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Superconductivity Web21

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What's New in the World of Superconductivity (October, 2013)

초전도 뉴스 −세계의 동향−

超导新闻 −世界的动向-

chāo dǎo xīnwén - shìjiè de dòngxiàng-

Yutaka Yamada, Principal Research Fellow
Superconductivity Research Laboratory, ISTEC

★News sources and related areas in this issue

►Basics 기초 基础 [jīchǔ]

Superconducting Accelerator in CERN Contributed to 2013 Nobel Prize, Higgs Boson

Royal Swedish Academy of Sciences and CERN (October 8, 2013)

The Royal Swedish Academy of Sciences has announced that the Nobel Prize in Physics for the year 2013 has been awarded to François Englert, Université Libre de Bruxelles (Brussels, Belgium) and Peter W. Higgs, University of Edinburgh (Edinburgh, UK) for "the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider." Englert (in collaboration with Robert Brout) and Higgs independently proposed their theories of how particles acquire mass in 1964. Together, their ideas are known as the Brout-Englert-Higgs (BEH) mechanism, and this mechanism now forms an essential part of the Standard Model of particle physics. Last year, in July 2012, their ideas were finally confirmed by the discovery of the so-called Higgs particle at the CERN laboratory. The discovery of the Higgs particle was the result of collaborations between the ATLAS and CMS projects and involved approximately 3000 people from around the world. CERN Director-General Rolf Heuer commented, "The discovery of the Higgs boson at CERN last year, which validates the Brout-Englert-Higgs mechanism, marks the culmination of decades of intellectual effort by many people around the world."

Source: "The Nobel Prize In Physics 2013: François Englert, Peter Higgs"
Royal Swedish Academy of Sciences press release (October 8, 2013)
URL: http://www.nobelprize.org/nobel_prizes/physics/laureates/2013/press.html
Contact: Perina Stjernlöf, Press Officer, perina.stjernlof@kva.se

Source: "CERN congratulates Englert and Higgs on Nobel in physics"
CERN press release (October 8, 2013)
URL:http://home.web.cern.ch/about/updates/2013/10/CERN-congratulates-Englert-and-Higgs-on-Nobel-in-physics
Contact: Press.Office@cern.ch

BINGHAMTON UNIVERSITY The State University of New York

First Computer-designed Superconductor

Binghamton University (October 8, 2013)

Aleksey Kolmogorov, an assistant professor of physics at Binghamton University, and his international colleagues have reported the successful synthesis of a superconductor designed, for the first time, entirely on a computer. Kolmogorov originally proposed the superconductor in 2010 and subsequently collaborated with European experimentalists to test the prediction. The resulting material, a novel iron tetraboride compound, is composed of two common elements, has a brand-new crystal structure, and exhibits an unexpected type of superconductivity for a material that contains iron—exactly as predicted in the original computation study. The superconductor design was originally created using an automated computational tool that Kolmogorov developed to identify previously unknown stable crystal structures. Surprisingly, a subsequent search revealed two promising compounds in a common iron-boron system. Further calculations suggested that one of the compounds should exhibit superconductivity at an unusually high temperature of 15-20 K. Researchers at the University of Bayreuth (Germany) have now produced a very small quantity of iron tetraboride in the predicted crystal structure; detailed measurements demonstrated the predicted superconducting property and, unexpectedly, an exceptional hardness. Kolmogorov commented, "The discovery of this superhard superconductor demonstrates that new compounds can be brought into existence by revisiting seemingly well-studied systems." The findings have been published in Physical Review Letters.

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Source: "Binghamton physicist contributes to creation of first computer-designed superconductor"
Binghamton University press release (October 8, 2013)
URL: http://discovere.binghamton.edu/news/superconductor-3-5435.html
Contact: Ryan Yarosh, ryarosh@binghamton.edu

▸Accelerator 가속기 加速器 [jiāsùqì]

Nb_3Sn High-field Magnet for CERN's HiLumi Accelerator

Oxford Instruments (October 25, 2013)

Oxford Instruments will collaborate with CERN in the prototyping and industrialization of HiLumi accelerator magnets, which will be used in the next-generation upgrade of the Large Hadron Collider (LHC) to high luminosity. This upgrade will enable a significant increase in the proton collision rate and will extend the research capabilities of the LHC. The HiLumi accelerator magnets will be constructed using Nb_3Sn superconducting technology and will have a high magnetic strength of 11 – 13 T. Dr. Steve Chappell, head of the consultancy business group at Oxford Instruments, commented, "We are really excited to be collaborating with CERN on HiLumi. In the spirit of partnership and innovation at the heart of our business, this is a valuable opportunity to learn from each other and together advance superconducting magnet technology."

Source: "Oxford Instruments collaborates with CERN on magnet development"
Oxford Instruments press release (October 25, 2013)
URL:http://www.oxford-instruments.com/news/2013/october/oxford-instruments-collaborates-with-cern-on-magne
Contact: http://www.oxford-instruments.com/contact-us?src=tn, on-line enquiry

►Management and Finance 경영정보 经营信息[jīngyíng xìnxī]

New Helium Source Facility Using Extraction of Helium from CO_2 Gas Source

Air Products (October 28, 2013)

Air Products has announced a new project to extract helium from a naturally occurring underground carbon dioxide (CO_2) gas source that is being processed by Kinder Morgan CO_2 Company, LP, in Colorado, USA.

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Helium production at the facility is scheduled to begin in the spring of 2015. Pure helium will be extracted from a CO_2 stream containing recoverable amounts of helium using a new technology process cycle. The purified helium will be liquefied on-site for subsequent delivery to Air Products' customers. Walter Nelson, Director of Helium Sourcing at Air Products, commented, "This is an innovative project and we see this as an opportunity to leverage our proprietary technology for future CO_2 on-purpose helium extraction projects. This is a critical step in finding new sources of helium at a time when there is a global shortage." Once operational, the facility will be the only site in the world where helium is being extracted from a gas stream composed primarily of CO_2. The facility is expected to produce as much as 230 million standard cubic feet per year, replacing more than 15% of the declining helium supply reserves.

Source: "Air Products 'Thinks Outside-the-Box' in Obtaining New Helium Source: Facility to Use Proprietary Technology to Extract Helium from Carbon Dioxide"
Air Products press release (October 28, 2013)
URL:
http://www.airproducts.com/company/news-center/2013/10/1028-air-products-thinks-outside-the-box-in-obtaining-new-helium-source.aspx
Contact: Art George, georgeaf@airproducts.com

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Feature Article: SQUID Applications ･Medical Applications - Development of Highly-Sensitive Biological Immunoassays utilizing Magnetic Markers

Keiji Enpuku, Professor
Research Institute of Superconductor Science and Systems
Kyushu University

Biological immunoassays are widely used medical tests to detect protein and pathogenic bacteria biomaterials originating from various types of diseases. The author and his group have investigated magnetic markers and high temperature SQUID magnetic sensors in the development of magnetic immunoassays. Advancements in low-noise SQUID sensor technology together with a selection of magnetic markers suitable for immunoassay studies have proved successful in significantly improving the sensitivity of magnetic immunoassays.

The biological immunoassay we developed requires a SQUID sensor that exhibits low frequency noise characteristics since the frequency of the measured signal is around 10 Hz. Figure 1 (a) shows the flux noise spectrum of a SQUID sensor at 77 K, developed jointly with the Superconductivity Research Laboratory (SRL). A comparison between the results using DC bias or AC bias to drive the SQUID was performed. As shown in the figure, the flux noise is given by $S_\Phi^{1/2}$=8 $\mu\Phi_0/Hz^{1/2}$ at high frequencies exceeding 100 Hz. A DC-biased SQUID has increased noise at low frequencies, given by 1/f. To the contrary, an AC-biased SQUID avoids low frequency noise increases, instead, having flux noise characteristics given by $S_\Phi^{1/2}$=15 $\mu\Phi_0/Hz^{1/2}$ at f = 1 Hz. Thus, a SQUID sensor exhibiting reduced low frequency noise has been successfully developed.

Magnetic markers (FG beads) manufactured by Tamagawa Seiki Co., Ltd. have been employed. These markers are in fact magnetic nanoparticles (Fe_3O_4) around 40 nm in size and coated with glycidyl methacrylate (GMA) polymer. The magnetic nanoparticles agglomerate forming a polymer with an approximate diameter of 270nm.

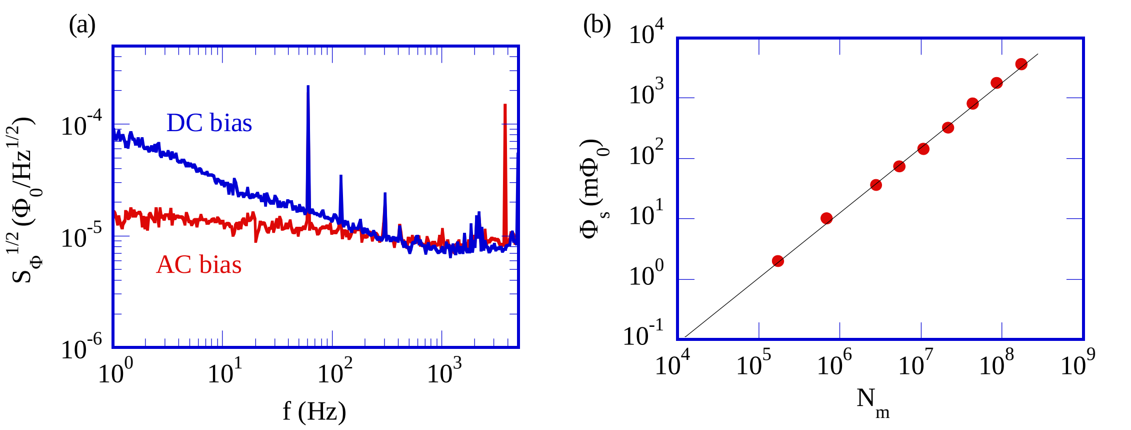

Fig. 1 (a) Flux noise spectra of high temperature SQUID sensor, (b) Detection of magnetic marker utilizing SQUID. The relationship between the numbers of magnetic markers N_m and the signal detected.

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Figure 1(b) shows the results of a magnetic signal detected from the magnetic markers acquired using a SQUID sensor. The horizontal axis shows the number N_m of magnetic markers, whilst the vertical axis shows the signal flux detected by the SQUID. As the peak-to-peak SQUID noise is approximately 0.05 $m\Phi_0$, it is understood from the results in Figure 1(b) that around 5 x 10^3 magnetic markers are detectable. Assuming that just one magnetic marker is bound with a single antigen, the results imply that it is possible to detect 5 x 10^3 antigens.

Detection trials of proteins (bioten) using these magnetic markers involved the following. Firstly, as shown in Figure 2(a), biotin was fixed to the surface of the polymer beads, or more specifically, 2,000 biotins fixed per one polymer bead. Next, the magnetic markers were conjugated by avidin, which was added into the liquid sample. The coupling between biotin and avidin produces magnetic markers that are partially bound to the polymer beads, and become bound markers. The remaining magnetic markers are free markers and both types are mixed in the liquid. It is possible to magnetically distinguish between the two sets of markers utilizing the Brownian magnetic relaxation of free markers and without the need for a washing process step.

Figure 2(b) shows the relationship between the numbers of biotin N bound to polymer beads with the associated signal flux. There is a correlation between N and the signal flux as shown in the figure, suggesting that immunoassays analysis can be performed precisely without the need of the washing process step. The sensitivity shows a successful detection of 2 x 10^4 biotin. The liquid volume for this test was 35 μl. When described in molar concentration, the detection ability is 9.5×10^{-19} mol/ml, which is sufficient to ensure very high sensitivity detection. One of the advantages of the magnetic method is to eliminate the washing process step necessary to separate free markers in the immunoassays. The aforementioned results indicate the possibility of high sensitivity immunoassays utilizing the method we developed. Further high sensitivity testing is anticipated when the performance of magnetic markers is enhanced.

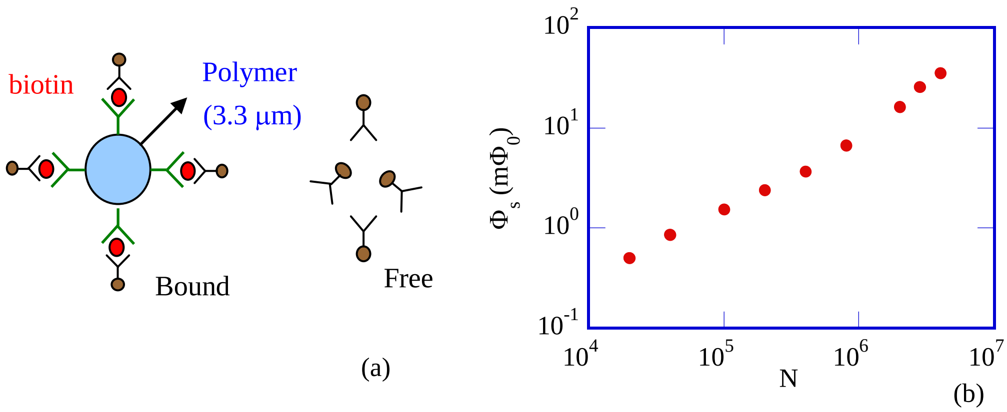

Fig. 2 Immunoassays using the magnetic marker method. (a) Detection of proteins (biotin) using bound polymer beads, (b) The relationship between the number of biotin N and their associated signal flux

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Feature Article: SQUID Applications ･Medical Applications - Ultra-Low Field NMR/MRI

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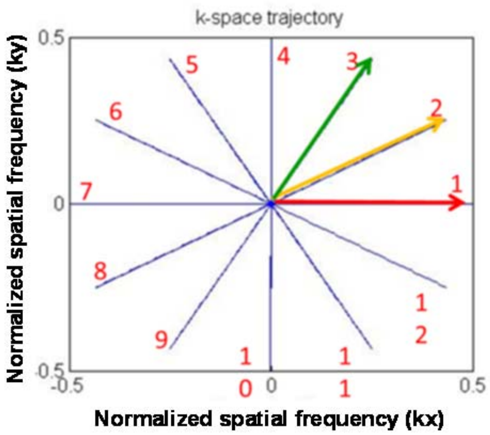
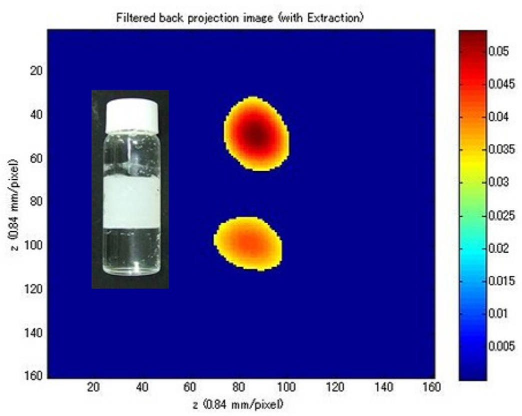
Graduate School of Engineering, Toyohashi University of Technology

Nuclear Magnetic Resonance (NMR) and Magnetic Resonance Imaging (MRI) work on the phenomenon that ^{1}H protons either absorb or emit electromagnetic energy exhibiting a specific frequency in the magnetostatic field. Both methods are utilized in many fields that include physics, chemistry and medical science. As conventional NMR/MRI systems utilize strong magnetic fields ranging from a few to several tens of tesla, superconducting magnets cooled using a helium refrigerator are necessary. This incurs high costs required for the construction of large-scale systems, making them complex in their design. In recent years, attention has focused towards ultra-low field NMR/MRI systems that employ highly sensitive SQUID magnetic sensors operating at low frequencies. Such systems do not require superconducting magnets and thus allows compact systems to be constructed at lower costs compared to conventional methods. The weak magnetostatic field generated by ultra-low field NMRs requires polarizing fields (Bp) of between 10-100 mT applied for several seconds to increase the magnitude of the nuclear spin. In a similar way to the strong magnetic fields in NMR, the rapid shut down of Bp causes a procession of the nuclear spin, returning to the original magnetostatic field direction via a free induction decay (FID) mechanism. Dependent on the direction of polarization, 90° or 180° RF pulse is sometimes applied after the shut down of Bp. Since the frequency of the FID signal has the same magnitude as the strength of the magnetostatic field, the ultra-low field NMR/MRI signal of several tens of micro-tesla is of a kHz order low frequency. Hence, sufficient sensitivity cannot be realized using an induction coil. Instead, an ultra-low field NMR/MRI system employing a highly sensitive, high temperature superconducting (HTS) SQUID operating at low frequencies has been developed.



(a) k-space trajectory



(b) 2D-image after reconstruction

Fig. 1 2D-images of divided water samples

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An ultra-low field NMR/MRI system requires an application of large polarizing field (Bp) in order to increase signal-to-noise ratios (SNR). Current investigations have been undertaken for a method to strengthen the polarizing field Bp, and have led to the development of technology that enables polarization using a 1.1 T permanent magnet. Figure 1 shows the results of 2D MRI image of a water bottle, acquired using a back projection method and exploiting the technology developed here. With the application of a rotating magnetic field gradient required for imaging, Figure 1(a) shows the FID signal obtained at 0°（G_y=56 nT/cm、G_z=0 nT/cm）and also at a 30° magnetic field gradient. The data was reconstructed using a Fourier transform, which produced a 2D-image corresponding to a 10 mL water sample volume, separated by silicone rubber, as shown in Figure 1(b). In the future, the author will endeavor to further improve the resolution with elaborate efforts applied in the field gradient.

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Feature Article: SQUID Applications ·Medical Applications - Magnetocardiography Measurements in Small Animals Using A Low Temperature Superconducting SQUID

Yoshiaki Adachi, Associate Professor
Applied Electronics Laboratory
Kanazawa Institute of Technology

The genes of small animals such as mice and rats can be relatively easily manipulated and using artificial models, allowing the realization of diseases due to genetic disorders. A number of small animals have been used in experimental trials to model diseases to enable a better understanding of the causes of genetic disorders and ways to treat diseases in humans. The author and his group have investigated magnetocardiograms (MCGs) as a non-invasive method that allows electrophysiological signals emanating from the heart of a small animal to be measured. The findings here will contribute to both a better understanding of disease models as well as allow innovative drug discoveries and developments to be made. Here, high-throughput screening tests can be done effectively and efficiently with a number of small animals without the need to shave their hairs to implant or attach electrodes to their bodies.

For MCG measurements a low temperature superconducting SQUID magnetometer array has been fabricated as shown in Figure 1 [1)]. A 9-channel directly coupled SQUID magnetometer array arranged in a 3 x 3 square matrix has been fabricated onto a 10 mm x 10 mm silicon chip, with a distance of 2.75 mm between the sensors. This array has a 2.5 mm diameter pick up coil on each sensor. The magnetic field resolution of each sensor was 8 $fT/Hz^{1/2}$ measured at white noise frequencies.

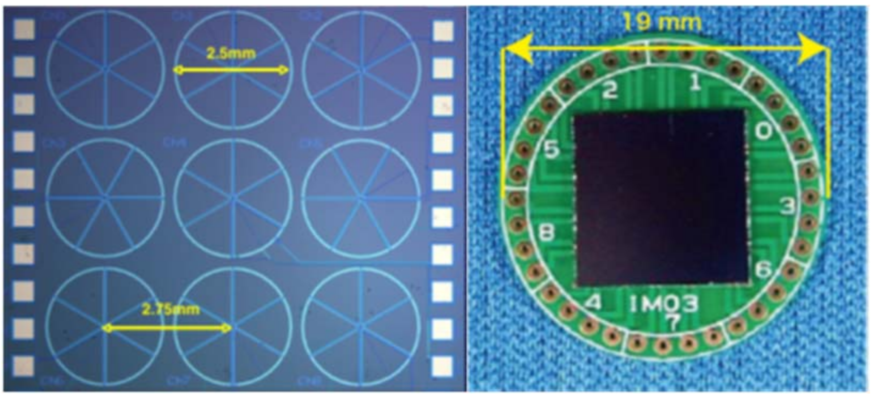

Fig. 1 Integrated 9-ch SQUID sensor (left), and an assembled SQUID sensor with a printed circuit board (right).

The MCG system has been constructed with the SQUID magnetometer array attached to a suspended dewar containing liquid helium, as shown in Figure 2 (left). The system is structurally designed so that a liquid helium reservoir is positioned outside the magnetically shielded box and only the sensor is positioned close to the center of shielded box. The cool-to-warm-separation of sensor was less than 2 mm. A one-time supply of around 6-liter volume of liquid helium in the reservoir is able to sustain superconductivity of the

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sensor for more than ten hours. The complete system overview is shown in Figure 2 (right). The shielded box is composed of two permalloy layers and an electromagnetic shield layer, realizing attenuating characteristics of around 60 dB at commercial power supply frequency bands. A reference sensor is assembled to capture and subtract the environmental noise signal within liquid helium dewar, which otherwise cannot be cancelled by magnetic shielding [2].

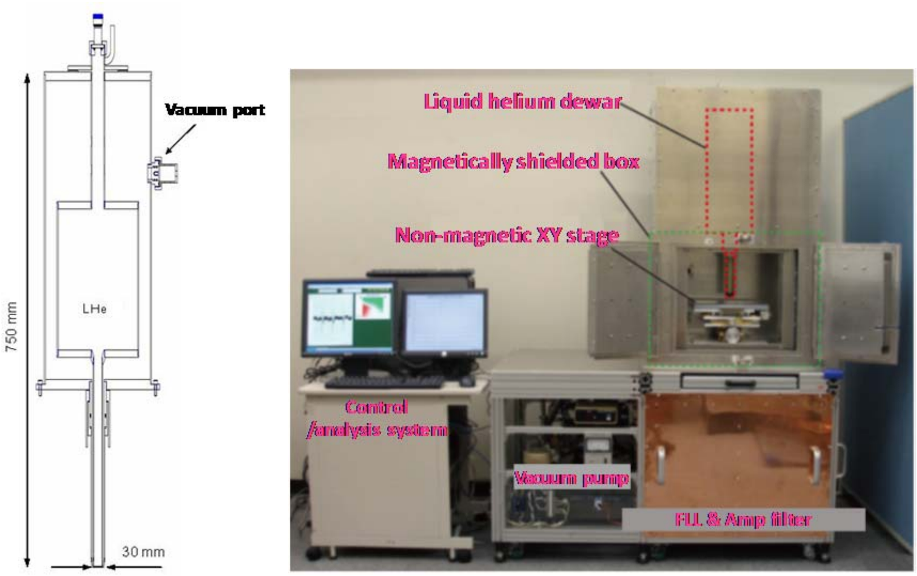

Fig. 2 Structure of a suspended dewar (left) and the overview of the MCG system designed for small animals (right)

Figure 3 (left) shows a set detecting a cardiac magnetic field emanating from a guinea pig utilizing the system developed. Simultaneous electrocardiogram measurements have been undertaken in order to ascertain the validity of the data. An example of the measured cardiac signal waveform from a guinea pig is shown in Figure 3 (center). The signals emanated from 135 heartbeats during a 30-second measurement interval were averaged with the reference trigger. P-QRS-T waves are clearly confirmed in all 9 channels of a magnetometer array. Figure 3 (right) shows a contour map of the R~S waves.

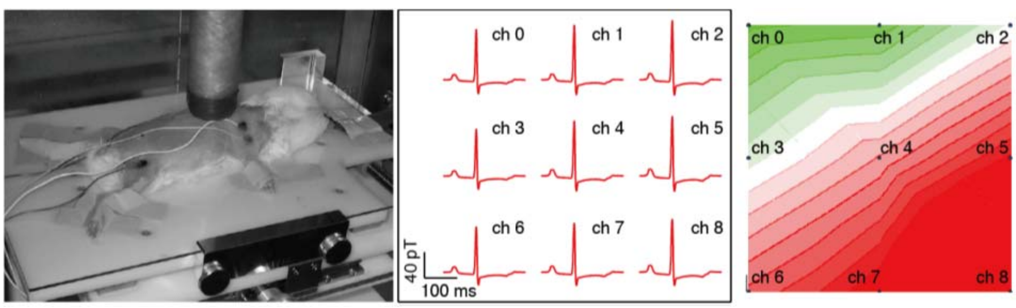

Fig. 3 The set detecting cardiac biomagnetism emanating from a guinea pig (left), Example of MCG signal waveform (center), and the distribution of the MCG signals measured (right). The waveform peaks represent the magnetic field source. On the contour map, the red-areas represent the magnetic field source whilst the green represents the magnetic field sink. The distance between the contour lines is 300 fT.

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The above-mentioned MCG system designed for small-animal experiments is being exploited for analysis of QT prolongation, the aims of which are to investigate disease models as well as a determining how medicines affect the heart [3]. An improved dewar assembly is utilized for the measurement system investigating the magnetoencephalography signals in small animals. The system is currently utilized in hearing research of small animals. The future plan is to capitalize on the remarkable progress of SQUIDs in recent years and integrate them in low-field MRI technology. Thus further research and development will lead to low-field MRI system designed for small animals [4].

References:
1) J. Kawai *et al.* “Fabrication and characterization of an integrated 9-channel superconducting quantum interference device magnetometer array”, IEEE Trans Applied Superconductivity, 15, 821–824, 2005.
2) M. Miyamoto *et al,* “Development of an MCG/MEG system for small animals and its noise reduction method”, Journal of Physics: Conference Series, 97, 012258, 2008.
3) K. Komamura *et al*, “Micro-magnetocardiography system with a single-chip SQUID magnetometer array for QT analysis and diagnosis of myocardial injury in small animals”, IEEE Trans Biomedical Circuits and Systems, 2, 260–268, 2008.
4) D. Oyama *et al,* “Development of SQUID-Based Compact Low-Field MRI System”, IEEE Trans Applied Superconductivity, 23, 1601604, 2013.

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