PSI Center for Accelerator Science and Engineering

A versatile, high accuracy, pulsed measurement device

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Abstract

Klystron modulators are key elements in free electron lasers. They provide high-voltage pulses to bias klystron tubes with energies of several hundred joules. Amplitude variations directly affect the gain and phase of amplified RF pulses and therefore the accelerating fields created by RF cavities. For machines such as the SwissFEL (Swiss Free Electron Laser), the required HV pulse stability must be better than 15 ppm (parts per million). Stability is calculated from 100 pulses up to 100 Hz as the relative standard deviation of gated averages around the pulse's flat-top region, where the RF pulse is amplified. Measuring such small variations often uses pulse offsetting technique and magnifying the flat-top region for better quantization resolution. This requires low-noise analog electronics like summing amplifiers and clippers with adequate bandwidth and settling time. Such a measurement setup usually uses an external differential amplifier and a high-performance oscilloscope with statistical analysis to measure stability. Our approach uses a RedPitaya STEMlab 125-14 board connected to a custom signal conditioner board developed at PSI (Paul Scherrer Institute) to monitor stability in klystron modulators. It captures both pulse current and voltage in real time and analyzes only the voltage for stability metrics. The concise design fits easily into modulator cabinets for ongoing, precise performance checks. Our system called the PMU (Pulse Measurement Unit) achieves a resolution limit of 5-6 ppm at a 1 microsecond measurement gate, exploiting 67% of the ADC full-scale range. We present the complete system and report on our initial operational experience.

System Description of the PMU

The PMU hardware consists of two components, the SCB (Signal Conditioning Board) and the RedPitaya digitizer. The function of the current transformer and capacitive voltage divider is to measure the physical quantities, the SCB adjusts the signal levels to match those of the ADCs for optimal measurement results.

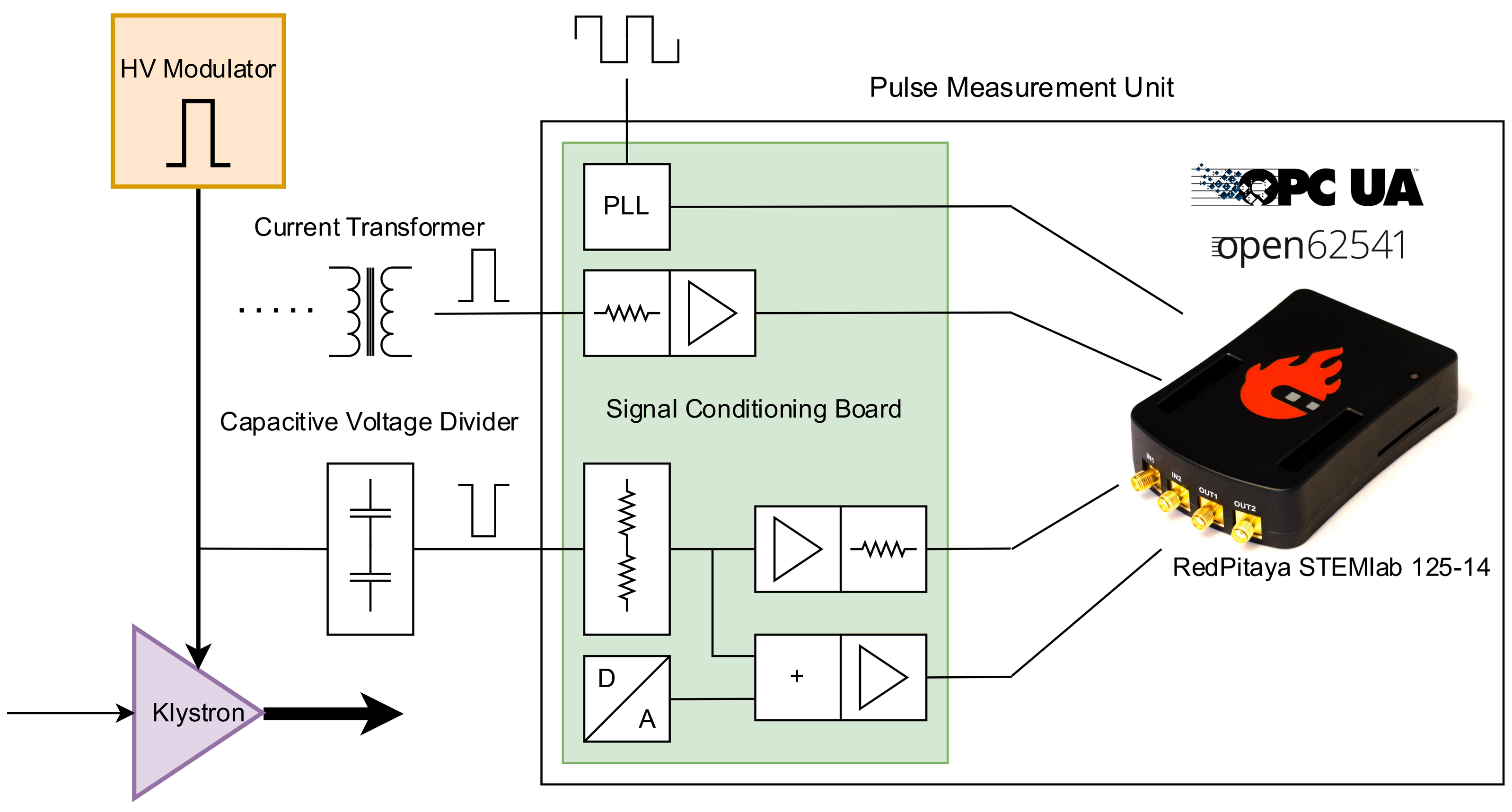

Fig 1: System context of the PMU

Only 3 ADC channels are required from the RedPitaya digitizer for the measurements, of these only two are relevant to the stability calculation. Current measurement with ADC1 is required for pulse power calculations. There are three main functions that have been implemented. **ADC Statistics** calculates the pulse stability over 100 consecutive pulses. The **Triggered Waveform Recording** can be enabled to start recording waveforms of all ADC channels. Furthermore, a threshold can be set at which the current recording will be stopped. We use this feature to record the klystron arcs. The purpose is to determine whether the arc occurred earlier or later in the pulse. Depending on that, we could ramp up the klystron faster or slower. This would allow us to increase the availability of the RF station and in the end the facilities uptime. The **Offset Adjustment** calculates the offset value that must be subtracted from the current signal to get the zoom in on the waveform. The offset value is written via SPI to the DAC located on the SCB. To ensure that we can easily integrate our PMU into the control system and, easily connect it to other control systems or devices, we have decided to run an **OPC-UA** server on the RedPitaya digitizer. In this way we can foster collaboration. All settings and measurement data are accessible via the OPC-UA server. We use the **open62541** implementation, which is licensed under the MPLv2 license in our application.

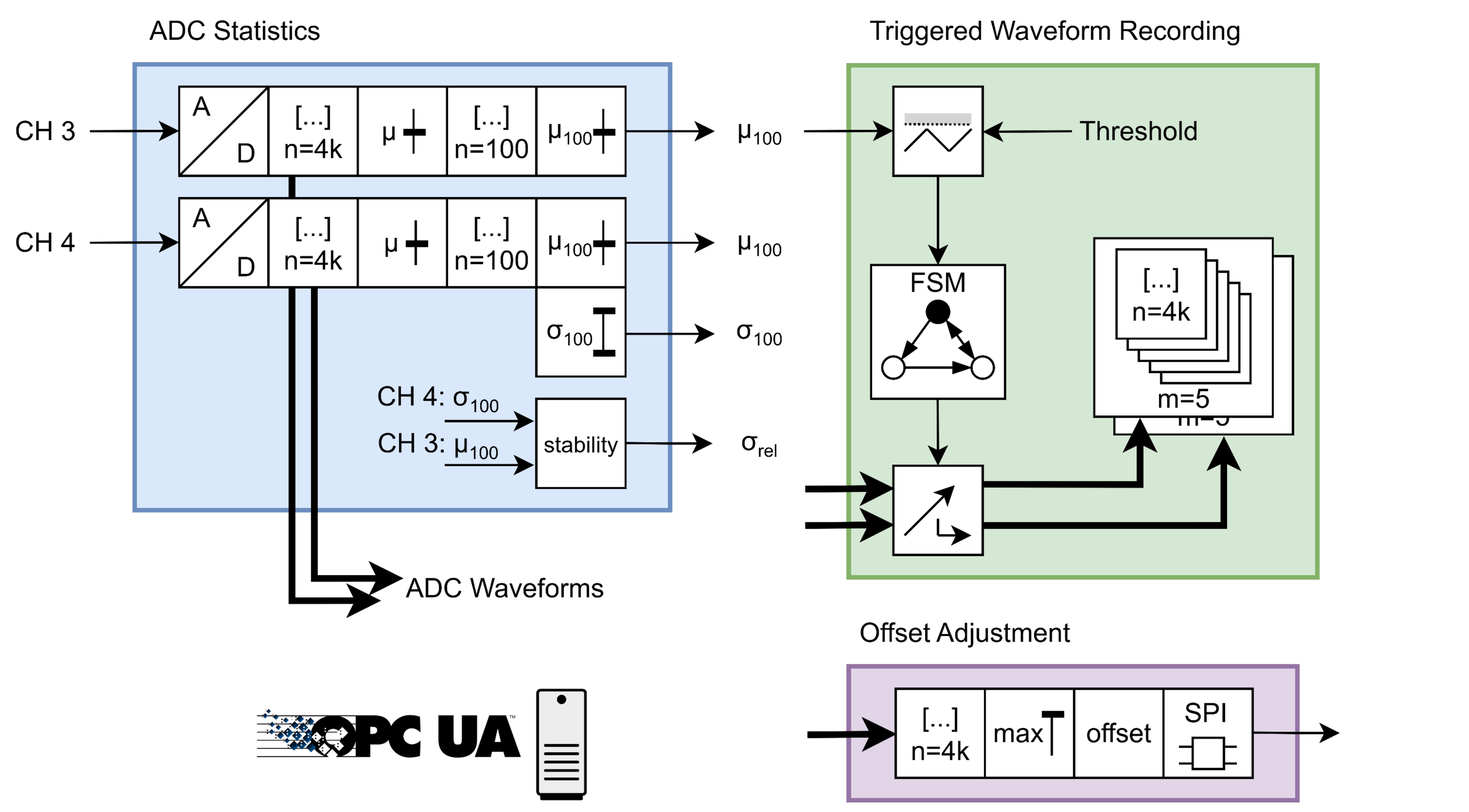

Fig 2: Software features implemented in the RedPitaya with a simplified representation of the functional blocks

Pulse Stability and Resolution

The two pictures below show a measurement at an injector RF station in SwissFEL. The difference signal (ADC4) remains saturated for a long time and then shortly enters the measurement range. This is the zoom effect achieved by subtracting the offset, which results in higher resolution.

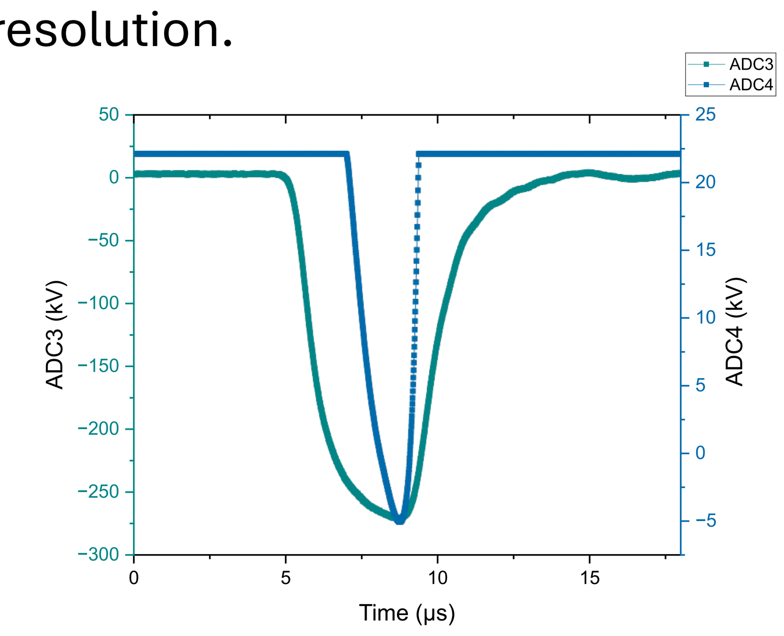

Fig 3: Display of the voltage (ADC3) and difference voltage (ADC4) pulses

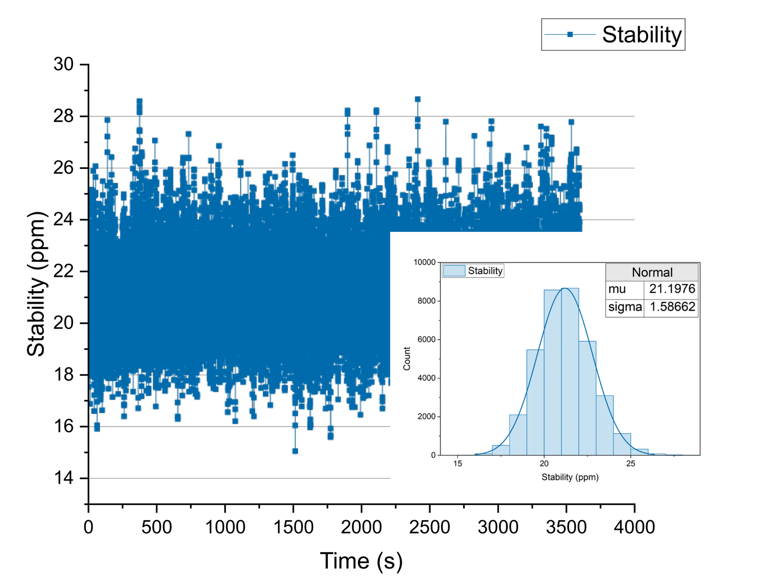

Fig 4: Trend of pulse stability over one hour

Conclusion and Outlook

Over the past several month, we have continuously monitored our modulators and observed consistently high system availability of the PMU. We are still working on further automation. The versatility of the PMU stems from our use with small variations in software and hardware for two other applications, such as Pulsed Magnet Controller or for RF amplifier stability measurements. We continously collaborate with other laboratories and are currently helping them to integrate the PMU into their facility.