MOPOPT017

Tera Sampling Rates With Photonic Time-Stretch for Electron Beam Diagnostics

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Motivations

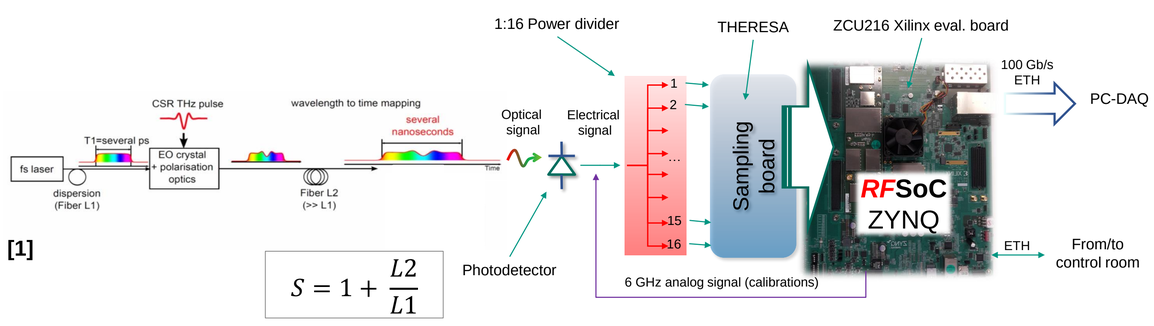
The acquisition of non-repetitive and statistically rare signals that occur on short timescales requires fast real-time measurements that often exceed the speed, precision and record length of conventional digitizers. Laser mode-locking, electron bunches in accelerators and optically triggered phases in materials are events that carry important information about the system from which they emerge.
Continuous acquisition over long observation times will open up new possibilities in the detection of rare events in accelerator physics.

Challenges

Ultrafast real-time instruments allow the acquisition of large data sets, even for rare events, only in a relatively short period of time. The real-time measurement of fast single-shot events with large record lengths is one of the most challenging problems in the fields of instrumentation and measurement.
High-bandwidth digitizer are expensive and due to limited internal memory and missing fast readout interfaces are not suitable for the continuous, long-term acquisition of analog input signals.

Digitizer Architecture for Photonic Time-Stretch

To overcome these limitations, the THERESA digitizer for continuous sampling of ultra-fast analog signals with a high repetition rate has been developed.



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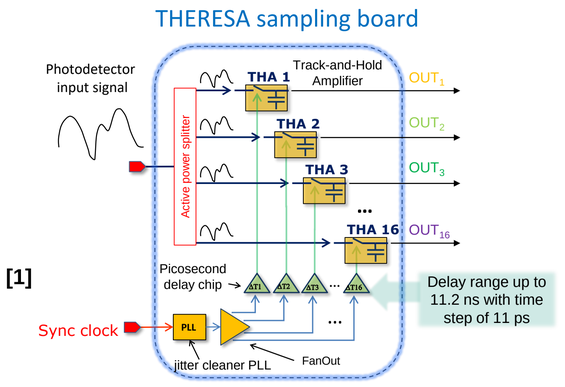

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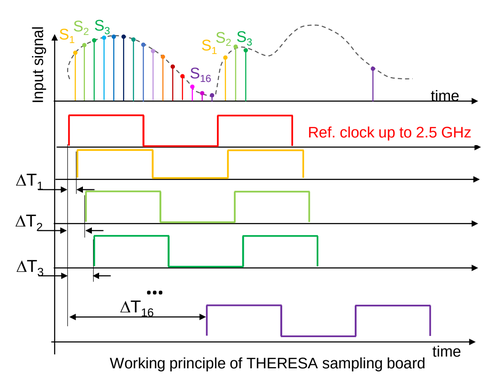


Photonic Time-Stretch System and Readout Architecture

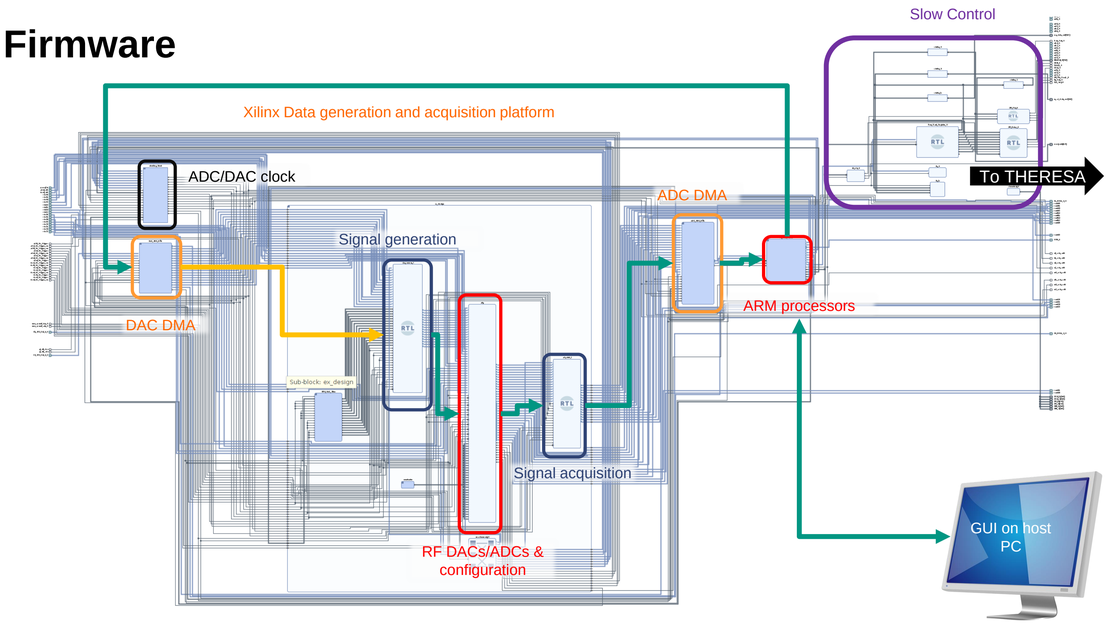
- Photonic time-stretch setup and photodetector → developed by PhLAM, Lille University [2]
- Wideband active power divider (0.5 to 80 GHz)
- THERESA sampling board with 16 parallel sampling channels
- Xilinx evaluation card ZCU216 based on ZYNQ-RFSoC
- High data throughput Ethernet data link operating at 100 Gb/s

Features

One key-feature of the THERESA architecture is its high flexibility in the sampling operation modes:

- *Continuous mode*: The individual phases of the 16 parallel sampling channels are distributed equally over the sampling interval. Considering a sampling rate of each individual ADC of 2.5 GS/s, the sampling rate achievable is up to 40 GS/s. When combined with the PTS and assuming a realistic time stretch factor S = 200, the sampling system operates at a frame rate of 40 GS/s · 200 = **8 TS/s**.
- *Fast sampling mode*: The phase of the channels is set with a minimum time distance of 11 ps. In that mode, the system will sample an input signal at the frame rate of 90 GS/s. When combined with the PTS the system operates at a frame rate of 90 GS/s · 200 = **18 TS/s**.

Firmware

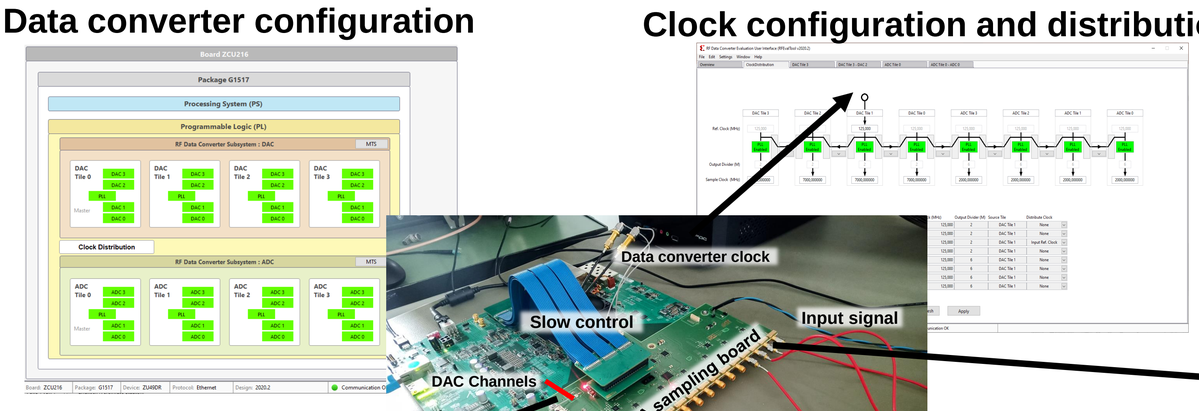


Calibration and Characterization

The time-interleaved sampling method requires a sophisticated calibration procedure. This method creates harmonic spurs occurring due to offset, gain, timing and bandwidth mismatches of the ADCs in the output spectrum.

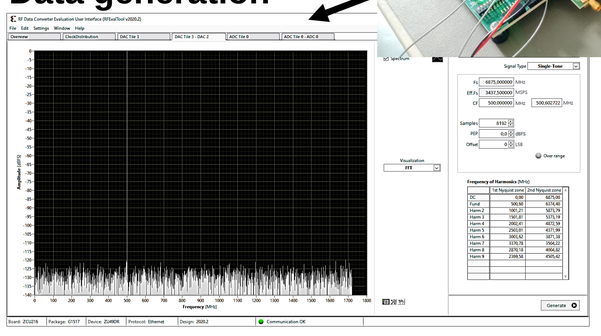
- **Gain and offset mismatch** is compensated by choosing the offset/gain of one ADC as reference and the offset/gain of the other ADCs are set to match that value as close as possible. It is measured by applying low frequency sinusoidal signal at different amplitude.
- **Phase and bandwidth mismatch** is compensated by hardware design (low skew between clock and analog lines and HF layout practice). To measure and reduce the **timing mismatch**, a low frequency (near DC) reference signal is generated and then subsequent measurements are performed at higher frequencies to separate the timing component of **bandwidth mismatch** from the timing mismatch.
- Signal generation and data acquisition is controlled by GUI
- Data analysis includes the output spectrum (Total Harmonic Distortion (THD), signal to noise (SNR), effective number of bits (ENOB), etc.)

Data converter configuration

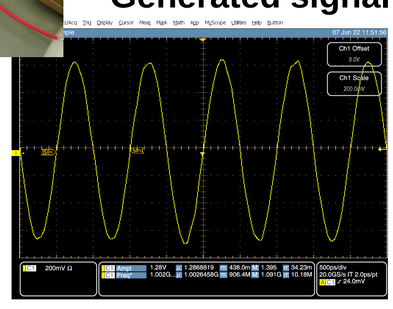


Clock configuration and distribution

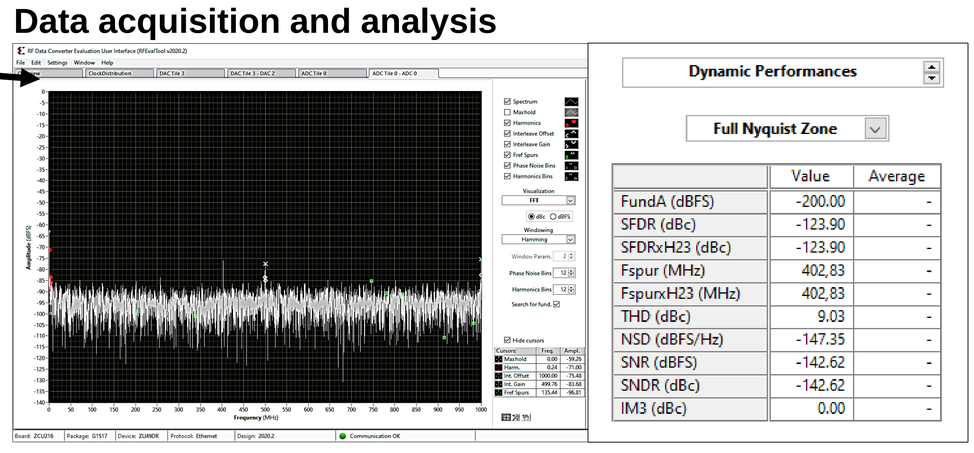
Data generation



Generated signal



Data acquisition and analysis



	Value	Average
FundA (dBFS)	-200.00	-
SFDR (dBc)	-123.90	-
SFDRxH23 (dBc)	-123.90	-
Fspur (MHz)	402,83	-
FspurxH23 (MHz)	402,83	-
THD (dBc)	9.03	-
NSD (dBFS/Hz)	-147.35	-
SNR (dBFS)	-142.62	-
SNDR (dBc)	-142.62	-
IM3 (dBc)	0.00	-

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[1] M. Caselle et al, Terabit sampling system with photonic time-stretch analog-to-digital converter, SPIE 2022
[2] E.Roussel et al, "Observing microscopic structures of a relativistic object using a time-stretch strategy", Scientific Reports (2015)