CEN/CLC/JTC 22/WG 3 "Quantum Computing and Simulation"

Convenor: **PAUL Alexandra MME**

system_calibration_functional_requirements

Document type	Related content	Document date	Expected action
Meeting / Document for discussion	Meeting: Delft (Netherlands) 29 Apr 2026	2026-03-20	

Description

Dear members,

Please find attached a document regarding the functional requirements for Control Electronics Layer.

Best regards,

Simon

CEN/CLC/JTC 22/WG 3 **N 225**

CEN/CLC/JTC 22/WG 3 "Quantum Computing and Simulation"
WG Secretariat: AFNOR
Convenor: Alexandra Paul

CEN-CLC-JTC 22_##_system_calibration_functional_requirements

Document type	**Meeting**	**Document date**	**Expected action**
Contribution		2026-19-03	For decision

Title	System Calibration Functional Requirements
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Organisations	TNO, Delft Circuits, University of Parma, Parity QC, C12, Alice & Bob
Representing	NEN, UNI, DIN, ASI, AFNOR
Work Item number	N/A
Work Item title	Cryogenic Solid State
Summary	This work provides a contribution on the description and functional requirements of the system calibration functionality, embedded within the control software layer.
Motivation	
Details (also next page)	

5.1 Functional Descriptions

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5.1.3 System calibration

The aim of calibration is to ensure that quantum devices operate with high fidelity and reliability by precisely tuning the control parameters of quantum gates, qubits, and measurement systems. Due to the inherent sensitivity of quantum systems to noise, decoherence, and environmental fluctuations, calibration is essential for minimising errors and maintaining the accuracy of quantum operations.

These tend to be a set of low-level procedures used to ensure that the quantum hardware operates within specified performance ranges. It encompasses all processes required to maintain stable, predictable, and high-fidelity behaviour of primitive operations as defined by the control software layer. Calibration is therefore a continuous activity that harmonises the behaviour of qubits, signal pathways, control electronics and readout mechanisms with the expectations of higher layers.

"Cold start" calibrations are comprehensive procedures to initialise all calibration parameters via a full calibration cycle. They are typically initiated after a system cool-down, system start-up, or when major drift or configuration changes have occurred. These procedures may include full characterisation of qubit properties, extensive assessment of control and readout channels, and global updates of operational parameters. Cold start calibrations generally require longer execution times and provide the reference baseline for subsequent operation.

"Warm start" calibrations, by contrast, are lightweight procedures to (re)adjust calibration parameters via a partial calibration cycle. They are typically performed while the system is already in its operational regime. They aim to quickly adjust specific parameters that have drifted outside their acceptable tolerance without requiring a full recalibration cycle. Warm start calibrations are designed to minimise interruption of system availability and typically focus on local or incremental corrections, such as adjusting a qubit frequency, retuning a gate parameter, or updating a measurement threshold.

5.2 Functional requirements

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5.2.3 System calibration

An adequate system calibration should support various capabilities. These capabilities include the detection and adjustment of (a) qubit-related parameters, (b) signal parameters, (c) transmission and pre-distortion parameters, and (d) measurement parameters. And further on, the system calibration should also support (e) a fully autonomous monitoring and re-calibration framework.

5.2.3.1 Requirements for tuning qubit parameters

This category defines procedures for determining and maintaining the physical parameters required to operate qubits correctly. The calibration functionality shall:

- **Determine operating frequencies and energy level spacings** to ensure that addressing of qubits is unambiguous and stable over time.
- **Monitor coherence-related properties** which allow higher layers to adjust scheduling or compilation strategies based on evolving qubit performance.
- **Compensate for slow drift in device characteristics** by periodically updating the relevant physical parameter estimates, ensuring that all assumptions made by the instruction set architecture remain valid throughout operation.

These procedures provide the baseline hardware characterisation used by all gate and measurement calibrations.

5.2.3.2 Requirements for tuning signal parameters

Instruction-level calibration ensures that primitive operations executed on one or multiple qubits behave according to their idealised abstract operation defined by the ISA. The goal is to maintain gate accuracy, stability, and reproducibility.

The generic instruction-level calibration functionality shall:

- **Calibration of amplitudes, durations, phases and timing relationships** required to align physical control actions with the logical gate model.
- **Calibration of multi-qubit interaction parameters** to ensure predictable execution of entangling operations within hardware constraints such as adjacency or lane limitations.
- **Calibration of crosstalk effects** to ensure that operations on different qubits or channels remain sufficiently isolated according to system performance requirements.
- **Validate gate-execution fidelity** allowing the system to expose quality metrics to higher layers, such as the HAL or FTQC/QEC units.

Instruction-level calibration thereby provides the physical realisation layer upon which gate-level execution instructions can reliably operate.

5.2.3.3 Requirements for tuning measurement requirements

Measurement calibration ensures that the processes that map quantum states to classical outcomes perform within required accuracy ranges.

The generic measurement-calibration functionality shall:

- **Establishing reliable discrimination thresholds or classification rules** to ensure that measurement outcomes reflect the actual physical state of the qubits.
- **Calibration of the measurement basis and associated pulse parameters** guaranteeing compatibility with measurement instructions defined in the ISA.

- **Characterisation of readout-chain performance** to ensure that the control software layer has access to realistic performance parameters, such as readout error rates, latencies, or expected noise levels.
- **Monitoring the stability of measurement performance over time** to provide triggers for re-calibration when measurement fidelity degrades.
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5.2.3.4 Requirements for tuning transmission and pre-distortion parameters

This category ensures that signals generated by the control electronics and transmitted through the control highway reach the quantum devices with the required integrity.

The generic functionality shall:

- **Calibration of the transfer characteristics of control and readout channels to** align pulse shapes, timing and amplitudes with expected behaviour at the device layer.
- **Define the pre-distortion configuration required for measurement pulses,** ensuring that pulse generators, after applying hardware-level corrections, reproduce the intended pulse shape at the qubit. The control-software layer shall specify the required predistortion settings, while the control-electronics shall implement them**.**
- **Verification and adjustment of the timing** across multiple channels supporting synchronisation needed for parallel control operations.

These operations ensure that the control software can rely on stable signal delivery conditions.

5.2.3.5 Requirements for autonomous tuning

Calibration processes must remain functional throughout system operation. To maintain this, the calibration framework shall:

- **Continuously or periodically monitor drift** in qubit parameters, gate performance, and readout behaviour, detecting deviations that affect the correctness of ISA-level operations.
- **Provide trigger mechanisms for targeted recalibration**, enabling recalibration of specific subsystems without requiring full system initialisation or disruption of unrelated components.
- **Maintain versioning and lifecycle management of calibration states**, ensuring reproducibility, traceability, and consistent operational conditions across all layers above the control-software layer.
- **Issue software-level signals** indicating when warm-start or cold-start calibration is required, and suspend affected operations until authorisation to recalibrate is granted by higher-level control layers.
- **Signal completion of the calibration process** once all required procedures have finished, enabling safe resumption of quantum program execution and guaranteeing that updated calibration states are in effect. This ensures that calibrated parameters remain valid during runtime and that system performance remains within required limits.