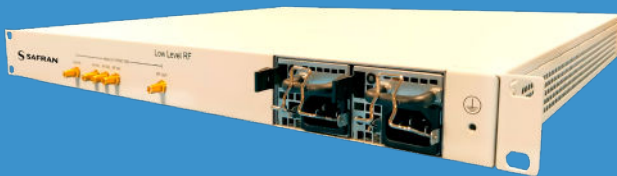# uTCA/STAND-ALONE DIGITAL LOW LEVEL RADIO FREQUENCY

Accurate control of the electromagnetic field inside accelerating cavities

The digital RF stabilization system is available on the uTCA or stand-alone form-factors for best in-class LLRF solutions. They are our industry leading fully digital RF systems designed to offer an accurate control of electromagnetic field inside any accelerating cavities and playing a key role in the overall performance of any particle accelerator. Our solution is tailored on customer needs and take full advantage of our previous expertise on PCIe-S LLRF equipment, now working with the most advanced crate technologies.

SAFRAN
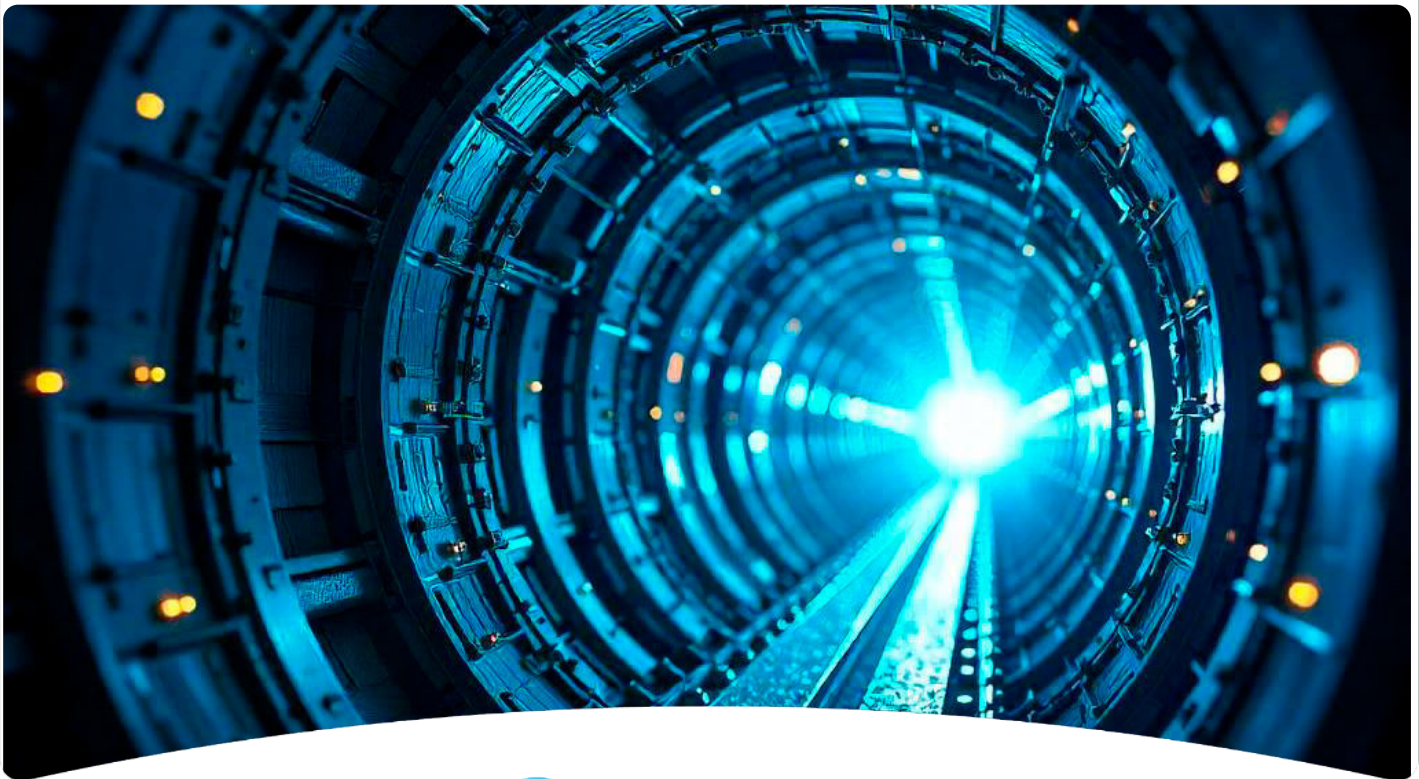
- Amplitude and phase control in continuous wave (CW) or pulsed.
- Real-time monitoring of RF signals, with live computation of detune frequency for resonance controls.
- Real-time monitoring of RF signals (Incident, reflected, cavity field ...).
- Two cavities control in one uTCA based LLRF system.
- Post interlock/alarm analysis capabilities.
- EPICS/TANGO control system support and easy user interface.
- Compatible with White-Rabbit and IEEE-1588 protocols. Seamless integration into the Timing system for triggering and timestamping control operations.
- Great performance:
  - Amplitude precision: 0.01% RMS
  - Phase precision: 0.01 degree RMS
  - Output added jitter: 142 fs RMS
  - Total loop delay < 0.95 us

Frequency range of operation
The system can operate with RF signals up to 1.5GHz.

Continuous and pulsed mode
Amplitude and phase or amplitude and frequency cavity field control y continuous wave or pulsed wave.

Open loop mode
Amplitude and phase control in open loop mode for cavity conditioning.

Closed loop mode
Amplitude and phase regulation, based on proportional-integral (PI) control loop, to stabilize the cavity field to the required values.

Feedforward
Ability to inject an arbitrary waveform to the control signal to compensate for beam loading effects.

Pulse shaping
Pulse edges smoothing capability to avoid abrupt voltage transitions.

VSWR
VSWR (arcing/reflection) detection and handling events. Configurable signal power thresholds and off RF time after event detection.

Cavity tuning
The LLRF can communicate with resonance control actuators such as piezos, stepper motors and temperature controllers to tune the RF cavities.

Frequency shift
The nominal RF frequency can be shifted +/-1MHz in open loop to adjust the RF signal to the resonant frequency of the cavity. This is of special interest during conditioning tasks.

Digital PLL
The frequency of the RF signal can be maintained at the resonant frequency of the cavities by means of the digital PLL feature. Monitoring the phase of the forward and cavity signals, the system can adjust the frequency of the RF signal generated in open loop. This feature is of special interest for the commissioning of superconducting cavities.

Machine diagnostics
The system stores the digitized signals for real time monitoring and for a postmortem analysis allowing the user to know at every moment the state of the system and the causes of an event.
The triggers to generate postmortem files are configurable, as well as the capture rate, depth, and pre-trigger capture time.

White Rabbit compatible
Compatible with White-Rabbit and IEEE-1588 protocols. Seamless integration into the Timing system for triggering and timestamping control operations.

Fast interlocks
Fast input interlock control to shut down the RF generation for protecting the machine.
Fast output interlock generation to communicate the alarm to other systems.

Easy Integration (EPICS/TANGO based)
Flexible control framework (EPICS/TANGO) and intuitive graphic user interface to configure and monitor the operation of the system.
Ready to be integrated into the Control System.

Full support
Complete support in every phase: commissioning, training, maintenance, updates.

Technical Specifications

System on Chip

SoC	Xilinx Zynq Ultrascale+ series
CPU	Quad ARM® Cortex™-A53 1.5GHz
Memory	8GB DDR4 16 GB SD card

Front End board

- RTM with double height and mid-size form factor uTCA.4
- 1 x RF MO Ref.: sine wave for LLRF reference.
- 7 x RF inputs to monitor up to two cavities.
- 2 x RF outputs to drive up to two cavities.
- Direct sampling architecture.
- RF input power dynamic range: [-60, +10] dBm.
- Maximum RF output power: +10dBm.
- Fail-safe for overheating mode.
- EEPROM memory.

Digitizer board

- 8 x ADC channels.
- 2 x DAC channels.
- 16 bits, 250MSPS ADCs - QDR LVDS interface.
- 16 bits, 1.5 GSPS DACs – DDR LVDS interface.
- 7 x configurable input/output TTL connectors.
- Zynq UltraScale+ FPGA from Xilinx.
- PLL for low phase noise distribution clocks.
- 8GB DDR4 for processor and data storage (postmortem analysis).
- ETH & SFP port (White Rabbit compatible).
- uTCA MMC controller.
- Fail-safe for overheating mode.
- uSD socket, uUSB port.

Management

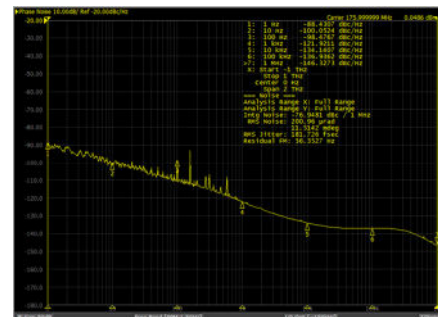|	
OS	Linux (Kernel v5.10 & buildroot)
Control	EPICS/TANGO
Monitoring	CSS/GUI & Taurus

Performance

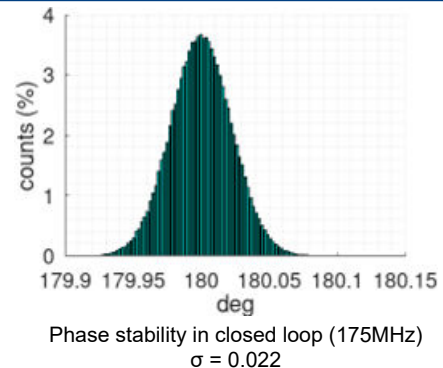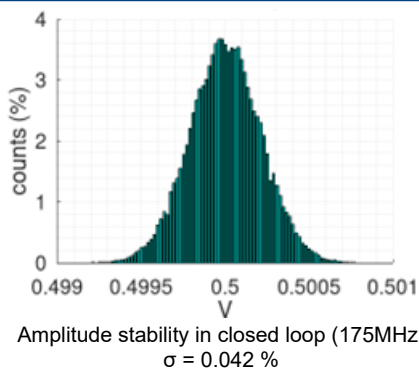|	
Amplitude precision	< 0.01% RMS (0dBm)
Phase precision	< 0.01º RMS (0dBm)
Amplitude stability	< 0.1% RMS (0dBm)
Phase stability	< 0.3º (0dBm)
Loop delay	< 0.95 us
RF added jitter	142 fs (1Hz-1MHz)

Added Jitter
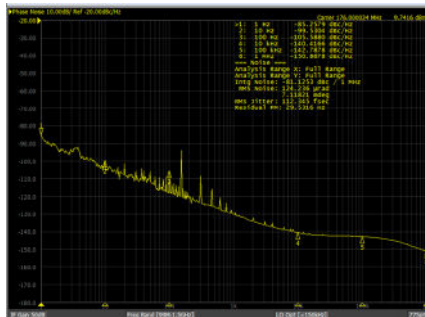
Master Oscillator jitter = 112 fs (176MHz)

LLRF output jitter = 182 fs (176MHz)

RF output stability

Amplitude stability in closed loop (175MHz)
σ = 0.042 %

Phase stability in closed loop (175MHz)
σ = 0.022

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