CEN/CLC/JTC 22/WG 3 "Quantum Computing and Simulation"
WG Secretariat: **AFNOR**
Convenor: **Lefebvre Catherine Mrs**

PWI_CryogenicSolidState_Draft01

Document type	Related content	Document date	Expected action
Meeting / Document for discussion	Meeting: VIRTUAL 26 Oct 2023	2023-09-18	

CEN/TC XXX

Date: 20YY-XX

prEN XXXXX:20YY

Secretariat: XXX

JTC 22 WG3 Quantum Computing

Cryogenic Solid State Quantum Computing

Functional Requirement

Draft 01, 2023-09-14

CCMC will prepare and attach the official title page.

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[NOTE to the drafter: To update the Table of Contents please select it and press "F9". To recreate the Table of Contents, select *Custom Table of Contents – Options* and choose the appropriate headings/titles to display. For further instructions, see the *CEN Simple Template Quick Start Guide*.]

European foreword

This document (prEN XXXX:20YY) has been prepared by Technical Committee CEN/TC XXX "Title", the secretariat of which is held by XXX.

This document is currently submitted to the CEN Enquiry/Formal Vote/Vote on TS/Vote on TR.

This document will supersede EN XXXX:YYYY.

EN XXXX:YYYY includes the following significant technical changes with respect to EN XXXX:YYYY:

This document has been prepared under a Standardization Request given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s) / Regulation(s).

For relationship with EU Directive(s) / Regulation(s), see informative Annex ZA, ZB, ZC or ZD, which is an integral part of this document.

[NOTE to the drafter: Add information about related documents or other parts in a series as necessary. A list of all parts in a series can be found on the CEN website: www.cencenelec.eu.]

Introduction

One of the many possible hardware architectures for quantum computing is “Cryogenic Solid State Quantum Computing”. This family of architectures include solutions based on superconducting qubits (like Transmons and Flux Qubits), semiconductor spin-qubits, topological qubits, artificial atoms in solids, etc. They have in common that their quantum devices should operate at very low temperatures in a cryostat, and that their operation is controlled from electronics outside the cryostat.

[NOTE to the drafter: If patent rights have been identified during the preparation of the document, the following text shall be included:

“The European Committee for Standardization (CEN) draws attention to the fact that it is claimed that compliance with this document may involve the use of a patent concerning (...subject matter...) given in (... subclause...) and which is claimed to be relevant for the following clause(s) of this document:

Clause(s)...

CEN takes no position concerning the evidence, validity and scope of this patent right. The holder of this patent right has assured CEN that they are willing to negotiate licences under reasonable and non-discriminatory terms and conditions with applicants throughout the world. In this respect, the statement of the holder of this patent right is registered with CEN. Information may be obtained from:

Name of holder of patent right ...

Address ...

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights other than those identified above. CEN shall not be held responsible for identifying any or all such patent rights.”]

1 Scope

This document describes the functionalities of modules for use in cryogenic solid-state quantum computers and associated functional requirements. It leaves further details about interfaces and quantification of requirements to other , future, CEN/TRs.

This document does not specify specific values, only functional requirements, and may offer informative examples that have been proven in practice. Functional requirements are mainly an enumeration of characteristics that are considered as relevant for future specification as well as a motivation why they are relevant.

Cryogenic solid-state quantum computers belong to an architecture family of which all members make use of a cryostat. The quantum device(s) within the fridge are usually controlled from outside by room-temperature control electronics, through a (huge) number of I/O channels. Examples of members within this architecture family are solutions based on superconducting transmons, superconducting flux qubits, semiconductor spin qubits, topological qubits and artificial atoms in solids.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

[NOTE to the drafter: The Normative references clause is compulsory. If there are no normative references, add the following text below the clause title: "There are no normative references in this document."]

EN XXXX, *Title of document*

EN XXXX-1:20YY, *General title of series — Part X: Title of part*

EN XXXXX (all parts), *General title of series*

[NOTE to the drafter: If a dated reference is impacted by a standalone amendment or corrigendum, list the main standard and include a footnote as follows:

EN XXXX:20YY[1], *General title*]

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply / the terms and definitions given in… and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp/

— IEC Electropedia: available at https://www.electropedia.org/

[NOTE to the drafter: The Terms and definitions clause is compulsory. If there are no terms and definitions, add the following text: "No terms and definitions are listed in this document."]

3.1

[1] As impacted by EN XXXX:20YY/A1:20YY.

term
text of the definition

3.2
term
admitted term
text of the definition

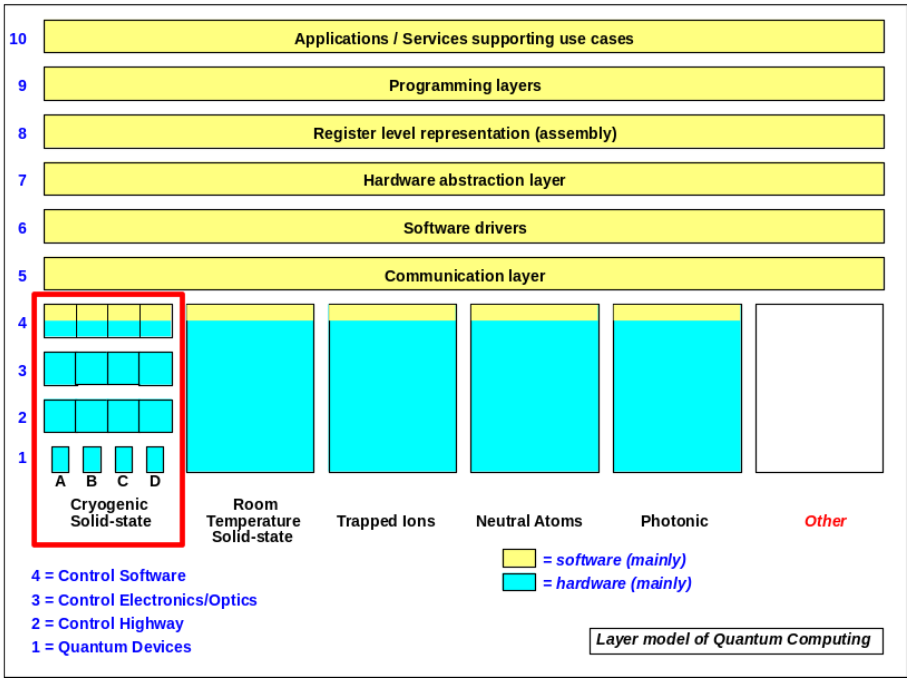
Note 1 to entry:

[SOURCE: EN XXXX:20YY, definition XX]

[NOTE to the drafter: If applicable, a list of 'Symbols and abbreviated terms' can be included as a subclause under Clause 3 or added as a separate Clause 4.]

4 Overview

The description of cryogenic solid state quantum computing comprises the hardware and software layers of the CEN/CENELEC Layer model [*], as shown within the box in figure 1. It involves an architecture family of which all members make use of a cryostat. The quantum device(s) within the fridge are controlled from outside by room-temperature control electronics, through a (huge) number of I/O channels. Examples of members within this architecture family are superconducting transmons, superconducting flux qubits, semiconductor spin qubits, topological qubits and artificial atoms in solids.



ED NOTE: Figure [*] This figure should remain the same as the one being specifiead as “Layer Model”. A box draws which part of that layer model is within the scope of the present TR

The description of this architecture family is organized as a stack of the following hardware and software layers, that are described in further detail in succeeding chapters :

- Layer 1: Quantum devices
- Layer 2: Control Highway
- Layer 3: Control Electronics
- Layer 4: Control Software

This architecture family involves different implementations of a quantum device. This is symbolically depicted in figure [*] by the characters A, B, C, D.

A module is an implementation that may be constructed from (smaller) modules and components. It could offer the functionality of a single layer, of multiple layers, or just of a fragment of a layer. A module may also support different operating modes, such that it complies with the requirements of multiple members and/or multiple architecture families. As such, the functionality of a module may cover multiple layers and/or families and/or members.

4.1 Subclause title

4.2 Subclause title

4.2.1 Subclause title

4.2.1.1 Subclause title

4.2.1.1.1 Subclause title

4.2.1.1.1.1 Subclause title

Text of subclause.

5 Layer 1 – Quantum Devices

The quantum devices in hardware layer 1 are modules with qubits that are operating at cryogenic temperatures and may be implemented as chip and/or on PCB (Printed Circuit Boards). They may have though requirements on shielding, operating temperature, magnetic aspects, etc.

5.1 Functional Description

The following members have been identified within this architecture family:

- Transmons;
- Flux qubits;
- Semiconductor spin qubits;
- Topological qubits;
- Artificial atoms in solids.

5.2 Function Requirements

6 Layer 2 – Control Highway

Hardware layer 2 covers all infrastructure needed for transporting microwave, lightwave, RF and DC signals (via electrical and/or optical means) between the control electronics at room temperature and the quantum devices at cryogenic temperatures.

It is usually a mix of transmission lines, filtering, attenuation, amplification, (de)multiplexing, as well as means for proper thermalization. A huge number of control channels are required to control many qubits in a fridge (which clarifies the name) and this can easily become very bulky. It could have tough requirements on aspects like heat-flow, thermal noise and vacuum properties.

6.1 Functional Descriptions

6.2 Functional Requirements

7 Layer 3 – Control Electronics

Hardware layer 3 covers all electronics for generating, receiving, and processing microwave, RF and DC signals. Some implementations make use of routing/switching and/or multiplexing of control signals at room temperatures. It may have some firmware on board to guide the signal generation and signal processing.

7.1 Functional Descriptions

7.2 Functional Requirements

8 Layer 4 – Control Software

Software (and hardware) layer 4 covers a mix of hardware and low-level driver software for instructing the control electronics and software for performing calibration. It has a software interface to higher layers for receiving sequences of instructions about when, where and what pulses are to be generated, and how to process and read-out the response.

Placed on top of quantum hardware, control software delivers high-performing qubit operations to higher level of abstraction in the quantum stack with minimal user intervention. It may include calibration means, low-level code to translate instructions from higher software layers into commands for guiding the control electronics/optics, and comprises the techniques used to define error-robust physical operations and associated supporting protocols designed to tune-up and stabilize the hardware.

Control software for quantum hardware is typically stored on digital computers, i.e., there is a very strict separation between the place where the control software is stored and the quantum registers. In the long term, control software may work in concert with Quantum Error Correction (QEC), which is supposed to lay at the assembly / register level programming layer, to provide broad coverage of various error types. More specifically, control software could improve the efficiency of QEC, i.e., reduce resource overheads required for encoding, by homogenizing error rates and reducing error correlations.

8.1 Functional Descriptions

8.2 Functional Requirements

9 Benchmarking (Low level)

Annex A
(informative)**111**

Title of Annex A, e.g. Example of a table, a figure and a formula

Annex BClause title

B.1.1 Subclause title

Annex CSubclause title

Annex DSubclause title

Annex ESubclause title

Text of the annex.

Annex FExample of a table

Table A.1 — Table title

Table header[a]			
Table text	Text[b]		
NOTE Table note.			
[a] Table footnote. [b] Second table footnote.			

[NOTE to the drafter: For indented text, it is recommended to create new cells instead of using tabs. Similarly, when aligning text to the right or center, use Word alignment buttons rather than tabs.]

Annex GExample of a figure

Dimensions in millimetres

Insert and Link Figure

Key

X definition for X

Y definition for Y

NOTE Figure note.

Figure text.

Figure A.1 — Figure title

Annex HExamples of formulae

A + B = C (1)

where

A is … ;

B is … ;

C is … .

[NOTE to the drafter: For simple formulae, the keyboard can be used. For more complex formulae, it is recommended to use MathType, if available, or MS Word Equation Editor.]

$$D_1 = 5,77 \times 10^{-13} \frac{C_1 \rho_1}{4\pi} \sum y_i \left(\frac{\mu_{en}}{\rho} \right) E_i \int B_i(1) \frac{e^{-\mu_i(1) s_1}}{\ell^2} dV \quad (2)$$

where

$B_i(1)$ is …

D_1 is…

…

Annex ZA
(informative)

Relationship between this European Standard and the [essential]/[interoperability]/[…] requirements of [Directive]/[Regulation]/[Decision]/[…][Reference numbers of the legal act] aimed to be covered

[NOTE to the drafter: This is the Generic Annex ZA template. For some Directives/Regulations, specific templates need to be used and these can be found on the CEN BOSS: https://boss.cen.eu/reference-material/FormsTemplates/Pages/]

This European Standard has been prepared under a Commission's standardization request [Full reference to the request "M/xxx"/"C(2015) xxxx final"] to provide one voluntary means of conforming to [essential] / [interoperability] / […] requirements of [Directive] / [Regulation] / [Decision] / […] [Reference numbers of the legal act] [Full title].

Once this standard is cited in the Official Journal of the European Union under that [Directive] / [Regulation] / [Decision] / […], compliance with the normative clauses of this standard given in Table […] confers, within the limits of the scope of this standard, a presumption of conformity with the corresponding [essential] / [interoperability] / […] requirements of that [Directive] / [Regulation] / [Decision] / […], and associated EFTA regulations.

Table ZA.1 — Correspondence between this European Standard and [Annex … of] / [Article(s) … of] [Directive] / [Regulation] / [Decision] [Reference numbers of the legal Act]]

[Essential]/ [interoperability]/[…] Requirements of [Directive]/[Regulation]/[Decision] […]	**Clause(s)/sub-clause(s) of this EN**	**Remarks/Notes**

[NOTE to the drafter, to be removed before publication:

This table can be used to accommodate all possible cases and independently how detailed correspondence is established or is possible to give:

- to declare the correspondence with a general statement 'all requirements are covered' by complying 'all (or indicated) clauses' (then the table would contain only one row);

- to declare more detailed correspondence (then the table would contain as many rows as needed).]

WARNING 1 — Presumption of conformity stays valid only as long as a reference to this European Standard is maintained in the list published in the Official Journal of the European Union. Users of this standard should consult frequently the latest list published in the Official Journal of the European Union.

WARNING 2 — Other Union legislation may be applicable to the product(s) / [service(s)] / […] falling within the scope of this standard.

Bibliography

[1] EN XXXX, *General title*