IEC 61788-22-1

Edition 1.0 2017-07

# INTERNATIONAL STANDARD

# NORME INTERNATIONALE

**Superconductivity –**
**Part 22-1: Superconducting electronic devices – Generic specification for sensors and detectors**

**Supraconductivité –**
**Partie 22-1: Dispositifs électroniques supraconducteurs – Spécification générique pour les capteurs et détecteurs**



IEC 61788-22-1:2017-07 (en-fr)

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**SUPERCONDUCTIVITY –**

**Part 22-1: Superconducting electronic devices –
Generic specification for sensors and detectors**

## FOREWORD

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International Standard IEC 61788-22-1 has been prepared by IEC technical committee 90: Superconductivity.

This bilingual version (2019-08) corresponds to the monolingual English version, published in 2017-07.

The text of this standard is based on the following documents:

| FDIS | Report on voting |
|---|---|
| 90/388/FDIS | 90/391/RVD |

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

The French version of this standard has not been voted upon.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61788 series, published under the general title *Superconductivity*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

# INTRODUCTION

Superconductivity offers various possibilities for the realization of sensing and detection of a variety of measurands. Several sensors and detectors have been developed, exploiting features like superconducting energy gaps, sharp normal-superconducting transition, nonlinear $I$–$V$ characteristics, superconducting coherent states, and quantization of magnetic flux. All these properties can be influenced by the interaction with electromagnetic fields, photons, ions, etc. Superconducting sensors and detectors have extremely high performance for energy resolution, time response, and low noise, most of which cannot be realized by any other phenomena.

The word "sensor" is normally used for measuring stationary or slowly changing electromagnetic fields, physical quantities such as current and temperature. On the other hand, the word "detector" is normally used for single quanta such as photons from infrared to $\gamma$-rays and individual particles. However, the boundary between "sensor" and "detector" is ambiguous. In this document, therefore, both "sensor" and "detector" are used. Additionally, a detector using a sensor is possible, for example, X-ray detector using transition edge sensor (TES) that measures temperature rise due to the deposition of measurand energy. In this document, for example, the terminology "transition edge sensor X-ray detector" is used for X-ray detection using TES.

Superconducting sensors and detectors have been applied to a variety of fields including medical diagnosis, telecommunications, mineral exploration, astronomical instruments, quantum information processing, and analytical instruments. For users, IEC standardization is necessary because there is confusing terminology, there are no graphical symbols for diagrams, and no test methods.

**SUPERCONDUCTIVITY –**

**Part 22-1: Superconducting electronic devices – Generic specification for sensors and detectors**

## 1 Scope

This part of IEC 61788-22-1 describes general items concerning the specifications for superconducting sensors and detectors, which are the basis for specifications given in other parts of IEC 61788 for various types of sensors and detectors. The sensors and detectors described are basically made of superconducting materials and depend on superconducting phenomena or related phenomena. The objects to be measured (measurands) include magnetic fields, electromagnetic waves, photons of various energies, electrons, ions, $\alpha$-particles, and others.

## 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.



IEC 60027 (all parts), *Letter symbols to be used in electrical technology*

IEC 60050-815, *International Electrotechnical Vocabulary – Part 815: Superconductivity*

IEC 60417, *Graphical symbols for use on equipment* (available at: http://www.graphical-symbols.info)

IEC 60617, *Graphical symbols for diagrams* (available at: http://std.iec.ch/iec60617)

ISO 1000, *SI units and recommendations for the use of their multiples and of certain other units*

ISO 7000*, Graphical symbols for use on equipment – Registered symbols* (available at: http://www.graphical-symbols.info)

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-815 and the following apply.

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

**3.1**
**additional positive feedback**
**APF**
method enhancing voltage-flux transformation ratio by using resistance and coupling coil to SQUID ring

**3.2**
**critical current modulation parameter**
$\beta_L$
parameter defined by $2LI_c/\Phi_0$, where $L$ is the SQUID washer inductance, $I_c$ is the critical current of a Josephson junction, for DC SQUIDs, and a parameter defined by $2\pi LI_c/\Phi_0$ for RF SQUIDs

Note 1 to entry: The term "shielding parameter" can also be used.

**3.3**
**Stewart-McCumber parameter**
$\beta_C$
parameter defined by $2\pi I_c R_n^2 C/\Phi_0$, where $R_n$ is the normal state resistance of a Josephson junction, and $C$ is the capacitance of a Josephson junction

**3.4**
**bridge junction**
junction formed from two superconductors connected by a superconducting bridge of small section



Note 1 to entry: The term "microbridge" can also be used.

**3.5**
**critical current**
$I_c$
maximum direct current that can be regarded as flowing through a Josephson junction without resistance



**3.6**
**critical current density**
$J_c$
critical current divided by the cross-section of the conductor or the junction area of the Josephson junction

**3.7**
**feedback coil**
coil that is inductively coupled to a SQUID operated in the flux locked loop (FLL) mode

**3.8**
**flux locked loop**
**FLL**
method that improves linearity and dynamic range of a SQUID by using negative feedback to keep the constant flux number in the SQUID ring

**3.9**
**gradiometer**
configuration of superconducting loops coupled to a SQUID magnetometer, or of multiple SQUID magnetometers that are arranged so as to be insensitive to homogenous magnetic fields or to be sensitive to magnetic field gradients

**3.10**
**metallic magnetic calorimetric detector**
type of superconducting device that the temperature increase of a metallic absorber is measured by sensing the magnetization change of the absorber because of measurand energy deposition

**3.11**
**microwave kinetic inductance detector**
type of superconducting device that uses the microwave surface impedance change of a superconducting strip because of measurand energy deposition

**3.12**
**normal state resistance**
resistance of a superconductor or a Josephson junction at a normal state

Note 1 to entry: In a superconductor or a TES, it is the resistance at a temperature just above the superconducting transition.

Note 2 to entry: In a Josephson junction, it is the tunnelling resistance at a bias voltage well above $2\Delta/e$.

**3.13**
**planar gradiometer**
kind of configuration of the flux pickup loop that measures a magnetic field gradient in the plane of the flux pickup loop coupled to a SQUID



**3.14**
**quasiparticle**
excitation combining properties of an electron and a hole that is created by breaking a Cooper pair in a superconductor



**3.15**
**superconducting hot electron bolometric mixer**
type of superconducting device that uses heterodyne mixing with the resistive transition from the superconducting state to the normal state in a superconducting microbridge because of measurand energy deposition

**3.16**
**superconducting quantum interference device sensor**
**SQUID sensor**
type of superconducting device that uses quantum interference occurring in a closed electrical circuit containing one or more Josephson junctions

Note 1 to entry: Every measurand, for example magnetic fields or electric currents, that is transformed into a change of magnetic flux threading the superconducting structure can be sensed by a SQUID.

**3.17**
**SQUID array**
**SQA**
device consisting of series and/or parallel arrays of multiple SQUIDs

**3.18**
**nano-SQUID**
device whose largest loop dimension is less than 500 nm

**3.19**
**SQUID ring**
multiply superconducting structure that contains one or more Josephson junctions

Note 1 to entry: The term "SQUID loop" can also be used.

**3.20**
**SQUID amplifier**
current–voltage converter using a single SQUID, SQUID array or other SQUID-based current sensor circuits

**3.21**
**subgap region**
lower branch of the hysteretic $I$–$V$ characteristic of a tunnel junction where the voltage is less than 2Δ

**3.22**
**subgap current**
quasiparticle tunnelling current in the subgap region of a tunnel junction

Note 1 to entry: In Josephson tunnel junctions, the whole subgap region is observable when the DC Josephson effect is suppressed by applying a magnetic field parallel to the plane of the junction area.

**3.23**
**superconducting strip detector**
type of superconducting device that uses the local resistive change in a long superconducting strip because of measurand energy deposition

Note 1 to entry: The name for a photon detector, superconducting nanowire photon detector, is not recommended for most cases, since the dimensions of superconductors are often in discord with the current definition of "nanowire" in ISO/TS 80004-2:2015, in which "nanowire" or "nanofibre" is defined as nano-objects with two external dimensions in the nanoscale that are approximately 1 nm to 100 nm, and the third dimensions significantly larger. The dimensions of the superconducting strip type meet the definition of "nanoribbon" or "nanotape" in most cases.



Note 2 to entry: The terms "nanoribbon" and "nanotape" have one external dimension in the nanoscale and the other two external dimensions significantly larger (typically by more than 3 times). In addition, the two larger dimensions significantly differ from each other. "Nanostrip" is preferable to "nanoribbon" and "nanotape" for superconducting sensors and detectors.



Note 3 to entry: An example of the superconducting nanowires is the strip with the dimensions of 10 nm × 30 nm × 10 µm. The difference between the thickness and width is approximately less than 3 times. That superconductor can be called "superconducting nanowire photon detector".

**3.24**
**superconducting tunnel junction detector**
type of superconducting device that uses the change of electron tunnelling between two superconductors or a superconductor and a normal conductor separated by tunnelling barrier because of measurand energy deposition

**3.25**
**temperature sensitivity**
superconducting transition edge steepness that is defined by $\mathrm{d}\ln R/\mathrm{d}\ln T$ where $R$ is the resistance and $T$ is the temperature of TES

**3.26**
**transition edge sensor detector**
type of superconducting device that uses the resistive change within a sharp normal-to-superconducting transition as a temperature sensor because of measurand energy deposition

# 4 Symbols

Units, graphical and letter symbols shall be taken from the following standards:

- IEC 60027 (all parts);
- IEC 60417;
- IEC 60617;
- ISO 1000;
- ISO 7000.

Graphical symbols for use on equipment and diagrams, such as superconducting region, normal connection, superconducting connection, normal-superconducting boundary, Josephson junction, are defined in Annex C, and IEC 60417 and IEC 60617. Graphical symbols specific to other sensors or detectors are defined in other parts of IEC 61788.

## 5 Terminology and classification

### 5.1 Terminology

Table 1 lists the measurands which are defined as categories, objects, or physical quantities that induce enegy deposition and are to be sensed or detected by superconducting sensors and detectors. The measurands, arranged in alphabetical order, are: atoms and molecules, elementary particles, physical quantities, and radiations. Each entry in Table 1 not only represents the measurand itself, but also its temporal or spatial distribution.

Any other terminology peculiar to one of the devices covered by this document shall be taken from the relevant IEC or ISO standards.

**Table 1 – Measurands**

| Category | Object | Physical quantity |
|---|---|---|
| Atoms and molecules | Atoms | Count, energy, flux, time |
| | Organic molecules | Count, energy, flux, time |
| | Nonorganic molecules | Count, energy, flux, time |
| | Other (specify) | |
| Elementary particles | Dark matters | Count, energy, flux, time |
| | Electrons | Count, energy, flux, time |
| | Neutrinos | Count, energy, flux, time |
| | Neutrons | Count, energy, flux, time |
| | Photons | Count, energy, flux, time |
| | Protons | Count, energy, flux, time |
| | Positrons | Count, energy, flux, time |
| | Other (specify) | |
| Physical quantities | Capacitance | Amplitude |
| | Current | Amplitude |
| | Inductance | Amplitude |
| | Magnetic field | Strength, distribution |
| | Magnetic flux | Density, distribution |
| | Magnetic susceptibility | Amplitude |
| | Polarization | Amplitude |
| | Resistance | Amplitude |
| | Voltage | Amplitude |
| | Other (specify) | |
| Radiations | Alpha-particles | Count, energy, flux |
| | Beta-particles | Count, energy, flux |
| | Electromagnetic waves | Amplitude |
| | Gamma-rays | Count, energy, flux |
| | Optical radiation | Count, energy, flux |
| | X-rays | Count, energy, flux |
| | Other (specify) | |



The objects for measurands fall into two classes: fields and physical quantities, and particles, as listed in Table 2. Based on these classes, detection mechanisms are classified into coherent detection for fields and physical quantities, and direct detection for particles.

**Table 2 – Classification of measurands**

| Classification | Measurand category |
|---|---|
| Field and physical quantities | Physical quantities |
| | Radiations (electromagnetic waves) |
| Particles | Atoms and molecules |
| | Elementary particles |
| | Radiations (individual electromagnetic radiation quanta) |

Table 3 lists the various types of sensors and detectors (alphabetical order). The sensors and detectors convert measurands to electronic signals. The word "sensor" tends to be used for devices that measure fields and physical quantities, while the word "detector" tends to be used for devices that measure single particles. When naming sensors or detectors, the following word order should be used for nomenclature: device structure or function; measurand; and a word of detector, magnetometer, mixer, sensor, or other words. Examples of full names and corresponding acronyms are also listed.

**Table 3 – Nomenclature of superconducting sensors and detectors: type, full names, and acronym examples**

| Type | Full names and acronym example |
| --- | --- |
| Metallic Magnetic Calorimetric (**MMC**) type | Metallic Magnetic Calorimetric $\alpha$-ray Detector (**MMC** $\alpha$-ray detector or **MMCAD**) |
| | Metallic Magnetic Calorimetric $\gamma$-ray Detector (**MMC** $\gamma$-ray detector or **MMCGD**) |
| | Metallic Magnetic Calorimetric X-ray Detector (**MMC** X-ray detector or **MMCXD**) |
| Microwave Kinetic Inductance (**MKI**) type | Microwave Kinetic Inductance Photon Detector (**MKI** photon detector or **MKIPD**) |
| | Microwave Kinetic Inductance X-ray Detector (**MKI** X-ray detector or **MKIXD**) |
| Superconducting Hot Electron Bolometric (**SHEB**) type | Superconducting Hot Electron Bolometric Photon Detector (**SHED** photon detector or **SHEBPD**) |
| | Superconducting Hot Electron Bolometric Terahertz Mixer (**SHEB** terahertz mixer or **SHEBTM**) |
| Superconducting Quantum Interference Device (**SQUID**) type | Superconducting Quantum Interference Device Amplifier (**SQUID** amplifier or **SQUIDA**) |
| | Superconducting Quantum Interference Device Current Sensor (**SQUID** current sensor or **SQUIDCS**) |
| | Superconducting Quantum Interference Device Gradiometer (**SQUID** gradiometer or **SQUIDG**) |
| | Superconducting Quantum Interference Device Magnetometer (**SQUID** magnetometer or **SQUIDM**) |
| | Superconducting Quantum Interference Filter Magnetometer (**SQIF** magnetometer of **SQIFM**) |
| | Superconducting Quantum Interference Device Array Magnetometer (**SQUID** array magnetometer or **SQUIDAM**) |
| Superconducting Strip (**SS**) type | Superconducting Strip Electron Detector (**SS** electron detector or **SSED**) |
| | Superconducting Strip Ion Detector (**SS** ion detector or **SSID**) |
| | Superconducting Strip Particle Detector (**SS** particle detector or **SSPD**) |
| | Superconducting Strip Photon Detector (**SS** photon detector or **SSPD**) |