Feature Article: Superconducting Microwave/Terahertz Wave Device Technology

- Recent Status of Superconducting Detectors and IEC Standardization Activities – Superconducting Sensor and Detector Standardization Proposals (Generic Specification) and International Vote Kick-off!

Masataka Ohkubo, Chief Innovation Coordinator
National Institute of Advanced Industrial Science and Technology

Superconducting detectors or sensors have enabled measurements that proved impossible using other technologies (although “detector” and “sensor” are synonymous, IEC standardization now considers the use of these two terminologies because the way they are used differs). It has been a while now since SQUIDs realized micro magnetic field detection sensitivities unrivaled by any other technologies, leading to their practical deployment in magneto-cardiograph, magneto-encephalograph, contamination test, mineral exploration etc. Now, their application to earthquake prediction is gathering attention. Recently, the development of an optically pumped atomic magnetometer exceeding SQUID sensitivities and progress of a non-superconducting sensor utilizing spintronics has advanced. Despite this, the SQUID still maintains its advantages as a measurement system for practical use. It has been a while now since a Superconductor-Insulator-Superconductor (SIS) mixer was employed as a heterodyne detector in radio astronomy applications. Amongst the opinions from individuals at the IEC propose that the term ‘SIS mixer’ should be more appropriate to a Superconducting Tunnel Junction (STJ) mixer. The above-mentioned superconducting detectors are all that can be categorized under the term coherent detection.

Additionally, superconducting detectors operated in direct detection mode emerged around thirty years ago, initially for the science to detect solar neutrinos and dark matter. The development of these types of detectors coincided with a now historical international workshop called, International Workshop on Low Temp Detectors (LTD). The type and performance characteristics of a direct detector are summarized in refs.1 and 2. Direct detection involves measuring cooper pair breakage caused by single-photon absorption leading to an energy dispersive spectroscopy of photon energy. This type includes STJ and Microwave Kinetic Inductance Detector (MKID). In addition to the detection principle, where the destruction of superconductivity is initiated by quantum energy, there are other types of superconducting sensors able to measure temperature increases as well as changes in magnetic susceptibility due to single photon absorption. These types can also be categorized as direct detection and include a Transition Edge Sensor (TES) and Metallic Magnetic Calorimeter (MMC). These detectors are now progressing for practical realization in the analysis equipment field to be utilized for R&D, including elemental analysis such as synchrotron radiation material analysis, mass analysis, SEM and TEM, in addition to astronomical studies such as radio telescope astronomy and cosmic microwave background (CMB) detection. The development of direct detection has progressed with the use of multi-element arrays that have enlarged the detection area as well as provided imaging capabilities. The development of an STJ has involved a parallel read-out with one read-out circuit per element, taking the advantage of high-count rates. A 100-pixel STJ can serve a high photon count-rate of 500k cps and suitable for synchrotron radiation applications. The development of a TES has seen the completion of a 10,000-pixel scale THz imager, by using a time division multiplexer.
In recent years, a simple-structured Superconducting Strip Detector (SSD) has been developed. The SSD has been fabricated by forming strips less than 1 μm wide in a superconducting thin film with a thickness ranging from several-nm to several 10's nm. This type of detector was initially utilized for single photon detection at telecommunication wavelengths. Currently, high quantum efficiencies and high-count rates are anticipated for quantum information communications. With regards to the term Superconducting Single Photon Detector (SSPD), which has been utilized by adding ‘superconducting’ to Single Photon Detector, was already used and applicable to semiconductor detectors. However, since any type of superconducting detectors enable single photon detection, opinions from individuals at the IEC and related communities state that the term “SSPD” is not appropriate for certain types of superconducting detectors. Currently, the proposal is for SSD. In case of photon detection, the recommended terminology is a Superconducting Strip Photon Detector (SSPD) and its abbreviation is the same, SSPD, as per its original acronym. SSDs have been realized for the detection of electrons, ions and molecules in addition to single photons at communication wavelengths, and its applicability to analysis equipment is also anticipated. There are many types of superconducting detector already in existence, and the emergence of further new types of detectors is expected in the future. The draft idea is to integrate the terminology according to its classification of structure (or functionality) + what to detect + detector (or sensor, mixer).

The proposal to establish an ad hoc group 4 to explore the standardization of superconducting sensors and detectors has been raised by Japan and approved at the IEC General Meeting held in 2010, Seattle. With participants comprising of 11 experts from around the world, standardization activities have been undertaken over the past three years. The outcomes from these meetings have seen the completion of a New Working Item Proposal (NWIP) with regards to Generic Specification (categorization of detectors, term, circuit symbol etc.) at end of 2013. The NWIP, which includes both coherent and direct detections, has entered international voting with effect from 10th January 2014. The voting period lasts for three months, closing on 11th April, with the anticipation of the approval from P member countries of IEC TC90. With the successful international approval for this NWIP, the establishment of a new WG is planned together with collaborations from IEEE. The standardization of terminology and electric circuit symbols that have been written in draft generic specifications will be progressed in collaborations with other WGs. Detailed specifications regarding the standardization and performance testing methods of each type of detector will follow suit in the future.
References:
1) M. Ohkubo, “Introduction to IEC standardization for superconducting sensors and detectors,” Prog. Supercond. 14, 106 (2012);
   http://ocean.kisti.re.kr/is/mv/showPDF_ocean.jsp?method=download&pYear=2012&koi=KISTI1.1003%2
   FJNL.JAKO201209857785508&sp=106&CN1=JAKO201209857785508&poid=kss1&kojic=CJDHBL&s
   Vnc=v14n2&sFree
2) B. Sadoulet, “Recent progress with low temperature particle detectors,” AIP Conf. Proc. 1185,  785
   (2009); http://dx.doi.org/10.1063/1.3292455
3) Shigetomo Shiki, Masahiro Ukibe, Nobuyuki Matsubayashi, Masaki Koike, Yoshinori Kitajima, Masataka
   Ohkubo, “X-ray Absorption Spectroscopy using Superconducting Tunnel Junction Detector for Trace
   Light Elements”
4) W. Holland, et al., “SCUBA-2: a 10,000-pixel submillimeter camera for the James Clerk Maxwell
   Telescope,” Proc. SPIE 6275, 62751E (2006); http://dx.doi.org/10.1117/12.671186
6) N. Zen, et al., “Ion-induced dynamical change of supercurrent flow in superconducting strip ion detectors
   with parallel configuration,” Appl. Phys. Lett. 104, 012601 (2014), and references therein;
   http://dx.doi.org/10.1063/1.4861225
7) “Increasing clarity for Japanese users, IEC databases for graphical symbols now available also in