Progress of IEEE-IEC Joint Standardization on Superconducting Electronics Devices:

Report on the Standardization Session at IWSSD2016

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***Abstract* – The report on the Standardization Session at the IWSSD 2016 Workshop is prepared as a technical paper. At the session covered were:**

- **Organization of the IEC–IEEE standardization effort in superconducting electronics, responsibilities and appointments.**
- **Registered graphical symbols in superconducting electronics, including explanation of Josephson junction symbol design logic – in analogy to semiconductor symbols.**
- **Round robin tests on HTS and LTS Josephson junctions, junction arrays and SQUIDs.**
- **A proposal for standardization of superconducting strip type photon detectors (SSPD).**
- **A road map for standardization of superconducting electronics.**

***Keywords* – Superconducting electronics, standardization, superconducting sensor, superconducting detector, IEC, IEEE, graphical symbols, round robin test, Josephson junction, JJ, Josephson junction array, superconducting quantum interference device, SQUID**

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I. THE STANDARDIZATION SESSION

REPORTER: Masataka Ohkubo, Convener of International Electrotechnical Commission - Technical Committee 90 / Working Group 14 (IEC-TC90/WG14)[1]

DATE: November 14, 2016

TIME: 15:00-18:00

PLACE: Room 301(3F), Tsukuba International Congress Center EPOCHAL, Japan

TITLE OF STANDARDIZATION: Superconducting electronic devices - Generic specification for sensors and detectors (IEC61788-22-1)

PARTICIPANTS: The meeting was attended by 16 participants with 7 IEC members, 4 IEEE members, and 5 newcomers.

The standardization session of the 3rd International Workshop on Superconducting Sensors and Detectors 2016 (IWSSD2016) was held at Tsukuba, Japan, on the first day of the Workshop. The IEEE-IEC (International Electrotechnical Committee) joint meetings have been taking place twice a year on average, during conferences such as ASC, EUCAS, ISEC, IWSSD, etc. The first meeting was held at ISEC2013 in Boston. Among the superconductivity conferences, the IWSSD is unique in that the workshop program contains both of scientific sessions and the standardization session. The IEEE-IEC joint meetings are open to all researchers and engineers as well as the IEEE and IEC committee members. Next meetings will be organized at ISEC2017, to be held in Sorrento, Italy, and EUCAS2017, Geneva, Switzerland.

The Working Group 14 (WG14) was established under the IEC Technical Committee 90 (IEC TC90) in 2010 in order to develop and publish international standards on "superconducting electronic devices - sensors and detectors." [1]. The IEC TC90 committee lead by the chairman Christian-Eric Bruzek (Nexans) and the secretary Jun Fujikami (Sumitomo) holds official meetings every two years, and informal meetings during conferences. Previous reports on our standardization efforts were published in Refs. [2, 3].

At the present meeting, it was confirmed that we take a step forward from IEC Committee Draft for Vote (CDV) to the Final Draft for International Standard (FDIS). The content of the CDV on "Superconducting Electronic Devices - Generic Specification for Superconducting Sensors and Detectors (IEC61788-22-1)" was examined. The international standard (IS) of the generic specification will be published in the middle of 2017, after the international vote for FDIS that will be circulated in April 2017 (IEC FDIS 61788-22-1). The IS of the generic specification, which will be followed by a series of ISs for measurement methods, covers measurands that are quantities to be measured by sensors and detectors, classification, nomenclature, terminology, brief explanation of different types of sensors and detectors, and graphical symbols in superconducting electronic devices. In nomenclature, the so-called Superconducting Single Photon Detector (SSPD) are redefined as Superconducting Strip Photon Detector (SSPD) or Superconducting Nanostrip Photon Detector (SNSPD) to maintain consistency with the ISO definition of nano-objects (ISO/TS 80004-2:2015), see [4]. For graphical symbols, first two symbols officially registered with an IEC database are introduced: normal-superconducting boundary and the Josephson junction (JJ).

The discussion in the IEC-IEEE joint meeting was devoted to the graphical symbols for Josephson junction (JJ) and other devices, the round robin tests of low- and high-T_c SQUIDs for measurement method standards, a new proposal for Superconducting Strip Photon Detectors (SSPDs), and the IOP roadmap of standardization in superconducting electronics.

It was announced that the chair of IEEE superconducting electronics standardization group has been transferred from Cathy Foley (CSIRO) to Robert Fagaly (LEIDOS). He is now preparing Project Authorization Request (PAR) that is equivalent to New Work Item Proposal (NWIP) of IEC. After the approval of PAR in IEEE, we can establish an official IEEE-IEC joint working group. Two new members from Germany were registered as IEC WG14 experts: Jörn Beyer (PTB) and Erik Heinz (Supracon). The current full list of the experts is available in Ref. [1].

II. GRAPHICAL SYMBOLS IN SUPERCONDUCTING ELECTRONICS

A. Introductory

First graphical symbols in the superconducting electronics field have been registered on Sep. 17, 2016 with the IEC 60417 database [5]: the normal-superconducting boundary and Josephson junction (JJ) shown in Fig. 1 and 2.

There was a natural question about the graphic JJ symbol, "Why do we have to change the conventional JJ cross symbol?" The answer to this question is that the JJ cross symbol is unfortunately incompatible with the existing IEC symbols. The cross symbol is assigned to an attribute that means magnetic effect or magnetic dependence. This will be discussed below in detail.

There are two IEC databases for graphical symbols: IEC 60417 - Graphical Symbols for Use on Equipment, which covers grounding, battery, AC/DC converter, transformer, power plug, etc., and IEC 60617 [6] - Graphical Symbols for Diagrams, which covers resistor, transistor, capacitor, etc. In addition to IEC 60417, we are now negotiating with the IEC TC3 which is responsible for IEC 60617, since double registration of the same symbols in both of IEC 60417 and IEC 60617 databases is recommended by them.

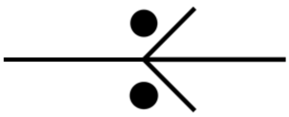


Fig. 1. IEC 60417-6370 Normal-superconducting boundary.
Left: normal conducting, right: superconducting

Fig. 2. IEC 60417-6371 Josephson junction.

The variation is an S-N-S line connection shown below.

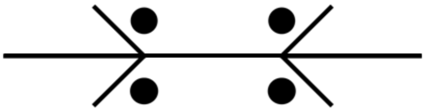
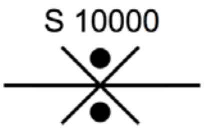


Fig. 3. A variation of IEC 60417-6370.

In these symbols, a pair of two dots symbolizes superconductivity or the Cooper pair. The Fig. 3 shows the connection of normal conducting line with two superconducting lines. The extremely small region of normal conducting line is the weak link creating a JJ. The structural logic of the symbols will be more preciously discussed below. Currently, SIS and SNS junctions are not distinguished. Since there is a request, some attributes to distinguish SIS and SNS can be added later.

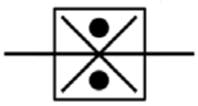
B. New Ideas of Symbols for Superconducting Devices

It is also possible to propose symbols for more complex devices with higher integration of JJs just like semiconductor integrated circuits. Proposals of other symbols that make diagram drawing in superconducting electronics easier are welcome. Please send any comment to m.ohkubo@aist.go.jp. The symbols below were proposed during the session. For the SQUID symbols, some experts pointed out difficulty in drawing inductive coupling with a superconducting ring. Further discussion is required.



Series array of 10,000 JJs, reference only

AC SQUID, reference only



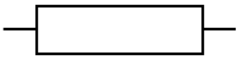
DC SQUID, reference only

Fig. 4. Symbols proposed at the session.

C. Introduction to Structural Logic of Graphical Symbols in IEC 60617 Database

Graphical symbols are not just drawings, but must have logic to symbolize circuit elements. Some examples in IEC 60617 are given below before explaining the logic of the JJ graphical symbols. The familiar zigzag symbol (**S01355**) for the resistor is currently obsolete and remains only for reference to old circuit diagrams so that the younger generation can recognize what the zigzag symbol is. New rectangle resistor symbol (**S00555**) replaced it in 1996. However, it isn't completely diffused worldwide even 20 years later. It is a matter of education, but this slow process should be accelerated by appropriate communication and dissemination activities by IEC and IEEE.

S01355, Obsolete, past resistor symbol

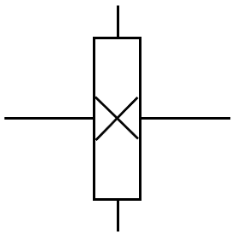


S00555 Resistor, general symbol

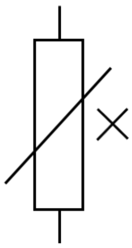
Fig. 5. Resistor symbols.

In IEC 60617, the cross symbol is assigned to an attribute for magnetic field effect or dependence (**S00123**). That attribute is used, for example, for the hall generator (**S00688**) with four connections by adding a cross (**S00123**) and additional two connections on the resistor symbol (**S00555**), or the magnetoresistor (**S00689**) by adding a cross and a variability line attribute on the resistor symbol, as follows.

S00123 Magnetic effect or magnetic dependence



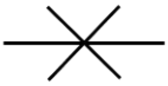
S00688 Hall generator



S00689 Magnetoresistor

Fig. 6. Examples of composite symbols containing the cross.

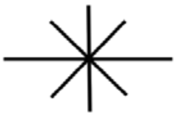
The conventional cross JJ symbol means a conducting wire that has a magnetic dependence, when two connecting lines for both sides are added. Therefore, it seems to be improper as a JJ symbol.



Example 1 of unacceptable symbol

Fig. 7. Example 1 of an inacceptable symbol.

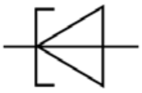
Addition of a vertical line to the above symbol also conflicts with an existing semiconductor symbol. The symbol below means a semiconductor device having some magnetic dependence with two ohmic connections. The vertical line for semiconductors will discussed large again.



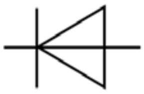
Example 2 of unacceptable symbol

Fig. 8. Example 2 of an inacceptable symbol.

For reference, the tunnel-diode-related symbols in IEC 60617 are shown below.



S00645 Tunnel diode (Esaki diode)



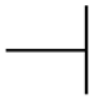
S00641 Semiconductor diode

S00637 Attribute of tunneling effect

Fig. 9. Tunneling and diode-related symbols.

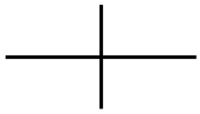
The **S00637** symbol is the attribute for tunneling effect. The **S00645** tunnel diode is composed of the **S00641** semiconductor diode and the **S00637** tunnel effect. Both of the tunnel diode and the Josephson junction received the Nobel prize simultaneously, but no JJ symbol was registered. The **S00637** tunnel effect attribute is suitable for JJ at first blush, but it is difficult to use it because it is asymmetric in contrast to the symmetric JJ property. Furthermore, it also symbolizes semiconductor region by the vertical line as shown in Fig. 10.

The structural logic of the semiconductor symbols in IEC 60617 is a good guideline for designing symbols in superconducting electronics. They defined a semiconductor region first. The term of “semiconductor region” is unfamiliar to us. The **S00613** semiconductor region below symbolizes the function of semiconductors with one ohmic connection.



S00613 Semiconductor region, one connection

The vertical line is the semiconductor region and the perpendicular line on the left side is the ohmic connection.



S00614 Semiconductor region, two connections

The vertical line is the semiconductor region and the perpendicular lines on both sides are the two ohmic connections.

Fig. 10. Semiconductor region symbols.

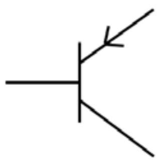
Semiconductor devices are formed by combining **S00613** or **S00614** with other functional elements or attributes. For example, the diode is the combination of **S00614** and a triangle to show the current direction. A PNP transistor is the combination of **S00613**, the attribute of emitter on the region of dissimilar conductivity type (**S00625**), and the collector on a region of dissimilar conductivity type (**S00629**). Field effect transistor symbol is formed by using similar components.

S00625

Attribute of emitter on a region of dissimilar conductivity type, P emitter on an N region

S00629

Attribute of collector on a region of dissimilar conductivity type



S00663 PNP transistor

Fig. 11. PNP transistor symbol and its components.

D. Structural Logic for Symbols of Josephson Junction

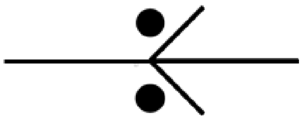
First of all, we have to define a superconducting region that symbolizes the function originating from superconductivity.

Superconducting region, one superconducting connection

The vertical two dots pair is the superconducting region and the horizontal line with the right angle wedge perpendicular to the dots' axis on the right side is the superconducting connection.

Superconducting region, one normal conducting connection

The vertical two dots pair is the superconducting region and the line perpendicular to dots' axis on the left side is the normal conducting connection.



Superconducting region, one superconducting connection, and one normal conducting connection (Normal-superconducting boundary)

The vertical two dots pair is the superconducting region, the perpendicular line with the right angle wedge on the right side is the superconducting connection, and the perpendicular line on the left side is the normal conducting connection.

Superconducting region, two superconducting connections with extremely small non-superconducting region (Josephson junction)

The vertical two dots pair is the superconducting region, the perpendicular lines with the right angle wedges are the superconducting connections. The non-superconducting region which is normal conducting or insulating is extremely small.

Fig. 12. Structural logic applied to symbol design of Josephson junction.

Another explanation of the above symbol is that the two dots pair symbolizing superconductivity is modified by the cross with magnetic dependence. This makes sense for JJ, because JJ is magnetic sensitive and the properties depend on magnetic field.

III. ROUND ROBIN TEST OF SQUID AND JJ

A. Introductory

The SQUID experts, Cathy Foley, Jörn Beyer, Ronny Stolz (IPHT), and Kiwoog Kim (KRISS) reported on the current status of HTS and LTS SQUID round robin test, and superconducting electronics research in Korea.

The first step of HTS SQUID measurement method standardization is a round robin test to characterize the environments of testing facilities worldwide. It is possible to unify specification sheets for both of HTS and LTS SQUIDs in future.

When we send SQUID chips, the US Department of Commerce Export Control Classification Number Category 6 – Sensors and Lasers 6A006 [7] should be referred. The regulation is

a.1.a: SQUID systems designed for stationary operation, without "specially designed" subsystems designed to reduce in-motion noise, and having a 'sensitivity' (the magnetic field resolution) equal to or lower (better) than 50 fT (rms) per square root Hz at a frequency of 1 Hz, and

a.1.b: SQUID systems having an in-motion-magnetometer 'sensitivity' lower (better) than 20 pT (rms) per square root Hz at a frequency of 1 Hz and "specially designed" to reduce in-motion noise."

In Japan, for example, we have to get permission from the Ministry of Economy, Trade and Industry, when the performance is better than the values specified above. Some documentation works are necessary, even when sensitivity is lower than the regulation values to certify the SQUID performance is worse than those values. It may different from country to country.

B. Round Robin Tests Underway

HTS RRT#0 (JJs)

Before SQUID RRT, HTS JJs measured at CSIRO in Aug. 2015 were transferred to SPAWAR and measurements are underway. The arrays will be circulated to other countries. The deadline of the HTS round robin test #0 is the starting date of ISEC2017. CSIRO will provides SQUID devices and possibly equipment such as Dewar and stick in future.

LTS RRT#0 (JJs and SQUIDs)

PTB Berlin working group 7.21 for cryosensors prepared LTS JJ and DC SQUIDs. The chip has two DC SQUIDs and two 19-JJ arrays. The chip was measured at PTB Berlin, IPHT Jena, and PTB Braunschweig. At PTB Berlin, the electronics used were Agilent DMU 1251 digital multimeter, Magnicon SQUID electronics, and Agilent DSO6104A digital oscilloscope. The chip will be circulated in Asian countries.

C. *South Korea Status Report*

The Korean academia recently focuses on materials like MgB_2, iron-based superconductors, and cuprate ones. The industries are looking for applications such as power cables, current limiters, storages, and magnets. Superconducting electronics research is mostly limited to Korea Research Institute of Standards and Science (KRISS) and Institute for Basic Science (IBS). The SQUID activity is only for LTS. They stopped the research on HTS SQUIDs.

KRISS completed the development of biomagnetic measurement systems. The KRISS's SQUID system technology was transferred abroad: a 152-channel LTS SQUID MEG system technology to an Australian company in 2016 and a 64-channel LTS SQUID MCG system technology to a German company in 2010. In Korea, they are proposing a new magnetic field measurement standard using proton spin-echo magnetometer.

KRISS is supplying SQUID amplifier for Metallic Magnetic Calorimetric Detectors (MMCDs) used for axion search experiment. They are also developing qubits. The MMC detectors are also used for high resolution alpha spectrometers, astroparticle physics projects such as Advanced Mo-based Rare process Experiment (AMoRE) for neutrino mass and Korea Invisible Mass Search – Low Temperature (KIMS-LT) for Weakly Interacting Massive Particles (WIMPs). The number of MMC module units is 30 in 2016, and will be upgraded to 1000 in 2020 to make a large-scale detector systems for particle physics.

Other activities in Korea include nano-devices like nanowire Josephson transistors, quantum dot superconductors, graphene Josephson junctions, and graphene supercurrent transistors. KRISS isn't responsible for industrial standardization in IEC or ISO, but they agreed to participate in the standardization efforts.

IV. PROPOSAL FOR STANDARDIZATION OF SUPERCONDUCTING STRIP TYPE PHOTON DETECTORS (SSPD)

A. Introductory

Lixing You (SIMIT) presented an introductory overview of physics, applications, business, and specifications of SSPD that is considered an important device for the quantum information technology field. That is one of the emerging fields of superconducting electronics. The SSPD performance in photon count rate, detection efficiency, dark count rate, and jitter is superior to that of semiconductor photon detectors or other type of superconducting detectors. However, there are no standard measurement methods.

B. Applications of SSPD

The applications include deep space laser communication, quantum key distribution, single photon imaging, laser ranging, etc.

C. Worldwide Business

Fifteen systems were already installed in China, which is equivalent to 1.2 M$. The SIMIT SSPDs are supplied to the ID Quantique (IDQ) company in Switzerland. The international market may be 5 M$/year. There are presently active five companies: SconTel (Russia), Single Quantum (Netherlands), Quantum Opus (USA), Photon Spot (USA), and Shanghai Photon Tech (China).

D. Proposal of New Project Team for SSPD

One way is to initiate new working group for SSPD measurement methods under IEC TC90 separately from WG14. Another way is to propose NWIP under WG14, organizing a new project team. The standardization strategy of the WG 14 was planned to make a series of succeeding standards. The first standard for generic specification is about to be published, which will be followed by JJ measurement method, SQUID measurement method, SSPD measurement method, and so on. Therefore, we agreed to create new project team under WG14.

V. ROAD MAP OF STANDARDIZATION IN SUPERCONDUCTING ELECTRONICS

We are planning to edit a road map issue on the IOP SUST journal. This road map will be a collection of a number of short overviews on different topics. Each article is about 3 pages long, and starts with a contextual piece. A plan of contents is as follows.

Introduction
Why do we need standards?
How do standards benefit companies, manufacturers and developers?
How do they benefit consumers?
Role of standards in global supply chains

VI. SUMMARY

1. IEC FDIS 61788-22-1 –Generic specification of sensors and detectors will be prepared in March 2017, and published as an international standard in the middle of 2017 after an international vote.
2. Two graphical symbols of normal-superconducting boundary (IEC 60417-6370) and Josephson junction (IEC 60417-6371) were registered with the IEC 60417 database – Graphical Symbols for Use on Equipment.
3. The negotiation with the technical committee for the IEC 60617 database - Graphical Symbols for Diagrams is in progress, and two symbols will be an issue of the next IEC TC3 international meeting taking place in Stockholm on Jan. 30-31, 2017. The WG14 proposal on the logic of the symbol structure will be discussed.
4. Graphical symbols are alive. If there are new ideas, we can take them into account. Please propose them to m.ohkubo@aist.go.jp in order to make our life easier.
5. LTS and HTS SQUID round robin tests have been initiated in order to make ISs on measurement methods.
6. A project team responsible for SSPD will be officially established.
7. The IOP SUST roadmap on superconducting electronics standardization is in progress.
8. Successive IEC-IEEE joint meetings will be held at ISEC2017, EUCAS2017, ASC2018,

IWSSD2018, etc.

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