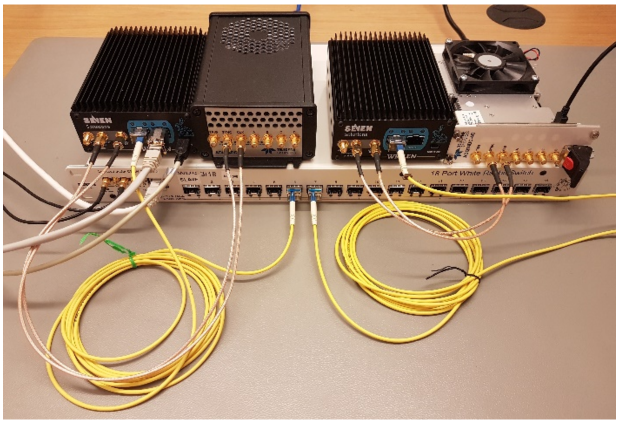

Figure 4 Test setup.

References

[1] https://ohwr.org/project/white-rabbit/wikis/home

[2] M. Lipinski, T. Włostowski, J. Serrano, P. Alvarez, “White Rabbit: a PTP Application for Robust Sub-nanosecond Synchronization,” ISPCS 2011