WP2: Low Level RF controls

DESY, HZB, CNRS

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Task 2.1: **Coordination of R&D on LLRF –** ***M1-M48***

Task 2.2: **Efficient field control for high loaded-quality factor cavities –** ***M1-M48***

Task 2.3: **Vibration analysis and detuning control of cavities –** ***M1-M36***

Task 2.4: **Integrated LLRF control using Ferro-Electric Fast Reactive Tuners–** ***M13-M48***

Task 2.5: **Energy efficient supervisory control and fault diagnosis–** ***M1-M48***

Task 2.2: Efficient field control for high loaded-quality factor cavities – *M1-M48*

- *Identify optimal loaded-quality factor (QL) to achieve efficient field control for various operation scenarios.*

→ *Can be carried out using numerical simulation (achievable stability vs. power)*
→ *Test at CMTB/AMTF/HoBiCaT (without beam)*
→ *Test at SRF guns, Ts4i & BerLinPro (with beam), other options?*

- *Evaluate methods for changing QL (at the cavity coupler and waveguide level).*

→ *Test and simulations are ongoing at HoBiCaT & AMTF / (3-stub tuner or phase shifter design)*

- *Investigate benefits of advanced ML-based combined RF and mechanical feedback controllers.*

→ *Started investigation to model transfer function PZT → RF (Max Herrmann @ DESY)*
→ *New position will be open at HZB.*

- *Demonstrate RF-efficient control in continuous wave (CW) and long pulse (LP) operation.*

→ *depends on results 2.2.1-3, but is already regular investigated e.g. at CMTB*

Task 2.3: Vibration analysis and detuning control of cavities – *M1-M36*

• *Characterize microphonics and detuning during cavity operation.*

→ *Measurements and characterization at several facilities feasible*

→ *Strongly depending on the facility, vary over time and operation setups*

→ *Long term microphonics at XFEL/FLASH (Yue Sun & A. Bellandi & H.S.@DESY)*

→ *Evaluation at HoBiCaT & future SRF gun test stands*

• *Characterize environmental disturbances and transfer to the cavity perturbation.*

→ *Test using ext. geophones at CMTB (PhD thesis Uni. Lodz)*

→ *More sophisticated sensor techniques envisioned (Distributed Fiber Optic Sensing)*

• *Investigate and develop detuning counter measures based on advanced feedforward, feedback and active noise cancellation including AI methods.*

→ *Improve LLRF diagnostics on detuning (e.g. Lueneberger Observer, PhD, B. Richter)*

→ *Advanced feedforward technique is worked on (A. Bellandi)*

→ *Surrogated models will be tested*

Task 2.4: Integrated LLRF control using Ferro-Electric Fast Reactive Tuners– M13-M48

- *Integrate a ferro-electric fast reactive tuner (FE-FRT) with a digital LLRF system*

→ *Hardware development 2026/27 within WP1*

→ *Simulation on effect and operation range can be carried out*

→ *When type and actuation is defined, digital interface can be defined*

- *Demonstrate microphonics compensation using a FE-FRT at a horizontal test stand*

→ *Depends on WP1 outcome*

Task 2.5: Energy efficient supervisory control and fault diagnosis– M1-M48

- *Develop schemes to adjust solid state amplifier (SSA) parameters for efficient RF generation.*

→ *Cryoelectra GmbH presentation last year at DESY/ Continue discussion on digital interface*

→ *Achievable drain voltage slew rate to be determined/update rates … level of few tens of ms*

- *Investigate RF control parameters for energy-efficiency optimization using ML methods*

→ *Started… e.g. Bayesian optimization of LFT compensation in LP operation (PhD student)*

- *Develop fault diagnosis and anomaly detection of LLRF systems using ML approaches*

→ *Started… e.g. Quench Detection, Microphonics Detuning Anomalies, …*

→ *Started …Fault diagnostics on digital HW e.g. PCIe failure & restarts, SEU on FPGAs…*

→ *Implementation of real-time Quench Detection on FPGA (N. Omidsajedi)*

- *Develop fault counter measures (i.e., fast detection and reaction) for sustainable cavity operation*

→ *On HW level some are implements/ wait for fast algorithm to be developed*

- *Develop a digital twin and surrogate models of LLRF systems to improve energy efficiency.*

→ *Modelling of entire system/software, combine achievements from other sub-WP2 packages*

→ *hardware in the loop first test ongoing (B. Dursum)*

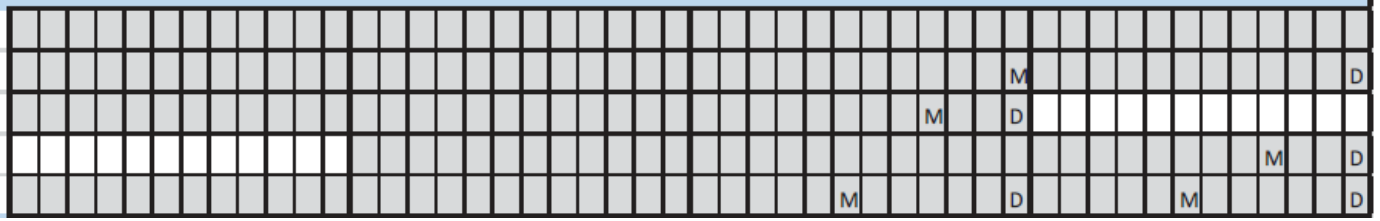
WP2 – LLRF: points of attention

- **Personnel setback**
  - since kick-off meeting in April, key person for R&D announced that he will leave DESY in Fall 2024
    ➔ mitigation: open replacement position
- **Changes in laboratory**
  - Delay: SRF gun test stand Ts4i likely not be available before 2026 (DESY)
  - Risk: CMTB may not be operable during FLASH202+ shutdown – 14 month (DESY)
    ➔ LLRF tests for LP and CP operation delayed
    ➔ Mitigation: prepare AMTF test stands with SSA operation
  - Additional loads: FALCO NRF gun test stand pulls resources (DESY)
- **Risks:**
  - Finding qualified personnel HZB (1 open position) / DESY (1 open position)
  - Other projects pulls resources, QL test slowed down (DESY)
  - Heavy load on SW and FW developers may delay development
- **New opportunities:**
  - New LLRF field detection hardware improve detection possibilities

    e.g. important collaborations with other WPs and/or the broader accelerator R&D landscape
    e.g. new challenges for the implementation of the tasks
    e.g. new opportunities potentially leading to revisited tasks/milestones/deliverables
    …

WP2 – LLRF: plans to achieve milestones & deliverables

WP2	Low Level RF Controls
2.1	Coordination of R&D on LLRF
2.2	Efficient field control for high loaded-quality factor cavities
2.3	Vibration analysis and detuning control of cavities
2.4	Integrated LLRF control using Ferro-Electric Fast Reactive Tuners
2.5	Energy efficient supervisory control and fault diagnosis



D2.1	ML based MC	Report on microphonics study & ML-based mitigation	2	DESY	R	PU	36
D2.2	SSA	Report on interface study of LLRF with SSA	2	DESY	R	PU	36
D2.3	LLRF control	Report on LLRF RF control studies	2	DESY	R	PU	48
D2.4	FRT based MC	Report on integration of FE-FRT in LLRF	2	HZB	R	PU	48
D2.5	Anomaly det.	Report on anomaly detection & LLRF optimization	2	DESY	R	PU	48

M2.1	Demonstration of energy-efficient SSA operation	WP2	30	Test report/publication
M2.2	Demonstration of detuning control techniques	WP2	33	Test report/publication
M2.3	Demonstration of RF control for CW/LP ops	WP2	36	Test report/publication
M2.4	Demonstration of ML and anomaly detection	WP2	42	Test report/publication
M2.5	Demonstration of FE-FRT Microphonics compensation	WP2	45	Test report/publication

→ Deliverables and Milestones are still fine and in reach

→ To support the WP2 program additional position will be open: 1) at DESY ~Q4/24 2) HZB soon

Position prepared, about to be released

WP2 – LLRF: budget plans

WP	WP Subject	CNRS	CERN	ESS	DESY	VUB	CEA	HZB	INFN	UKRI	UL	*EPFL*	EU-budget kEUR	Matching personnel kEUR	Matching materials kEUR	Total budget kEUR
	Technology Areas															
WP.1	Ferro-Electric Fast Reactive Tuners							LEAD					989,3	784,0	277,8	2051,1
WP.2	Low-Level RF Controls				LEAD								498,9	612,0	204,0	1314,9
WP.3	Nb3Sn-on-Cu films for 4.2-K cavity operation								LEAD				871,4	616,0	232,0	1719,4
WP.4	HOM Dampers & Fundamental Power Couplers	LEAD											572,2	620,0	296,0	1488,2
	TOTAL FOR iSAS Technology R&D												2931,8	2632	1009,8	6573,6

→ No deviations