Tristan Technologies, Inc.

About

Tristan Technologies is a successful R&D and manufacturing firm with 22 years of leadership in cryogenic magnetic detection systems.

Mission

Advanced cryogenics and magnetic imaging systems
Specialists in engineering to your custom specifications

Description

Tristan Technologies is well known in the Biomagnetic medical and research industry as the supplier of state of the art and innovative diagnostic equipment. The organization's customers include well established brands of hospitals, research institutes and scientific universities from around the world. Tristan Technologies has produced the first ever clinical application for SQUIDS- the Tristan Biomagnetic Liver Susceptometer- providing a safe and reliable indication of the level of hepatic iron stores. Tristan Technologies also has several patented cryogenic and biomagnetic technology.

Tristan Technologies' forte lies in the fact that it caters to the customer's requirement for a piece of equipment, designed to work for the purpose specified by the customer. Tristan Technologies presently occupies a 8,500 square feet facility in the Sorrento Mesa area of San Diego, over 3,000 square feet of which is devoted to cryogenic and magnetometer fabrication. Tristan Technologies has designed, developed, and manufactured components and systems for a wide variety of biomagnetic measurements, from research to clinical applications, for geomagnetic measurements in oil and mineral exploration, magnetic anamoly detection and rock magnetometry, for ultra-low level electromagnetic measurements utilizing both LTS and HTS SQUID sensors, and for measurements in Cryogenics, Magnetic Field Sensing, and NMR and microwaves.

Tristan Technologies is a commercial supplier of SQUID-based laboratory, biomagnetic, geophysical and non-destructive evaluation (NDE) instrumentation. Its standard products include LTS and HTS SQUID components, cryogenics and systems. Tristan also manufactures a line of closed cycle (cryocooled) refrigeration systems. Tristan is recognized as the leading supplier of custom LTS and HTS SQUID instrumentation and systems. Tristan's manufacturing personnel have had wide experience in the fabrication, assembly and testing of cryogenic and SQUID instrumentation, with many having more than two decade's experience. Tristan's capabilities include all aspects of thermal and cryogenic design, mechanical design and software implementation in both embedded and system level instrumentation for low noise magnetic measurements. The organization also has an extensive history in research projects, individually and cooperatively for private customers, industry universities and government laboratories and R&D centers.

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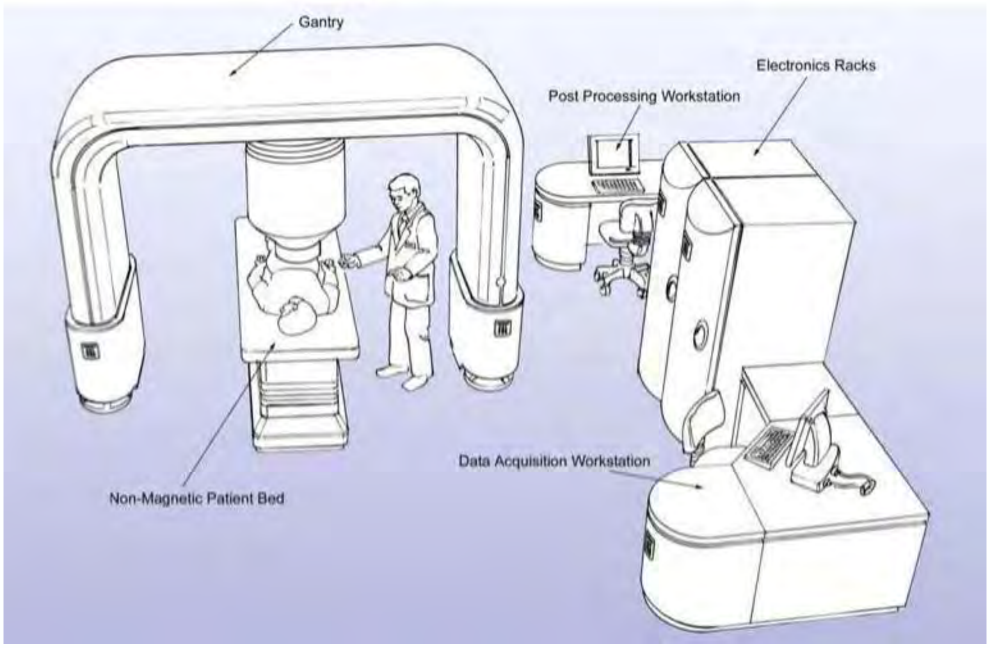
TRISTAN PRODUCTS

SQUID instruments and Systems

from

Tristan Technologies



System layout of Model 663 Spinal Cord Measurement System (see page 6 for actual photos)

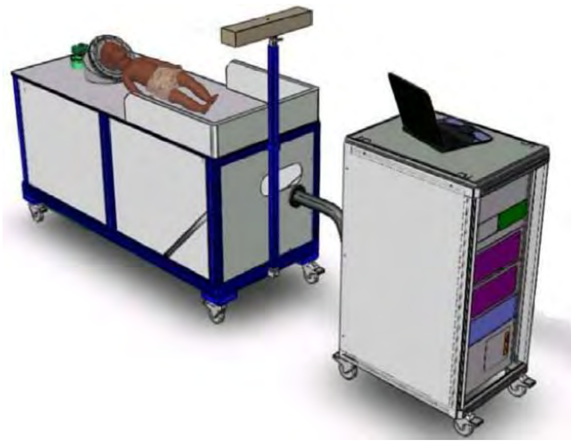
SMM-770 magnetic microscope

model 607 MicroSQUID™ system

babySQUID® *Neonatal Biomagnetometer*

TRISTAN TECHNOLOGIES

A new, noninvasive investigational tool for pre- and full-term infants



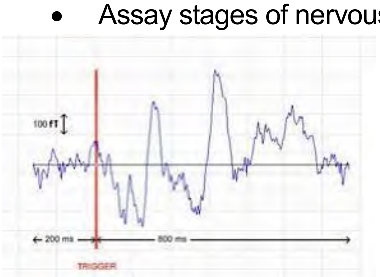
Mapping brain function and detection of neurological abnormalities in infants

Detection of cortical function in newborns is needed for clinical intervention in the early stages of neurological disorders, before external signs appear and the conditions develop and worsen. Areas where babySQUID® could be used for neonatal neurological assessment include:

- Epilepsy
- Cerebral palsy
- Perinatal asphyxia
- Hypoxemic-ischemic encephalopathy
- Periventricular white matter injury
- Monitoring recovery from trauma

Identifying how infants learn is of interest to many sectors of society, but such studies rely heavily on behavioral analyses. Having a direct measure of cortical activity would provide precise information on the dynamic response in the brain during learning processes. Potential uses of babySQUID® for developmental studies include:

- Mapping of sites and dynamics of sensory functions - auditory, somatosensory, and visual modalities
- Assay stages of nervous system development



babySQUID® measurement of the temporal response of an eight month old infant after right index finger somatosensory stimulus.
(single channel shown)

The Tristan babySQUID® (patents issued and pending) is classified as an investigational device and is currently offered for research use only. Tristan is in the process of seeking both CE (European) medical device directive and FDA (U.S.) certification for clinical use. Specifications subject to change without notice.

Unique Features of babySQUID®

Superior spatial resolution and sensitivity

- babySQUID® is significantly more sensitive to neuronal sources than conventional whole-head MEG systems
- Spatial resolution is four times better than existing whole-head MEG sensors
- Better spatial resolution than EEG (EEG signals are distorted by skull defects (fontanels and sutures), making it difficult localize epileptiform tissue
- No need for gluing and attaching any EEG leads
- Rapid scanning: A typical clinical scan can be completed within thirty minutes
- Anti-vibration construction; infant motion will not cause vibrational artifacts
- Sensor noise < 20 fT/√Hz

- A dense array of closely-spaced sensors is located just below the outer surface of a headrest.
- Allows measurement of the occipital area (infant in nose-up position), and parietal and temporal areas (infant lying on its side)
- Includes position tracking device and software. No need to immobilize the head. This permits measurements during sleep or relatively quiescent wakefulness

Unshielded Operation

- babySQUID® is designed to operate outside the large and expensive magnetically shielded rooms needed for adult MEG measurements
- The measurement cradle and its companion electronics cart are portable and can be wheeled in and out of elevators, obstetric suites and neonate ICUs

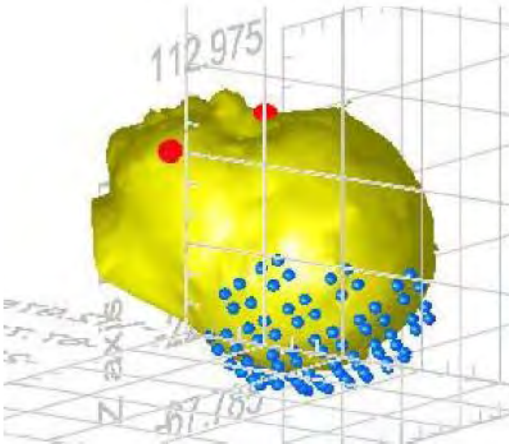
BabySQUID® System Description

Principles of Operation

Like adult Magnetoencephalography (MEG), babySQUID® uses superconducting sensors to non-invasively detect and map magnetic fields generated by cortical neural activity. However, babySQUID® takes advantage of the fact that the infant's scalp and skull are very thin. Tristan's fabrication methods put the sensing coils very close to the infant brain's sources of activity, even though SQUIDs must operate in an ultra-cold liquid helium environment. The net result is a significant increase in amplitude of neonate MEG signals. Also, the high density of detectors results in higher spatial resolution as compared to adult whole-head MEG. The large improvement of signal to noise means a capacity to operate in clinical environments without the usual magnetically shielded room.

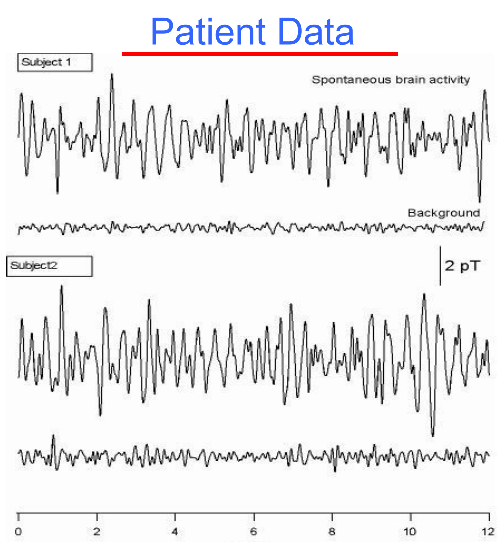
System Components

- Sensor/Cradle/Bed on mobile cart – easily accessed height
- Power supplies and computer on companion mobile cart to minimize noise
- Subject Tracking - optical tracking system updates movement at 30 Hz with 1/2 mm accuracy
- Part-wise mapping or optional optical one-click 3D imaging system

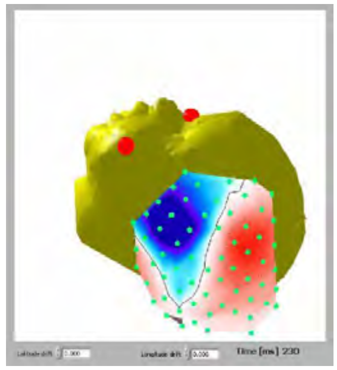


SQUID Sensor Array

- 300 cm^2 sensor coverage area
- 76 detection coils
- Coil type: 6 mm-diameter first order gradiometers. Adjacent coils can be electronically combined to form planar (dB_z/dx and dB_z/dy) gradiometers
- Coil gap: < 5 mm from sensor to outer surface
- Coil sensitivity: better than 20 fT/√Hz
- Reference channels: 8-element tensor array for noise reduction by subtraction of common mode noise



Spontaneous activity obtained from two 6-month old infants in an unshielded hospital room.



Evoked Response of an 8 month old infant Left hemisphere MEG slow wave response 230 msec after right index finger somatosensory stimulus Red indicates +1 picoTesla, and blue represents -1 picoTesla, resulting from a flow of neural current between the two regions. The separation of the regions gives a measure of the current source depth.

Data Acquisition and Display

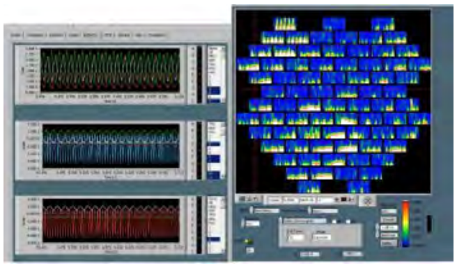
The award-winning* babySQUID® acquisition and display software is LabVIEW® making it easy to use and expand.

Data Acquisition

- Data acquisition at 10 kSamples/sec. Faster rates (up to 100 kSamples/sec) are available on request
- 24 bit data acquisition hardware, operating under MS Windows® (other operating systems available on request)
- Output ports for triggering sensory stimuli
- Data export utilities to BESA and EMSE software packages for mapping sources onto cortical locations
- Expandable for EEG and other sensors

Display Software

- Raw data and averaged data side by side
- Scrolling vertical or overlapped channel display
- Real time, playback, and simulation modes
- Signal analysis features include IIR, FIR, wavelet, and spatial filtering, and filter editors
- Foreign language support available
- Display modes include: grouped channels (below left) and time-frequency spectrograms (below right)



Both of these packages can import MRI data and superimpose it with MEG and EEG data, so that the user can see where in the brain activity is occurring, and follow its movement.

Power and Physical Requirements

- Power: 1.5 kW filtered circuit
- Patient bed: 1 m x 2 m x 1.1m (40" x 79" x 42")
- Patient bed weight: 200 kg (440 lbs)
- Instrument cart size: 19" electronics rack
- Instrument cart weight: 150 kg (330 lbs)

Larger coverage areas, higher channel counts, and/or different coil dimensions and configurations are available on request. Contact Tristan for additional information.

All Tristan products are covered by a 1-year warranty. Service contracts may be purchased to provide post warranty coverage.

TRISTAN TECHNOLOGIES

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Artemis123®

Whole Head Neonatal Biomagnetometer

A new, noninvasive investigational tool for pre- and full-term infants

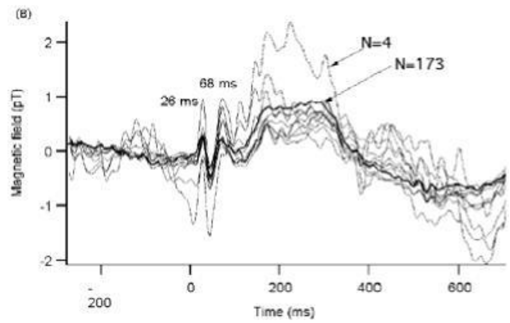
Mapping brain function and detecting neurological abnormalities in infants

Detection of cortical function in newborns is needed for clinical intervention in the early stages of neurological disorders, before external signs appear and the conditions develop and worsen. Areas where Artemis123®[1] can be used for neonatal neurological assessment include:

- Autism
- Epilepsy
- Cerebral palsy
- Perinatal asphyxia
- Hypoxemic-ischemic encephalopathy
- Periventricular white matter injury
- Monitoring recovery from trauma

Identifying how infants learn is of interest to many sectors of society, but such studies rely heavily on behavioral analyses. Having a direct measure of cortical activity would provide precise information on the dynamic response in the brain during learning processes. Potential uses of Artemis123® for developmental studies include:

- Mapping of sites and dynamics of sensory functions - auditory, somatosensory, and visual modalities
- Assay stages of nervous system development



Somatic evoked magnetic field (SEF) obtained from a 7-month old as a function of number of averages from N=4 to 173 epochs. The waveforms are the differences of the SEF at two field extrema. This shows that a small number of averages are needed to acquire SEF data. (data acquired using a Tristan babySQUID® system).

Unique Features of Artemis123®

Superior spatial resolution and sensitivity

- Significantly more sensitive to neuronal sources than conventional whole-head MEG systems
- Similar or better spatial resolution compared to existing whole-head MEG sensors
- Better spatial resolution than EEG (EEG signals are distorted by skull defects (fontanels and sutures), making it difficult localize epileptiform tissue
- Rapid scanning: a typical clinical scan can be completed within thirty minutes
- Anti-vibration construction; infant motion will not cause vibrational artifacts
- Sensor noise level < 10 fT/□Hz
- A dense array of closely-spaced sensors located just below the outer surface of a headrest.
- Allows simultaneous measurement of the occipital area and parietal and temporal areas
- Includes position tracking device and software, permitting measurements during sleep or relatively quiescent wakefulness
- The measurement cradle and companion electronics cart are portable and can be wheeled in and out of elevators, obstetric suites and neonate ICUs

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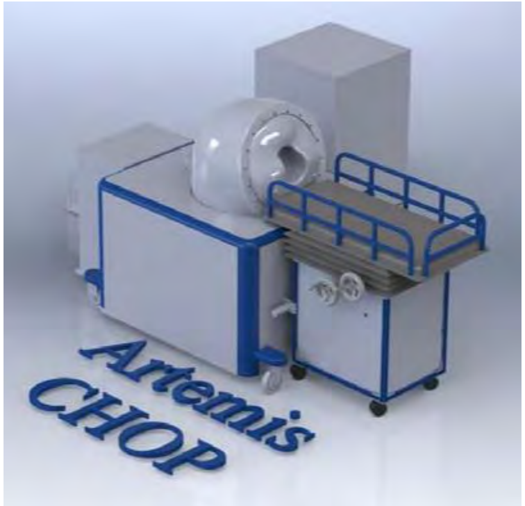
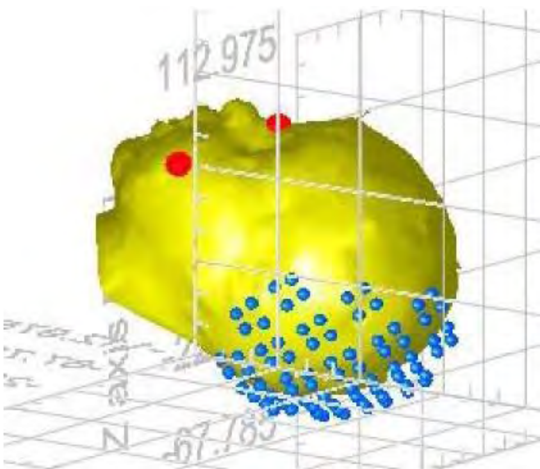
1 Artemis123® is a registered trademark of Tristan Technologies, Inc.



Artemis123® System Description

Principles of Operation

Like adult Magnetoencephalography (MEG) systems, Artemis123® uses superconducting sensors to non-invasively detect and map magnetic fields generated by cortical neural activity. However, Artemis123® takes advantage of the fact that the infant's scalp and skull are very thin. Tristan's fabrication methods put the sensing coils very close to the infant brain's sources of activity, even though SQUIDs must operate in an ultra-cold liquid helium environment. The net result is a significant increase in amplitude of neonate MEG signals. Also, the high density of detectors results in higher spatial resolution compared to adult whole-head MEG.



System Components

- Sensor/Cradle/Bed on mobile cart – easily accessed height
- Power supplies and computer on companion mobile cart to minimize noise
- Subject Tracking - optical tracking system updates movement at 30 Hz with 1/2 mm accuracy
- Part-wise mapping or optional optical one-click 3D imaging system

SQUID Sensor Array

- 606 cm^2 sensor coverage area
- 100+ detection coils
- Coil type: 15 mm-diameter first order gradiometers. Adjacent coils can be electronically combined to form planar gradiometers
- Coil gap: ~8 mm from sensor to outer surface
- Coil sensitivity: better than 10 fT/□Hz
- Reference channels: 12-element tensor array for noise reduction

Power and Physical Requirements

- Power: 1.5 kW filtered circuit
- Patient bed: 1 m x 2 m x 1.1m (40" x 79" x 42")
- Patient bed weight: 200 kg (440 lbs)
- Instrument cart weight: 150 kg (330 lbs)

Larger coverage areas, higher channel counts, and/or different coil dimensions and configurations are available on request. Contact Tristan for additional information.

All Tristan products are covered by a 1-year warranty. Service contracts may be purchased to provide post-warranty coverage.

TRISTAN TECHNOLOGIES

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The Tristan babySQUID® (patents issued and pending) and Artemis123® are classified as investigational devices and are currently offered for research use only. Tristan is in the process of seeking both CE (European) medical device directive and FDA (U.S.) certification for clinical use. Specifications are subject to change without notice.

Fetal EchoCardiography/ TruckSQUID [1] (fMCG)

TRISTAN TECHNOLOGIES

A new, noninvasive investigational tool for pre- and full-term infants

- 21 SQUID channels configured as 7 vector gradiometers, 20 mm diameter coils with 8 cm baseline to maximize captured fMCG information
- Small probe profile with 20 mm sensor-to-patient standoff for easy positioning in close proximity to fetus
- Gantry movement offers five degrees of freedom for patient accommodation
- Uses proprietary technology to bring the sensor coils very close to the subject to increase signal/noise performance
- Optional echo/Doppler subsystem for simultaneous detection of hemodynamic and electrophysiologic abnormalities
- Subject Tracking – optional optical tracking system updates movement at 30 Hz with 1/2 mm accuracy
- Part-wise mapping or optional optical one-click 3D imaging system

Mapping cardiac functions and detecting neurological abnormalities

The fMCG is a unique system for fetal magnetocardiography (fMCG) measurements. It allows the clinician to analyze a fetus rapidly for electrophysiologic abnormalities such as fetal arrhythmias. This system is the first clinical mobile system that provides full intrauterine characterization of a fetus with life-threatening heart conditions.

Unique Features of TruckSQUID®

- Vector field mapping capability
- Deep source detection capability
- Liquid Helium dewar hold time 5-7 days
- Windows-based acquisition and display software
- Advanced data processing based on spatial filtering and ICA
- Optional Ultrasound probe

SQUID Sensor Array

606 cm^2 sensor coverage area

21 channels

Coil type: 20 mm-diameter axial gradiometers (7 unit). 15 mm planar gradiometer.(14 unit).

Coil gap: ~8 mm from sensor to outer surface

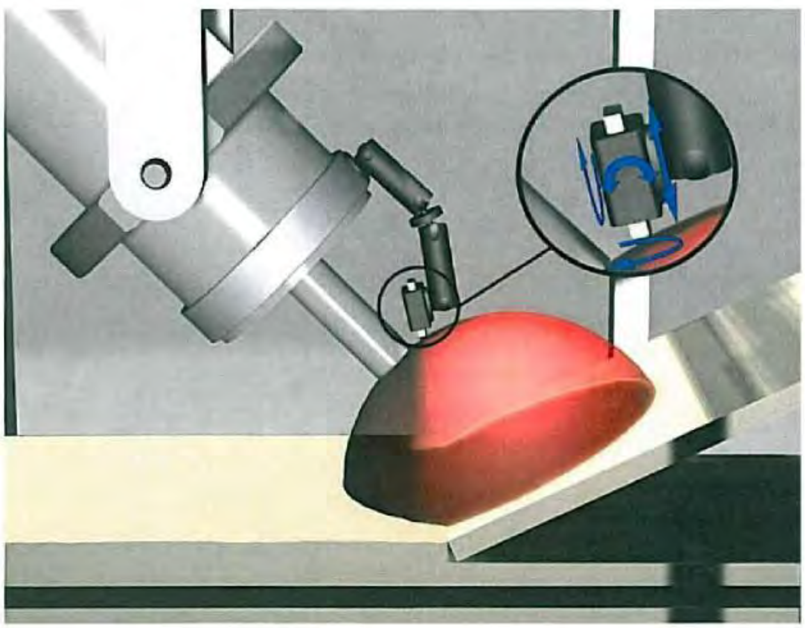
Coil sensitivity: better than 10 fT/⎿Hz

Reference channels: 3 axis magnetometer optional.

Power and Physical Requirements

Power: 1.5 kW filtered circuit
Patient bed: 1 m x 2 m x 1.1m (40" x 79" x 42")
Patient bed weight: 200 kg (440 lbs)
Instrument cart weight: 150 kg (330 lbs)

Larger coverage areas, higher channel counts, and/or different coil dimensions and configurations are available on request. Contact Tristan for additional information.



TruckSQUID™ shown with optional Ultrasound probe

All Tristan products are covered by a 1-year warranty. Service contracts may be purchased to provide post-warranty coverage.

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TV SQUID probe for FMCG

The Transvaginal (TV) SQUID probe for FMCG is used to detect cardiac defects in a fetus as early as during the 10th- 13th week of pregnancy of the mother. This early detection can save the fetus' life by performing intrauterine surgery on the mother.

Tristan and its key personnel have produced a number of measurement systems for a variety of applications. Additional information on Tristan's commercial product line can be found at our website: http://www.tristantech.com. Some of them are listed here:

- Multiple single- and multi-channel SQUID magnetometers for NDE and paleoarcheology use. These are state-of-the-art systems, some with spatial resolutions approaching 1 µm.
- Multiple single- and multi-channel SQUID magnetometers for biomedical applications for animals and humans. The Ferritometer® is routinely used for clinical assessment of iron overload diseases. This system is a turnkey operation including patient scanning bed, computer control, along with complete data acquisition and analysis software.
- Tristan's magnetometer systems are based on its iMAG® line of commercial SQUID electronics, which have been supplied worldwide to both end users and OEMs.
- Tristan's model DRM-300 geophysical rock magnetometer uses closed cycle refrigeration to eliminate the need for liquid helium and reduce operating costs. This technology is available for use on many of Tristan's products.

Systems built by Tristan's present personnel during the time period of 1991-1996 include:

- A DC and AC susceptibility variable temperature and field platform. Twelve systems were made. These systems integrated SQUID magnetometers, sample motion control, sub-mK thermal control from 2 – 350 K, variable applied fields to 17 T and truly user-friendly automated control software. This product demonstrated Tristan's ability to produce state-of-the-art complex analysis equipment with minimal user requirements.
- A six-channel system for Vanderbilt University for general-purpose NDE studies. Comprised of a magnetometer, dewar, electronics, software and multiple magnets, this system has extremely high sensitivity (10^{-14} tesla) and sub-mm resolution.
- A three-channel Superconducting (SQUID) NDE system for use by a large Japanese steel company, comprising magnetometer probe, dewar, superconducting magnets, custom electronics, and custom software. Using a welding robot, this compact system is scanned over samples.
- A dual-channel magnetometer system for use by a private company to study materials for nuclear-fuel rod integrity. The package includes a magnetometer probe, dewar, computer controlled sample scanner, electronics and software.
- A compact (12") six-channel high sensitivity susceptometer capable of generating tesla fields and operating in both vertical and horizontal orientations. The ultra-compact system, when attached to the end of a robot arm, is used by a large Japanese nuclear reactor inspection company for scanning the interior of nuclear pressure vessels.
- The first commercial scanning magnetic microscope (SMM-1000) to study small electronic circuits and material samples. This comprised a dewar, cryogenic sample handling stage, magnetometer, custom software, vacuum system, and custom electronics. It is comparable to a SEM in complexity. Nine detection coils were fabricated in a linear array with 100 µm coil separation. Spatial resolution was at the µm level.
- A mixed stage (Gifford-McMahon/Joule-Thomson) cryocooler that routinely achieved 2 K.

There are many applications for SQUIDs. General areas where SQUIDs are used include:

Laboratory Applications include measurements of current, voltage, resistance, magnetization, etc. along with exotic (General Relativity, magnetic monopole) applications.

Current:	10^{-12} ampere/√Hz	dc Resistance:	10^{-12} Ω
Magnetic Fields:	10^{-17} tesla/√Hz	Mutual/Self Inductance:	10^{-12} Henry
dc Voltage:	10^{-14} volt	Magnetic Moment:	10^{-10} emu

Geophysical Applications include oil and mineral exploration, pollutant monitoring, magma flow measurements, rock magnetometry and paleoarcheology, etc.

Tristan HTS SQUID gradiometer in flight

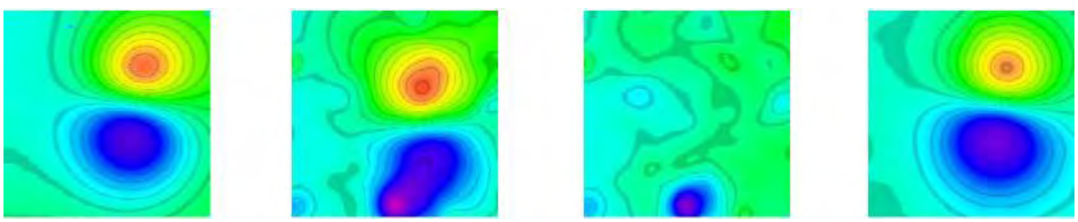
DRM-300 3-axis cryocooled rock magnetometer

Non-Destructive Test & Evaluation (NDE) scanning systems are used for defect detection, corrosion measurement, magnetic microscopy, etc. Some examples of SQUID NDE include:

Intrinsic currents measurements, such as:
- Remnant magnetization
  - Embedded magnetic sensors *(see figure below)*
- Flaw-induced perturbations
- Johnson noise in metals
- Eddy currents in an applied ac field (flaws)

Hysteretic magnetization due to:
- cyclic stress (strain)
- simultaneous dc & ac magnetic fields

Magnetization of paramagnetic, diamagnetic and ferromagnetic materials in dc fields.



A B C D

SMM-701 magnetic field scans of an embedded strain sensor under a 4 cm thick concrete overcoating. **A** - bare sensor showing dipole characteristics, **B** - sensor under concrete, **C** - bare concrete. Image **D = B – C** is a digital subtraction of B and C showing that it is possible to image objects deep underneath magnetically complex coverings. The scans cover a 6 cm x 6 cm area.

Medical Applications include:

Studies of the Brain—Neuromagnetism
- Epilepsy
- Neonatal and prenatal Brain Disorders
- Presurgical Cortical Function Mapping
- Peripheral nerve and spinal cord studies
- Drug Development and Testing
- Stroke
- Alzheimer's
- Neuromuscular Disorders
- Performance Evaluation

Animal Systems
- Pharmaceutical drug development

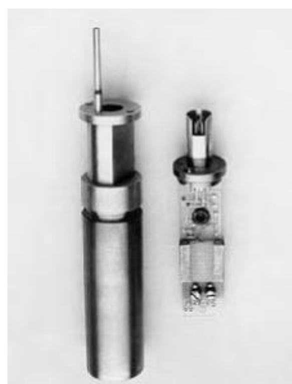
Studies of the Heart—Magnetocardiography
- Arrhythmia
- Heart Muscle Damage
- Fetal Cardiography

Other Medical Applications
- Non-invasive *in-vivo* Magnetic Liver Biopsies (Ferritometry)
- Studies of the Stomach—Gastroenterology
  - Intestinal and Mesenteric Ischemia
- Lung Function and Clearance Studies
- Peripheral and Single Nerve Studies
- Organ Transplant Rejection Risk
- Blood Flow Disorder

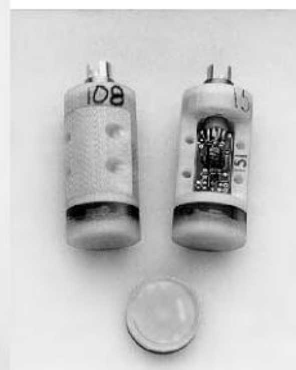
Tristan non-magnetic dewars

Model 607 biomagnetometer

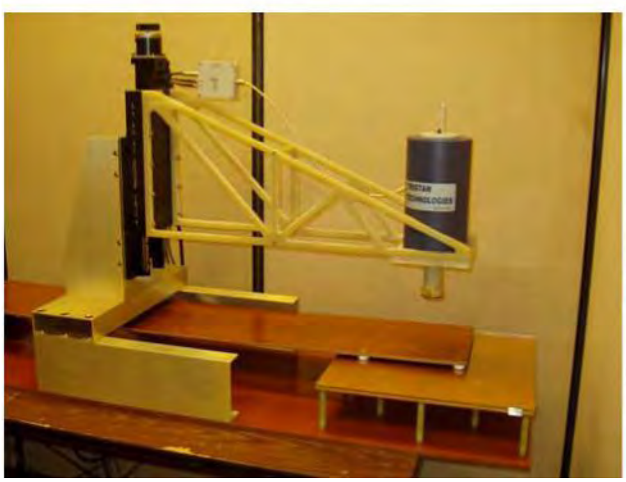
iMAG® electronics and laboratory probes



LTS SQUID sensor



HTS SQUID sensor



SMM-701 NDE scanning system

Model SMM-770 Scanning SQUID Microscope

The following Tristan systems illustrate just some of Tristan's capability to design and manufacture a broad range of sophisticated measurement systems. In particular, we have made a wide variety of high density, high number count, and close gap measurement systems. We also have extensive experience in refrigeration systems and cryocoolers extending over 20 years. Our biological and medical systems can be supplied with *fully* integrated with electronics, source localization software, gantries, and patient beds, each component designed to the specifications required for the application.

Model 663 Spinal Cord Measurement System

Designed to non-invasively measure spinal cord activity and localize the source of the activity. The system is adaptable for humans or animals. The system acquires data at the rate of 108,000 samples per second on each of its 71 channels, more than 10 times faster than conventional MEG devices. The system includes 8 tensor reference channels for noise reduction; signal acquisition, processing and display workstations; a sensor positioning gantry; a patient bed; patient/sensor position indicator.

(Left) Installed model 663 spine system dewar , showing pneumatically assisted x-y, and z- orientation control. (Center) Dewar insert, with array of 71 channels plus reference channels. (Right) Control electronics rack for 108 kSample/sec data acquisition and RAID arrays for simultaneous monitoring, storage, and data upload.

Ferritometer®

Tristan's Ferritometer® is a clinical instrument to quantitatively measure liver iron stores in patients suffering from Hemochromatosis, Thalassemia and Sickle-Cell Anemia. The Ferritometer® uses biomagnetic liver susceptometry (BLS) to quantitatively and accurately measure iron stores in the liver and spleen for adults and children. Tristan has delivered this system to hospitals in Europe and the United States, Unlike needle biopsies, the BLS method is rapid, non-invasive and provides more accurate data. The Ferritometer® operates in an unshielded environment (no MSR).

microSQUID™ (animal study) Systems

Animal experiments require that the detection coils be much closer (a few mm) than human MEG systems (typically 20 mm). Tristan's microSQUID™ technology permits small diameter detection coils to be placed within a few mm from the dewar bottom. This combines high spatial sensitivity along with the unsurpassed sensitivity of SQUID magnetometers. MicroSQUID™ systems feature small diameter (typically < 5 mm) detection coils and very close (< 4 mm) spacing between the detection coils and room temperature.

babySQUID®

Tristan's babySQUID® Neonatal Biomagnetometer is a MEG system specifically designed for detecting cortical function in newborns. The magnetometer is located in the infant bed with the detection coils pointing upward towards the infant. The rectangular device at the end of the infant bed is the projector for the optical positioning system. It is designed to operate without the need for a MSR. The measurement cradle and its companion electronics cart are portable and can be wheeled in and out of elevators, obstetric suites and neonate ICUs. It has 76 detection coils with a sensor coverage area of 300 cm^2. Using 6 mm detection coils with 17 fT/√Hz sensitivity, its spatial resolution is four times greater than existing whole-head MEG sensors. An optical one-click 3D imaging system is used to track patient movements. Its award winning open architecture software is LabVIEW® based, making it easy to use and expand.

monkeySQUID™

The monkeySQUID™ is a research tool made to meet the specific requirements of research on mapping functional neurophysiology in primates. It is used to non-invasively measure weak magnetic fields produced by electrical activity within the cortex and to characterize and locate the source of the activity.

OTHER BIOMAGNETIC MEASUREMENT SYSTEMS

The Model 637 Biomagnetometer (gutSQUID®) is used for measurement of the Basic Electric Rhythm (BER) associated with intestinal activity. The specific application is detection of Mesenteric Ischemia, a life threatening condition with no conventional reliable method of diagnosis. Pre-clinical trials are underway. Tristan's personnel fabricated the first commercial system for HTS cardiac measurements in unshielded environments. Tristan has also built systems for peripheral nerve studies, adult magnetoencephalography and magnetopneumography.

SQUID Systems for Biomedical Research

Applications

- *Magnetoencephalography* (MEG) for functional imaging
  - Mapping cortical events and spontaneous rhythms
- *Magnetocardiography* (MCG)
  - Adult and fetal magnetocardiography
- Spine/Peripheral Nerve Functional measurements
- Liver Iron (hepatic iron stores) Assessment
- Intestinal ischemia
- Magnetopneumography (lung transport mechanisms)

Fig 1. Dewars sized for custom applications. Both liquid nitrogen, liquid helium dewars are shown.

Features

- Safety and Convenience — noninvasive measurements
- High temporal resolution of signals
- Optimum placement, with sensors closer to sources
- Integrated systems:
  - Custom dewars, gantries, patient beds;
  - Patient positioning and tracking systems;
  - Custom sensor design and configurations;
  - Data acquisition and user interface software;

Fig 2. Spine measurement system complete with gantry, subject positioning device, and patient bed shown in a magnetically shielded room.

Technologies

- Advanced Josephson Junction Technology
  - o Microprocessor-based multichannel control electronics
- Complex Custom Design Coil Arrays
  - o 2 mm to 2 cm diameter detection coils
  - o magnetometers and gradiometers (1st and 2nd order)
  - o axial or planar, symmetric or asymmetric gradiometers
- Custom Dewars and Cryocooled systems
  - o adjustable tails with coil-to-subject distances less than 5 mm
  - o ultra-low boil-off dewars; cryogen free or cryocooler assisted
- Custom Electronics and Software
  - o electronic noise cancellation hardware and software
  - o sophisticated data acquisition and monitoring software
- Sophisticated Modeling
  - o finite element analysis for optimal coil and dewar design
  - o thermal analysis for highest dewar performance
  - o electromagnetic modeling for RF and magnetic shielding

Tristan Technologies, Inc.

SQUID Magnetometers

Principles of operation

Biomagnetic measurements encompass many of the major organs of the body, including heart, brain, liver, lungs and muscles. Diagnostic procedures based on Biomagnetism have emerged in cardiology and neurology, and are emerging in gastroenterology as well.

Every bioelectric event has a magnetic analog. Biomagnetic signals range in bandwidth from essentially dc to several thousand Hertz, with peak field intensities from about 50 fT to 10^6 fT. The sources of these fields vary from localized groups of neurons in the brain, to more dispersed muscle tissues in the heart, to magnetic particles distributed throughout the lungs.

Because biomagnetic signals are so small, they require extremely sensitive detection systems. The only instrument with the necessary sensitivity and bandwidth for this work is the SQUID magnetometer.

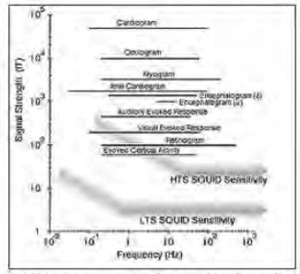


Fig. 2 Magnetic signal strengths from several significant biological sources

SQUID magnetometer system require the following components:

- **Detection coil(s)** to sense changes in external magnetic field and transform them into an electrical current
- **Input coil(s)** to transform the resulting current into a magnetic flux in the SQUID sensor; electronics to transform the applied flux into a voltage output
- **A cryogenic region** to keep the SQUID sensor(s) and coil(s) superconducting
- **Signal conditioning electronics** to convert the detected magnetic signals into voltages that can be recorded
- **Acquisition hardware and software** to acquire, store and analyze data

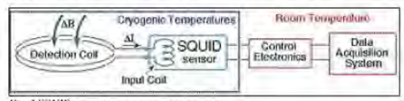


Fig 2 SQUID magnetometer system components

System Design

System sensitivity is a function of SQUID sensor sensitivity, detection coil diameter, number of turns, and magnetometer/gradiometer design.Detection coils may be gradiometers rather than magnetometers, to reject environmental noise. Sensitivity, number of detection channels, arrangement and spacing between channels are all are tailored to user applications.

Because environmental noise can impair detection of biomagnetic signals, , systems are typically housed inside a large magnetically shielded room (MSR). Unshielded operation is also possible using spatial filtering and an array of reference coils and subsequent electronic subtraction of common mode noise.

Ancillary equipment

- Gantries with fixed or multiple degrees of freedom
- Non-magnetic patient beds with manual or computer controlled motion of XYZ travel
- Subject positioning and tracking systems
- Data acquisition and real-time monitoring system
- Third party source analysis software, data compatability with source analysis software

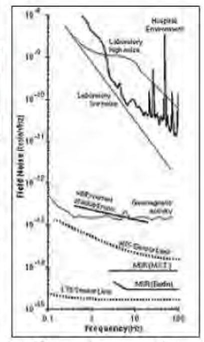


Fig. 2 Measures of environmental noise

Tristan Technologies, Inc.

General Facts about Biomagnetometer Applications

What is measured —biomagnetic fields

Bioelectric activity generates corresponding biomagnetic fields that can be detected with Tristan SQUID magnetometers. While CT or MRI imaging yield structural information, biomagnetic measurements detect neuronal events and offer real-time functional imaging.

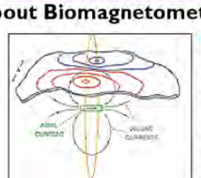


Fig 3. Origin of magnetic field detectable with sensors outside the body.

Advantages

SQUID based measurements are noninvasive and inherently safe. The detection system does not contact the subject, and subject preparation is simple and fast. Magnetic fields suffer much less distortion than voltage potentials, permitting more accurate localization. Insulating barriers (skull, blood, scalp, and anatomical open spaces) do not attenuate or distort magnetic fields they do with electrical potentials.Moreover, there are magnetic measurements, which have no electrical analogs (e.g. static magnetic fields, magnetic susceptibility). There are also magnetic measurements where a noninvasive procedure is not possible (e.g., fetal cardiography). The measurement of a magnetic field is a reference-free vector value rather than electric potential (scalar), so that unique information from 3 orthogonal directions can he obtained for any given sensor position.

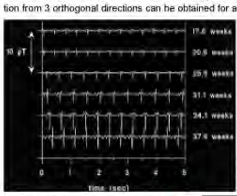


Fig.3 Fetal MCG over stages of gestation ranging from 17 to 37 weeks of gestation.

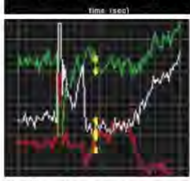


Fig.3 Traces from two 3-axis sensors separated by 5 cm over subject's forearm. from 61-sensor Model 637 system. Peak (white) moved 5 cm in 2 msec (time cursor in yellow).

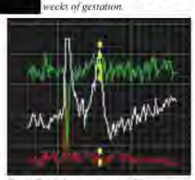


Fig. 3 Data from two pairs of 3-axis sensors

Biomedical Applications

- **Brain mapping**

Magnetoencephalography can map sensory and spontaneous activity within several millimeters in the volume of cortex, while distinguishing events separated by milliseconds, thus providing unique information about cortical communications.

- **Adult Heart**

Magnetocardiography (MCG) provides dynamic maps of heart function, and can be used to map sources and distinguish between as normal and abnormal events.

- **Fetal Heart**

The fetal MCG is a unique capability because the fetus has a natural electrical insulation, making EKG difficult or impossible. Magnetic fields are not blocked, and fetal abnormalities and arrythmias can be seen as early as 17th week of gestation with fMCG.

- **Spine/peripheral nerve function**

Nerve conduction involves rapid axonal spikes, of a duration on the order of 1 msec. Tristan's unique ultra high-speed system exceeds100,000 samples per second per channel, and can detect a 2-msec change over a 5 cm distance along a spinal cord or peripheral nerve in a human subject.

- **Detection of Mesenteric Ischemia**

Intestinal wall necrosis is difficult to diagnose without invasive surgery. Research using a model 619 indicates that SQUIDs could replace invasive and risky laporotomy to indicate surgery or to rule out mesenteric ischemia.

Tristan Technologies, Inc.

Tristan Model 637

Fig. 2 Modified 37 position system for spine measurements, with 61 sensor channels and 8 reference channels Shielded room, and gantry and patient bed are shown

The Model 637 is a fully integrated magnetic source imaging system with 37 sensor channel positions. Measurement coverage is nearly 500 cm^2, and the array is dense enough to make important biomedical maps with a single instrument placement over scalp or torso.

Flexible Design: Each channel position can accommodate from 1 to 3 (orthogonal) sensors, yielding up to up to 111 independent sources of data. The typical sensor coil diameter is 1 cm, in hexagonal close packed spacing. Sensor geometries can be tailored (and later changed) to allow the researcher to adjust the spatial frequency measurement capability of the system. Systems are tailored to user application: 1st or 2nd order gradiometer options tailored to noise reduction and depth of sources. An 8-element reference channel system works to reduce the influence of environmental noise sources.

System features: Systems typically include a gantry (with x,y,z, tilt, and rotation) and adjustable patient bed, along with hardware and software for data acquisition and signal analysis. The system features coil-in-vacuum construction.

Mapping capacity: Placed near the scalp over the temporal or tempo-parietal regions of brain, the system can detect and map dipolar sensory events with a single placement. Cardiac (and fetal heart) measurements can also yield source maps with a single placement of the instrument.

Applications

- **BMagnetoencephalography (MEG)**

Single placement map of sensory cortical source or abnormal spontaneous event (such as an interictal epileptic spike or slow wave).

- **Magnetocardiography (MCG) and fetal MCG**

With a gantry and real-time data monitoring, the user can adjust the system position quicklyfor recording heart (or fetal heart) data. The 37 channel array is suited for using spatial filters to separate maternal from fetal heart signals.

- **Assessment of Spine/Peripheral Nerve Function**

Because spinal signals involve action potentials, there is an option to acquire data in excess of 100,000 samples per second per channel. This permits tracking of axonal events, and allows tracking of very rapid changes in nerve conduction.

- **Detection of intestinal ischemia**

Very low frequency field changes (8-15 cycles per minute) characterize intestinal signals, which are associated with intestinal ischemia. Data acquisition includes multiple temporal filters, and time-frequency displays that permit effective real -time monitoring.

Fig.2 Time series (15 msec) from human radial nerve. 13 of the 37 positions have 3 axis vector channels.

Tristan Model 619

Fig.3 19 sensor position system for intestinal measurements, showing partially populated array. This insert is upgradeable to 37 sensor positions

The Model 619 is a fully integrated measurement system with 19 sensor channel positions, and can accommodate a variety of dense or sparse sensor packing. Sensors are typically 1-cm in diameter. The measurement coverage of the standard model 619 is ~180 cm^2 (15 cm diameter). Vector gradiometers can be used on some or all channels: to sample field gradient in all 3 orthogonal directions,

System features: The system includes hardware and software for data acquisition and signal analysis. System options include a gantry (with x,y,z, tilt, and rotation) and adjustable patient bed, along with hardware and software for data acquisition and signal analysis. The system features coil-in-vacuum construction.
Flexible design: A unique option is to upgrade to a larger channel-count system after initial installation. Each channel position can accommodate from 1 to 3 (orthogonal) sensors, yielding up to up to 57 independent sources of data.
Options: Sensors can be 1st or 2nd order gradiometer options, tailored to noise reduction and depth of sources. Customized (2nd order gradiometer and vector coils) are available. A high speed option (100,000 samples per second per channel) permits spine and peripheral nerve conduction measurements. An 8-element tensor gradiometer or 4 element vector gradiometer can be included as a set of reference channels for noise reduction.

Applications

The Model 619 is ideal for measurements such as nerve conduction, intestinal measures, or fetal cardiography, where 3D source localizations are not a requirement

- **Magnetoencephalography (MEG)**
- **Magnetocardiography (MCG)**
- **Fetal Magnetocardiography/fetal MCG**
- **Spine/Peripheral Nerve**
- **Intestinal ischemia**

The Model 619 system can be used to measure intestinal ischemia and is sized to meet cardiac and fetal cardiac research requirements.

Upgrading to larger array:
The model 619 can also be supplied in a 25 cm diameter version which can be economically upgraded (retrofit) to a 37 position system.

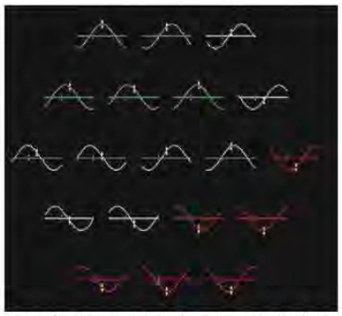


Fig.3. 19 channel sensor layout display of waveforms resulting from dipolar source located beneath the center sensor coil. The time shown is 50 msec, and the time axis on the display can be adjusted

Tristan Model 607

The Tristan Model 607 is a compact and economical laboratory system, with 7 sensor channel positions. Each of the channel positions can accommodate from 1 to 3 (orthogonal) sensors, yielding up to up to 21 independent sources of data. The 607 comes with a data acquisition and display system, and an optional gantry subject bed. The Model 607 system is an ideal starter system in a SQUID-measurement laboratory, and can be adapted to very close-in sample measurements. The system samples from a 9 cm-diameter circular area.

Fig 2. Close gap model 607 system installation with gantry in its magnetically shielded room. Subject bed/stage is not shown.

Applications

- **Brain** - Magnetoencephalography (MEG)
- **Heart** - Magnetocardiography (MCG and fetal MCG)
- **Spine/Peripheral Nerve**
- **Spine/peripheral nerve function**
- **Intestinal Ischemia**

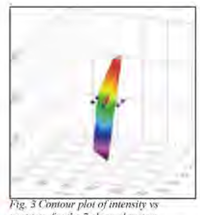


Fig. 3 Contour plot of intensity vs position for the 7 channel system, sampling a small, nearby cortical source.

Fig.1. Dewar with adjustable dewar tail mechanism shown at bottom

Optional Features

Animal Systems

The Model MS 607 microSQUID™ version of the Model 607 with can be used with animal preparations and in-vitro samples. Tristan's exclusive close spacing methods and materials result in placing superconducting sensors less than 5 mm from the room-temperature sample. The instrument can be used with exposed brain or intact animal preparations, and allows noninvasive measurements to be taken in parallel with electrode recording techniques.

Adjustable Dewar Tail

Tristan's unique adjustable tail technology permits closer spacing between sensor and room-temperature sources. The adjustable tail feature allows the user to adjust the tail gap distances for cool down and for measurement, adding a factor of safety and reliability.

Dewars and Sensor Geometries for CustomApplications

The combination of sensor array size (7, 19, or 37 positions) and sensor diameter (2 cm down to < 1mm) depends on the area of coverage needed, and the distance from source to sensors. the specifications are custom designed for specific measurement applications (from monkey to rat; or *in vitro* tissue slices).

Measuring Liver Iron Stores

The Tristan Ferritometer® is a diagnostic instrument which measures iron stores rapidly and non-invasively. Its advanced design with a superconducting magnet and SQUID detection system gives an accurate measurement of iron concentration in the liver and spleen for adults and children. The measurement is a volumetric technique, yielding average iron concentration measured over many milliliters of organ tissue, which accurately portrays total iron stores. A typical needle biopsy removes very small amounts of tissue and can easily give erroneous data. A small (few hundred gauss—less than a refrigerator magnet) magnetic field magnetizes the liver, and a SQUID

- **Non-invasive**
  - Replaces surgical biopsy for Iron Measurements
  - Eliminates Discomfort and Risk
  - Allows Pediatric Measurements
- **Direct Measurement Method**
  - Accurate and Reproducible
  - Allows Frequent Serial Measure ments
  - Rapid Results
  - Measurement Time Under 10 Minutes
- **First SQUID based system for clinical measurements**
  - Over 15 year operational period
  - Thousands of patients measured
  - Broad patient range: 2 months - 80 years of age, 5 - 220+ lbs

Fig.3 Ferritometer® system with patient bed and computer control system shown. The system operates without a magnetically shielded room.

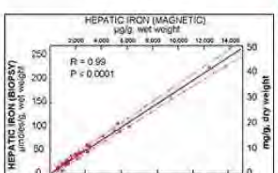


Fig 2. Figure courtesy of G. Brittenham

Applications

Iron overload diseases such as genetic hemochromatosis and siderosis caused by blood transfusions. The following uses have been established:

- transfusional siderosis (genetic ß-thalassemia major and sickle cell disease, or other transfusion dependent anemias)
- ß-thalassemics scheduled for bone marrow transplantation (BMT) or in ex-ß-thalassemics after BMT scheduled for iron depletion therapy
- patients scheduled for interferon therapy in liver diseases
- assessment of the long-term efficacy of different iron chelators under study
- diagnosis and assessment of genetic hemochromatosis (GHC), phlebotomy therapy of GHC.

Efficacy

Comparison to surgical biopsy in peer-reviewed studies have shown a high degree of correlation to SQUID measurements.

[1] The Ferritometer® is classified as a Class I (non-invasive) device under the European communities Medical Device Directive. While FDA certification has been applied for, it should be considered an investigational device for use in the United States.
[2] Brittenham GM, Farrell DE, Harris JW, Feldman ES, Danish EH, Muir WA, Tripp JH, Bellon EM. Magnetic-susceptibility measurement of human iron stores. *New Engl J Med* 1982; 307:1671-1675.)

Custom Features

Real-Time Data Monitoring System

Hardware and proprietary software data acquisition interfaces permit the user to monitor and evaluate the quality of data being collected in real time, to plan repeated measurements, or reposition the instrument. In addition, spatial and temporal filters can be designed and adapted to preview data in real time. Wavelet analysis, artifact rejection, and complex selective averaging functions are also included in the real-time monitoring package. The monitoring suite includes the following functions:

- Real-Time, Playback, & Simulation
- Filters & Filter editors
- Monitoring Displays
- Data Averaging
- Artifact Rejection

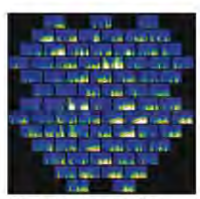


Fig.2 Joint time frequency analysis display. Each rectangle contains frequency content vs time for one sensor channel. display

Subject Positioning/Tracking System

A combined hardware/software system maps the 3D surface area of the subject and then tracks position and movements during data acquisition to compensate for subject movement. Several options are available for subject topography (manual stylus, laser scanner, or camera-and-grid system) and subject tracking (RF or optical instruments). Fiducial markers make it possible to co-register SQUID measurements with MR or CT structural images. The system enables standard source mapping regardless of subject movement.

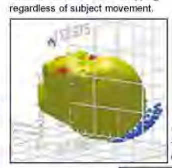


Fig. 3 Real-time display shows location sensors relative to head. Changing subject position is refreshed at a 30 Hz rate.

Reference Arrays for Noise Reduction

The greatest obstacle to SQUID measurements is external noise sources. Reference channels can be used to subtract common mode noise and reduce external noise by 60 dB or more, depending on the type and number of channels used. Figure p8 fig 4 shows how just a simple noise reduction algorithm can attenuate low frequency drift by nearly 40 dB.
Tristan can supply 3, 4 or 8 element reference arrays. The 8-element tensor is the preferred array for noise reduction; it consists of the three field components (B_x, B_y, B_z) and the five unique gradients (dB_x/dx, dB_x/dy, dB_y/dy, dB_x/dz, dB_y/dz) necessary to specify the gradient field(s) at the reference location.

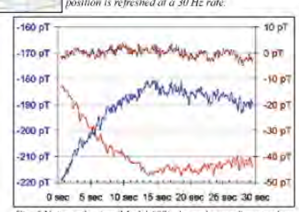


Fig. 3 Noise reduction (Model 607): 1st order gradiometer low frequency drift (blue); reference magnetometer (red) attenuated by 65x. Difference trace (brown).

About Tristan Technologies

Tristan makes advanced superconducting measurement devices and systems based primarily on SQUIDs. The technology is unmatched in its capacity to detect small electromagnetic signals, and its great promise continues to inspire new inventions and developments both within Tristan and on the part of its academic and commercial collaborators.

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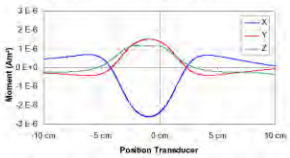
DRM-300 Rock Magnetometer

The Tristan model DRM-300 is a compact and easy to use SQUID magnetometer system for measurement of remnant magnetization of geophysical samples. The use of SQUID technology allows unparalleled sensitivity. Closed cycle refrigeration eliminates the need to transfer liquid helium. Its small footprint minimizes needed laboratory space.

Features:

- Three orthogonal detection coils
- SQUID detection circuitry
- 10^{-12} Am^2 Sensitivity
- Wide Dynamic Range
- Room Temperature Bore
- Closed-cycle 4-Kelvin refrigeration
- Self-replenishing liquid helium ballast for Quiet Mode operation
- Automated Sample Insertion Stage
- Internal Superconducting and mu-metal Magnetic Shields
- Compact size – small footprint



System response to two different customer supplied samples

DRM-300 Rock Magnetometer (cryocooler compressor not shown)

Tristan's model DRM 300 Rock Magnetometer offers technical enhancements to achieve superior sensitivity and dynamic range without sacrificing reproducibility or ease of use. Superconducting QUantum Interference Devices (SQUIDs) are used to detect and amplify the magnetic moment of samples placed into the sensitive volume of the detection coils. The change in detected magnetization is directly proportional to the magnetic moment of the sample. The detection coils in the model DRM-300 are wound in a Helmholtz-like configuration to provide a region of uniform sensitivity at the center of each coil set. There are three separate detection coil sets configured to simultaneously measure the three orthogonal components (B_x, B_y, B_z) of the induced field generated by the sample when it is inserted into the sensitive region of the detection coils.

A Gifford-McMahon closed cycle refrigerator liquefies gaseous helium to supply the cryogenic environment. The detection coils, SQUID sensors and superconducting shield are kept at operating temperature by thermal contact to a liquid helium ballast reservoir. The clear bore sample tube is kept at room temperature and permits samples as large as 19 mm diameter (larger sample sizes available on special order). A cryogenic temperature controller ensures millikelvin stability of the SQUID sensors. The closed cycle cryocooler is mounted far from sensors to minimize the field along the sample path.

For ultimate sensitivity, the DRM-300 can operate with the cryocooler turned off for periods of more than two days. An optional vibration isolation stand allows the system to continuously operate without significant vibrationally induced noise from the cryocooler compressors and valve motors.

Further reduction of the ambient magnetic field can be achieved by driving the superconducting niobium shield above its transition temperature to remove any trapped magnetic fields in the superconducting shield. A demagnetization circuit is standard with all DRM-300 systems.

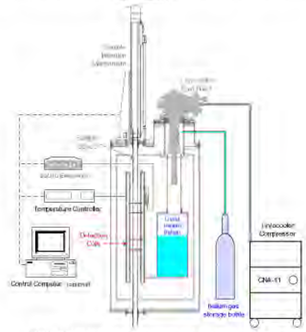
Options

Further customization and enhancement for the DRM-300 is possible through the offered options.

- **Vibration isolation system**
  The DRM-300 is designed to operate with the cryocooler turned off (for as long as 2-3 days). The detection coils, SQUID sensors and superconducting shield are kept at operating temperature by thermal contact to the liquid helium ballast reservoir. Additional vibration isolation is provided if continuous operation of the cryocooler is desired The Vibration Isolation Stand (Option 3V) is provided for noise free data acquisition during cryocooler operation. The independently vibration isolated and weighted frame, surrounds the dewar and the *mu-metal* shields. It has its own independent vibration isolation footpads which rest directly on the floor, independent of the rest of the system.
- **External Magnetic Shield options**
  An optional mu-metal shield mounted outside the dewar is offered for further reduction of external noise. Tristan can also supply magnetically shielded rooms or three-axis cancellation coils.
- **Oven and de-gaussing Stage option**
  On request, Tristan can supply degaussing systems, microwave heating and/or conventional ovens for sample preparation and handling prior to measurement.
- **Computer control, data acquisition system and software**
  A fully automated LabView® based control software for data acquisition and sample handling can be supplied.

System Specifications

SENSOR:	Three Superconducting QUantum Interference Devices (SQUIDs) operating at 4 K
SENSITIVITY:	10^{-12} $Am^2/\sqrt{Hz}$ (10^{-9} emu) white noise
DYNAMIC RANGE:	10^{-5} Am^2 (140 dB), higher ranges available on special order
CRYOGEN FILLING:	Not needed – Self-replenishing liquid helium ballast for Quiet Mode Operation utilizes commercial grade helium gas cylinders for the process
HOLD TIME:	infinite, 2+ days with cryocooler off
SHIELDING:	Internal superconducting and mu-metal magnetic shields
POWER:	100/120/200/220 V_{AC}; 50/60 Hz; single phase; 1.5 kVA
DIMENSIONS	43 cm outside diameter 115 cm overall length
WEIGHT:	77 kg (168 lb) magnetometer 75 kg (165 lb) cryocooler compressor
SAMPLE DIAMETER:	19 mm diameter (other diameters available)



DRM-300 schematic (vibration isolation stand not shown)

Model SMM-401 nanoSQUID

The Tristan model SMM-401 is a powerful non-contact scanning microscopy for imaging magnetic field distributions. The SMM-401 uses a superconducting SQUID sensor to provide outstanding spatial resolution and high sensitivity

Features:

- 100 µm spatial resolution
- 1.4 pT/√Hz field sensitivity
- Room temperature sample
- 25 µm gap between sensor and sample
- Non-magnetic scanning stage
- Low helium consumption

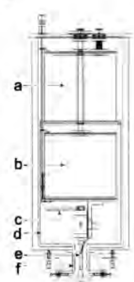
Applications

The SMM-401 is particularly useful in the areas where high sensitivities, especially at low frequency, are a requirement including Micropaleontology and Biomagnetism

Magnetic image of a homogeneously magnetized, 50 µm-thick geological thin section taken from the Martian meteorite ALH84001, and a line scan through the image showing a feature size of 120 µm. Courtesy of F. Baudenbacher *et al*

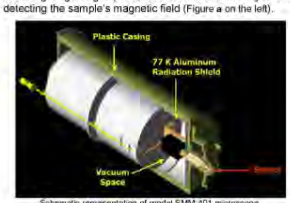
Magnetic microscopy image of a 1 mm by 2 cm by 1 cm slice of martian meteorite ALH84001, overlayed on top of a visual photo of the same slice. The colors give the field intensity, with red and yellow (blue) corre-sponding to upward (downward) magnet-ization. The fusion crust on the upper left side of the sample (visible as a thin black rind in the visual photograph) has been remagnetized in the Earth's field, while the interior of the meteorite retains the weaker, heterogeneous magnetism it acquired on Mars. *[Courtesy J. Kirschvink, Caltech]*

The magnetic field of the sample in the model SMM-401 is detected with a superconducting SQUID sensor. The sensing coil is mounted on the end of a sapphire rod keeping the superconducting sensor at liquid helium temperatures. The SQUID sensor is housed in the vacuum space of a cryostat behind a thin sapphire window and cooled through a thermal link to a liquid helium reservoir.



Cross section of Model SMM-401 SQUID microscope dewar: liquid nitrogen (a) and liquid helium (b) vessels, lever mechanism (c), liquid nitrogen-cooled radiation shield (d), cold finger (e), and bellows mechanism (f).

Careful thermal shielding assures reduction of the heat load allowing the sample is situated just below the sapphire window at bottom. The sample is scanned in close proximity to the window by a precision piezoelectric nonmagnetic scanning stage. High spatial resolution is obtained by directly detecting the sample's magnetic field (Figure **a** on the left).

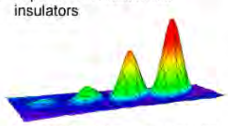


Schematic representation of model SMM-401 microscope

SQUID Magnetic Scanner
For Non-Destructive Testing

The Tristan model SMM-601 Magnetic Scanner is designed to measure magnetic fields with a spatial resolution better than 300 μm. It can be used to image diverse objects such as:

- subsurface cracks and flaws
- embedded magnetic sensors
- composite structures
- corrosion sites – hidden or exposed
- impurities in metals and insulators



Scan of 1, 3, 5, and 10 mm holes in a steel plate

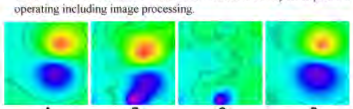
Besides measuring magnetic fields, the SMM-601 can also be configured to detect:

- induced magnetization
- aging and stress in ferromagnetic materials
- magnetic susceptibility
- eddy currents
- magnetic hysteresis
- Barkhausen effect
- rock magnetometry

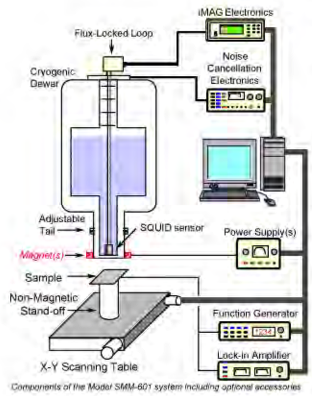
TRISTAN TECHNOLOGIES

Model SMM-601 Scanning SQUID Microscope with dc and ac biasing magnets

- The SMM-601 is a fully featured measurement system that allows the user to extract a magnetic image of the object being measured over the entire dc – 50 kHz frequency range. The adjustable tail dewar allows the spacing between the detection coil and sample(s) to be as small as 3 mm.
- Its low frequency response means large penetration depths (deep penetration). Another advantage of the model SMM-601 is its ability to operate in tesla fields. This allows it to make susceptibility measurements on the same sub-mm spatial resolution scale. In addition, it can operate in ac fields with dc – 50 kHz bandwidths for eddy current measurements.
- The SMM-601 allows computer controlled scans of objects over a large (15 x 15 cm) area with 25 μm stepping capability.
- The use of a dc SQUID sensor gives it unparalleled sensitivity. Its flat phase response allows both in-phase and quadrature information to be obtained without distortion. If ultimate sensitivity is needed, larger detection coils with resolutions exceeding 5 fT/√Hz are available. Additional detection coils can be supplied to give vector information.
- The SMM-601 requires minimal setup. Automated setup and computer control makes measurements rapid and repeatable. The use of open architecture software allows the user to customize nearly all aspects of operating including image processing.



Magnetic field maps of an embedded strain sensor under a 4 cm thick concrete overcoating. **A** - bare sensor showing dipole characteristics, **B** - sensor under concrete, **C** - bare concrete. Image **D = B – C** is a digital subtraction of B and C showing that it is possible to image objects deep underneath magnetically complex coverings. The scans cover a 6 cm x 6 cm area.



Components of the Model SMM-601 system including optional accessories

The standard model SMM-601 is configured to detect electric currents and to measure remnant magnetic fields. It includes a Single-Channel Scanning SQUID Magnetometer Probe, iMAG® SQUID Electronics, Cryogenic dewar, Room Temperature Scanning Stage, Computer Control and Data Acquisition System, and Imaging Software. The model SMM-601 can be supplied with additional capabilities to extend its measurement capabilities.

OPTIONS AND ACCESSORIES

Additional Detection Channels: The model SMM-601's measurement capabilities can be extended to multi-channel capabilities. This can mean either vector (B_x, B_y and B_z) capabilities or additional vertical (B_z) measurement sites to reduce measurement time. Noise reduction channels can also be added for sites where environmental noise is excessive.

dc Field Capability: This option consists of a superconducting magnet that generates a vertical (B_z) field on the sample. This allows magnetic susceptibility measurements on insulators, conductors and ferrous materials to be performed. Available field strengths can be between 0 and 10 000 oersted. We encourage the user to discuss his or her requirements for alternate field strengths.

Scan Area: Larger scan areas and higher resolution stepping (25 μm standard) are available upon request.

ac Field Capability: This option allows a small ac magnetic field to be imposed on the sample. The field is vertical (B_z) and can have a peak-to-peak magnitude up to 1 oersted. This capability is of particular interest when eddy current measurements are desired.

Horizontal Field (B_x and B_y) Sheet Inducer: A horizontal field sheet inducer, which can apply an ac magnetic field parallel to the test surface, to induce a large extended eddy current in a desired orientation, can be used to image cracks or material loss deep in conductive (*e.g.*, aluminum) structures.

ac Field Compensation Electronics: When an ac signal is directly coupled into the system, the resultant signal (from the field coils) may be much larger than the signal from the sample. In the case of a ferromagnetic materials such as carbon steel, the induced magnetization (even with a small ac field) may be quite large and the dynamic range of the data acquisition system may not be adequate to track this large signal while still resolving the small signal from defects in the metal.

To minimize this, Tristan can supply an ac Compensation system to null the ac signal in the detection coil and extract the induced signal in the object being measured.

SPECIFICATIONS

SENSOR: Low temperature superconducting quantum interference device (SQUID)

SPATIAL RESOLUTION: Better than 300 μm

SENSITIVITY: 6×10^{-14} tesla/√Hz (60 fT/√Hz) for 3 mm coils

DISTANCE TO SAMPLE: Adjustable to be less than 5 mm

OPERATING BANDWIDTH: dc - 50 kHz. Measurements can be made at any frequency. Bandwidths above 50 kHz are available.

CRYOGENIC COOLING: To avoid low frequency noise below 200 Hz, the system uses liquid helium to cool the sensor.

CRYOGENIC HOLD TIME: Time between refills of liquid helium is typically 3 days

SAMPLE SCANNING RANGE: 15 cm x 15 cm in x-y directions; larger scan areas available

SCAN STEP SIZE: Adjustable with minimum step size of 25 μm.

SAMPLE PREPARATION: None required. Samples are measured at room temperature

POWER REQUIREMENTS: 100, 115 or 220 VAC, 50 or 60 Hz

dc Field Option: greater than 10 gauss with 10 A power supply

Specifications subject to change without notice

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Scanning Magnetic Microscope

The Tristan model SMM-770 Scanning Magnetic Microscope is designed to measure magnetic fields above a planar surface with unparalleled spatial resolutions.

Using a liquid nitrogen SQUID sensor, it can be used to image room temperature objects such as:

- traces on a circuit board or multi-chip module
- shorts to ground planes
- current distributions
- magnetic inks used in currency

Magnetic image of dollar bill section

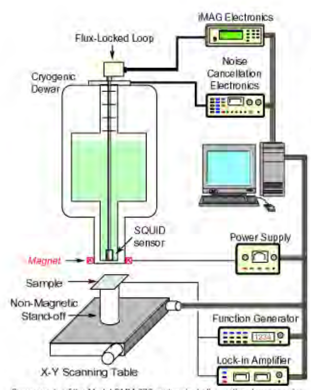
- insulators, ferrous and non-ferrous metals to detect cracks, voids and corrosion
- nanoparticle distributions
- flux-motion in HTS materials

The SMM-770 can also be configured to detect:

- induced magnetization
- magnetic susceptibility
- eddy currents
- magnetic hysteresis
- micropaleontology
- magnetobiologic activity

Model SMM-770 Scanning SQUID Microscope with dc and ac biasing magnets

- The SMM-770 is a fully featured measurement system that allows the user to extract a magnetic image of the object being measured over the entire dc – 10 kHz frequency range.
- Whether the samples are circuit boards, multi-chip modules, steel or aluminum plates, composites or even plastics, the SMM-770 can measure surface and even deeply embedded sources with a spatial resolution down to 50 μm.
- The use of a High Temperature Superconducting dc SQUID sensor gives it unparalleled sensitivity with the ability to measure fields smaller than 20 pT/√Hz. Tristan's HTS sensors can also operate in applied magnetic fields up to 1000 oersteds.
- The SMM-770 allows computer controlled scans of objects over a large (15 x 15 cm) area with 25 μm stepping capability with sub-micron stepping available. The user has the ability to preprogram the scan coordinates.
- The SMM-770 requires minimal setup. Automated setup and computer control makes measurements rapid and repeat-able. System soft-ware provides the ability to control the critical system components, acquire data from the SQUID sensor, and analyze the data to determine the magnetic properties of the sample being measured. The use of open architecture software allows the user to customize nearly all aspects of operating including image processing.



Components of the Model SMM-770 system including optional accessories

The Standard SMM-770 is configured to detect electric currents and to measure remnant magnetic fields. It includes a Single-Channel Scanning SQUID Magnetometer Probe, iMAG® SQUID Electronics, Cryogenic dewar, Room Temperature Scanning Stage, Computer Control and Data Acquisition System, and Imaging Software. The SMM-770 can be supplied with additional capabilities to extend its measurement capabilities.

OPTIONS AND ACCESSORIES

SCAN AREA: Larger scan areas (*e.g.*, 30 cm x 30 cm) and higher resolution stepping (25 μm standard) are available upon request.

Substitution OF HTM-1 SQUID Sensor: For measurements where sensitivities significantly below 20 pT/√Hz are needed and ultimate spatial resolution is not as important, Tristan can substitute the model HTM-1 sensor with a significantly larger (1 mm) detection coil with a sensitivity better than 3 pT/√Hz. The HTM-8 (8 mm coil) sensor with a sensitivity better than 0.05 pT/√Hz is also available.

Fixed Field Capability: This option consists of a fixed field that generates a vertical (B_z) field on the sample. This allows magnetic susceptibility measurements on insulators, conductors and ferrous materials to be performed. System noise is dependent upon field.

ac Field Capability: This option allows a small vertical ac magnetic field to be imposed on the sample. This capability is of interest when eddy current measurements are desired. This option can be used simultaneously with the dc Field Option for added flexibility in magnetic characterization.

Horizontal Field (B_x and B_y) Sheet Inducer: A horizontal field sheet inducer, which can apply an ac magnetic field parallel to the test surface, to induce a large extended eddy current in a desired orientation, can be used to image cracks or material loss deep in conductive (e.g., aluminum) structures.

ac Field Compensation Electronics: When imaging conductive materials, if an ac signal is directly coupled into the system, the resultant signal (from the field coils) may be much larger than the signal from the sample. To minimize this, Tristan can supply an ac Compensation system to null the ac signal in the detection coil and extract the induced signal in the object being measured.

SPECIFICATIONS

SENSOR: High temperature superconducting quantum interference device (SQUID) operating at 77 K

SPATIAL RESOLUTION: Better than 50 μm

SENSITIVITY: 2×10^{-11} tesla/√Hz (20 pT/√Hz)

OPERATING BANDWIDTH: dc - 10 kHz. Measurements can be made at any frequency. Bandwidths above 20 kHz are available.

CRYOGENIC COOLING: To avoid low frequency noise below 200 Hz, the system uses liquid nitrogen to cool the sensor.

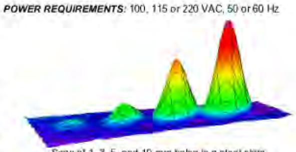
CRYOGENIC HOLD TIME: Time between refills of liquid nitrogen is typically 3 days

SAMPLE SCANNING RANGE: 15 cm x 15 cm in x-y directions

SCAN STEP SIZE: Adjustable with minimum step size of 25 μm

SAMPLE PREPARATION: None required. Samples are measured at room temperature

POWER REQUIREMENTS: 100, 115 or 220 VAC, 50 or 60 Hz



Scan of 1, 3, 5, and 10 mm holes in a steel plate

Specifications subject to change without notice

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Magnetometers for Geophysics

TRISTAN TECHNOLOGIES

Mineral surveys, magnetotellurics, magnetic detection of induced polarization, and other magnetic detection methods are important geophysical tools. Superconducting magnetometers and gradiometers offer several advantages over other detectors commonly used for such measurements.

- **Constant Sensitivity from dc to 10 kHz**
- **Magnetic Field Resolution of 10^{-14} Tesla**
- **Gradient Resolution of 10^{-15} Tesla/meter**
- **True dc Response**
- **Flat Phase Response**
- **Wide Dynamic Range**

Tristan manufactures the most complete line of ultrasensitive geomagnetic measurement systems available. From compact single and three channel magnetometers to 8-channel tensor arrays, Tristan offers a variety of fully configured system packages for geophysical measurements.

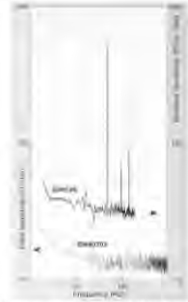
The basic geophysical measurement system offered by Tristan is the model G377. It measures all three vector components of the Earth's magnetic field (B_X, B_Y, B_Z). The small size and portability of the model G377 makes it convenient for field use. It can also be supplied with different size dewars for airborne (model NLD-530 dewar) and borehole (Model NGD-830 dewar) use. Planar Gradiometers can also be substituted if measurements of magnetic field gradients are required.

Model G377 three axis magnetometer system

Tristan offers three basic sensors for geophysical measurements, the HTM-8 and the higher sensitivity HTM-16 are magnetometers (B_x, B_y, B_z); the optional HTG-10R measures planar gradients (dB_z/dx).

The model G377 can be supplied with fewer sensors or a mixture of magnetometers and planar gradiometers if needed. The picture below shows a single channel planar gradiometer (HTG-10R sensor) being used in airborne measurements.

Model 701G system mounted at end of boom



Measured sensitivities of HTM-16 (SM90703) and HTG-10R (G90126) sensors

Tristan offers variants of the model G377. The Model 703 is identical to the G377, but uses the smaller 5" diameter Model 530 dewar. The Model 701G uses a single HTG-10R gradiometer in the Model 530 dewar. Tristan can also offer fast 5 µsec reset times for transient measurements. For even greater sensitivity and dynamic ranges, Tristan can supply liquid helium versions of the G377 and its variants.

OPTIONAL DEWARS

Model NGD-830 borehole dewar

Model NGD-1080 dewar with T877 tensor probe

Model NLD-530 dewar

G377-803

Model G377

Operation Principle: 3-Axis 77 kelvin dc SQUID Magnetometer - Measuring the relative change in magnetic field simultaneously in B_x, B_y and B_z axes.

Range:	±5 µT/√Hz
Bandwidth:	dc to 10 kHz wider bandwidths available
Slew Rate:	> 1 µT/sec (peak-to-peak)
Sensitivity:	50 fT/√Hz: HTM-8 20 fT/√Hz: HTM-16 1 fT/m√Hz: HTG-10R
Cryogen:	Liquid Nitrogen
Volume:	7 liters
Hold time:	2-3 weeks
Power:	120 or 240 V_{AC}, 50 Watts (12 Volt Battery Supply Optional)
Outputs:	Analog, RS-232 or IEEE-488 Visual Alphanumeric display
Controller:	321 mm x 121 mm x 300 mm (12.6" wide, 4.8" high, 11.8" deep)
Weight:	3.6 kg (8 lbs.)
NGD-1030 dewar	(7 liters) *Standard on G377* 406 mm high, 250 mm diameter (16" high, 9.8" diameter)
Weight:	Full - 12.2 kg (27 lbs.) Empty - 6.6 kg (14½ lbs.)
NGD-830 dewar	(¾ liter) *optional* 600 mm high, 83 mm diameter (24" high, 3¼" diameter)
Weight:	Full – 3.5 kg (7½ lbs.) Empty – 2.7 kg (6 lbs.)
NLD-530 dewar	(1 liter) *Standard on 703* 311 mm high, 127 mm diameter (12¼" high, 5" diameter)
Weight:	Full – 1½ kg (5 lbs.) Empty – 2¼ kg (3¼ lbs.)

Contact Tristan for custom systems, or if you need additional information.

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specifications subject to change without notice

T877 Tensor Gradiometer

TRISTAN TECHNOLOGIES

The Tristan model T877 SQUID tensor gradiometer is designed to measure magnetic fields and gradients for geophysical measurements.

It is a valuable tool for:

- Magnetotellurics
- Controlled Source Measurements
- Borehole Measurements
- Transient Electromagnetic Measurements (TEM)
- Unexploded Ordinance (UXO)
- Magnetic Anomaly Detection
- Environmental Waste Detection
- Airborne Measurements
- Site Survey Measurements

Superconducting magnetometers and gradiometers offer several advantages over other detectors commonly used for Magnetic Anomaly Detection, MagnetoTellurics, magnetic detection of induced polarization, and other geophysical measurements. Superconducting detectors offer constant sensitivity from dc to tens of kHz (or higher), and magnetic field resolution up to 10^{-5} nT√Hz with magnetic gradient resolution up to 10^{-5} nT/ft√Hz and a dynamic range of 140 dB. These systems are well suited to field use, being lightweight, reliable, fast to set up, and easy to use.

The T877 magnetometer/gradiometer offers several important advantages over other magnetometers. It is a vector magnetometer, in contrast to the proton precession device which responds only to the magnitude of the field. With a three-axis vector magnetometer, both the magnitude and direction of the field can be determined. With eight sensing elements in a tensor configuration, the complete magnetic field gradient can be determined. Its performance is not impaired by the presence of large gradients and — unlike fluxgate devices — SQUID magnetometers do not saturate. In comparison to large induction coils, the T877 is not awkward or cumbersome in deployment and use. The T877's dc response avoids giving undue emphasis to high frequency phenomena such as the ubiquitous lightening induced sferics.

Because of the superconducting nature of SQUID magnetometers, they offer not only dc response, but also flat frequency response well past 10 kHz. Their flat phase response allows for seamless data integration, unlike conventional magnetometers which suffer from 90° (or higher) phase shifts.

The Tristan Model T877 is a field-proven rugged, highly sensitive superconducting SQUID magnetometer/gradiometer designed for geophysical exploration and measurement. With the full tensor configuration, it is possible to obtain complete characterization of magnetic dipole sources at long range, obtaining localization and classification information. This has been shown theoretically by Wynn[1] and demonstrated in the field. All that is necessary is knowledge of the magnetic field components (H_x, H_y, H_z) and the five unique field gradients ($\partial B_x/\partial x$, $\partial H_y/\partial x$, $\partial H_x/\partial z$, $\partial H_y/\partial z$, $\partial H_z/\partial z$). The T877 combines eight individual magnetometers into an array that yields all necessary field and gradient components.

T877 sensor housing showing cold electronics

For airborne operation, Tristan can supply custom dewars including horizontal or other customer specified configurations.

[1] Wynn, *et al.*, "Advanced Superconducting Gradiometer/Magnetometer Arrays and a Novel Signal Processing Technique", *IEEE Trans on Magnetics*, **11**,701-707 (1975)

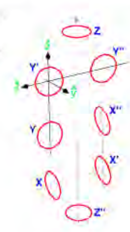
TENSOR CONFIGURATION

- The magnetic field vector, H, can be expressed in terms of Cartesian components $H = (H_x, Hy, H_z)$. For each component, there are three spatial derivatives along orthogonal directions, generating nine components of the second rank magnetic field gradient tensor. This tensor can be represented by the matrix:

$$\begin{pmatrix} \frac{\partial H_x}{\partial x} & \frac{\partial H_x}{\partial y} & \frac{\partial H_x}{\partial z} \\ \frac{\partial H_y}{\partial x} & \frac{\partial H_y}{\partial y} & \frac{\partial H_y}{\partial z} \\ \frac{\partial H_z}{\partial x} & \frac{\partial H_z}{\partial y} & \frac{\partial H_z}{\partial z} \end{pmatrix} \rightarrow \begin{pmatrix} \frac{\partial H_x}{\partial x} & & \\ \frac{\partial H_y}{\partial x} & \frac{\partial H_y}{\partial y} & \\ \frac{\partial H_z}{\partial x} & \frac{\partial H_z}{\partial y} & \end{pmatrix}$$

- According to Maxwell's equations, only five of these tensor elements are independent, which is what the SQUID tensor array measures.
- The T877 can be used to create both axial and planar gradients by electronic subtraction of magnetometer signals. The figure to the right shows the relative orientation of the magnetometer coils. The five needed gradients are formed by the following relationships between the eight sensors of the Model T877:

$$H_x = \frac{1}{3}(X + X' + X''),$$
$$H_y = \frac{1}{3}(Y + Y' + Y''),$$
$$H_z = \frac{1}{2}(Z + Z''),$$
$$\frac{\partial H_x}{\partial x} = \frac{X - X'}{b},$$
$$\frac{\partial H_x}{\partial z} = \frac{X'' - X}{a},$$
$$\frac{\partial H_y}{\partial z} = \frac{Y' - Y}{a},$$
$$\frac{\partial H_y}{\partial x} = \frac{Y' - Y''}{b},$$
$$\frac{\partial H_z}{\partial z} = \frac{Z - Z''}{c}$$



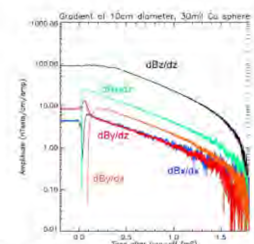
where a, b, and c are the coil-to-coil center spacings

SYSTEM COMPONENTS

- Model HTM-8 HTS dc SQUID Magnetometer Sensors (8)
- Model NGD-1080 Liquid Nitrogen Dewar
  Horizontal and borehole dewars available on request
- Model NGI-108 cryogenic insert and cryogenic cables
- Model iMC-303 iMAG® SQUID Electronics Control Unit
- Model iFL-301-H Flux-Locked Loops (8)
- Model CC-60 six meter fiber-optic composite cables (8)
- Manual and accessory pack

for details on individual components, see their respective data sheets

Specifications subject to change without notice



Data from Controlled Source Measurement of a 10 cm diameter hollow (30 mil thick) copper sphere showing data from the five independent tensor gradients. Data was collected at 1 µsec intervals.

SPECIFICATIONS

SENSOR:	High temperature superconducting quantum interference device (SQUIDs) operating at 77 K
OPERATING RANGE:	± 900 nT
BANDWIDTH:	dc to 10 kHz (wider bandwidths available)
SENSITIVITY:	Better than 50 fT/√Hz Better than 80 fT/cm√Hz
CRYOGEN:	Liquid Nitrogen
DEWAR VOLUME:	7 liters
HOLD TIME:	nominally 2 weeks
POWER:	120 or 240 V_{AC}, 50 Watts (12 Volt Battery Supply Optional)
OUTPUTS:	Analog ±3 Volts RS232 or IEEE-488 Visual Alphanumeric display
CONTROLLER:	321 mm wide, 121 mm high, 300 mm deep (12.6" x 4.8" x 11.8") 3.6 kg (8 lbs.)
DEWAR:	467 mm high, 250 mm diameter (18.4" high, 10" diameter) Weight: Full: 15.2 kg (33 lbs.) Empty: 9.6 kg (21 lbs.)

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TRISTAN TECHNOLOGIES

Biomagnetic Liver Susceptometer

Measurement of Liver Iron Stores by Magnetic Biopsy

The Biomagnetic Liver Susceptometer is a diagnostic instrument which measures iron stores rapidly and non-invasively. Its advanced design with a superconducting magnet and SQUID detection system gives an accurate measurement of iron concentration in the liver and spleen for adults and children.

- **Non-invasive**
  Replaces Surgical Biopsy for Iron Measurements
  Eliminates Discomfort and Risk
- **Allows Pediatric Measurements**
- **Direct Measurement Method**
  Accurate and Reproducible
  Allows Frequent Serial Measurements
- **Rapid Results**
  Measurement Time Under 10 Minutes

BLS Methodology

Non-invasive Biomagnetic Liver Susceptometry (BLS) exploits the effects of magnetism and superconductivity. Biological materials such as ferritin and hemosiderin are weakly attracted to an applied magnetic field (paramagnetic behavior) while water and body tissue are very weakly repelled (diamagnetic). Ferromagnetic materials e.g., nickel and steel, are strongly attracted to applied fields. No naturally occurring human tissue is ferromagnetic.

In the BLS method, a weak magnetic field of 0 - 20 millitesla is generated within the body tissue by an external superconducting field magnet, similar to that used in a MRI scanner, but a hundred times weaker. The applied fields are measured by a superconducting magnetometer known as a SQUID (Superconducting QUantum Interference Device). The SQUID sensing system has the ability to measure distortions in the magnetic field at the part per billion level.

When an organ, such as the liver, is placed in a magnetic field, it will slightly distort the applied field. If the liver is normal or anemic, the local field will be reduced slightly. If the liver is iron overloaded, the local field will be enhanced. Hence the change in the detected magnetic field is directly related to the iron concentration in the liver.

To minimize the body's contribution to the distortion in magnetic field, a small bag of water is placed between the detector and skin surface. Since the susceptibility of body tissue is close to that of water, the resultant measurement is essentially that of a magnetized liver (or spleen) moving in a magnetic field within a uniform (diamagnetic) environment; the only change seen by the detection coils is due to the liver (or spleen) itself.

For higher accuracy, our software removes the actual contribution of overlying tissues (skin, bone, muscle, fat, etc.). This gives the iron concentration of the liver (or spleen) alone, allowing accurate measurements for obese patients and normal patients with atypical liver/spleen depths.

To date, the BLS method has been applied to organs such as livers and enlarged spleens (> 300 ml) with a total error of [Fe] = 0.05 - 0.4 mg/g tissue (wet weight). Repeatability (serial measurements over three weeks) on single subjects of better than 95 % has been demonstrated.

Specifications

Magnetic Field: 20 mT at coil face, stability better than 0.1 ppm/hour. 5 Gauss line 14 cm from dewar tail.
Detection Coil Sensitivity: 100 $fT/\sqrt{Hz}$.
Liquid Helium Capacity: 35 liters/10 day hold time.
Patient Bed Capacity: 135 kg.
Ultrasound: 3.5 MHz linear array, ±0.5 mm resolution
Data Base: Open file structure with ability to customize to user preferences.
Total System Noise: 0.02 mg/g [Fe[concentration (wet weght), as measured by a liver phantom at a distance of 15 mm.
Measurement Range: 0.05-30 mg/g (wet weight), equivalent to 0.2 to 100 mg/g (dry weight).

Options

For researchers interested in extending measurement capabilities, Tristan offers the following options:

- Additional Detection Channel
  This includes a third detection coil with different spatial sensitivity.
- Active Noise Cancellation
  Needed for sites with high environmental noise.
- AC Field Capability
  AC-field modulation of the magnetic field. This can allow research on alternate methods of BLS.

The Tristan Biomagnetic Liver Susceptometer is classified as an investigational device and is offered for research use only. Tristan is in the process of seeking both CE (European) medical device directive and FDA (U.S.) certification for clinical use. Specifications subject to change without notice.

Site Requirements

The model BLS requires a minimum 3.7 m x 4.6 m x 6 m (12' x 15' x 20') space. Total system weight is 1,500 kg. Power requirement is 7 kVA. A vibration free platform for the gantry is required and the system should be sited in a magnetically quiet environment. Contact Tristan to discuss site surveys for magnetic and vibration measurements. All Tristan products are covered by a 1-year warranty. Service contracts may be purchased to provide post warranty coverage.

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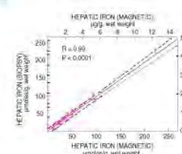
Clinical Relevance

The standard quantitative measurement of iron stores has required a surgical or needle liver biopsy. This method requires a physiochemical analysis with its associated time delay in obtaining results. It also assumes that iron is evenly distributed throughout the liver. In addition, the needle biopsy is not without discomfort and, in some cases, significant risk.

The most common assessment of iron stores is the serum ferritin measurement. Clinical studies have shown serum ferritin measurements to be a poor predictor of actual iron stores with correlation coefficients (R) ranging as low as 0.24 for ß-Thalassemia intermedia patients[1]. Serum ferritin estimates can be incorrect by as much as a factor of ten.

Biomagnetic Liver Susceptometry (BLS) has long been recognized as providing accurate quantitative measurements of iron stores. The graph[2] shows a comparison of hepatic iron concentration as determined by BLS (x-axis) and by chemical analysis of liver tissue obtained by clinically indicated needle biopsy (y-axis).



With the ability to take into account the contribution of overlying tissues, BLS measurements can be extended to adults and children who have wide variations in organ depth and body fat. Another advantage of BLS is that it is a volumetric technique, giving an average iron concentration measured over many milliliters of organ tissue which more accurately portrays total iron stores. A typical needle biopsy which removes very small amounts of tissue can easily give erroneous total iron stores.

[1]R. Galanello *et al* (against atomic absorption after percutaneous biopsy) and B. R. Saxon *et al* (surgical biopsy and magnetic biopsy)
[2]Courtesy, G. M. Brittenham. Magnetic and biochemical measurements were made within 1 month; patients with cirrhosis or with biopsy specimens less than 5 mg, wet weight, were excluded.

Measurement Protocol

On the first visit, patient information including name, age, height, weight and total body fat is taken.

The depth and shape of the liver (or spleen) is measured by ultrasound and entered into the patient data base.

The patient is positioned on a movable bed such that the central mass of the liver (or spleen) is directly beneath the detector.

The bed is elevated until the patient just touches the detector and the water bellows is filled.

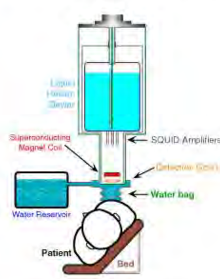
The patient is then automatically lowered about 10 cm over 10 seconds. As the bed lowers, water flows into the bellows keeping the space between the patient and detector filled.

The change in magnetic field measured by the magnetometer is recorded as a function of the distance of the liver from the detector coils.

The computer immediately analyzes the data and gives a preliminary result as soon as the bed motion stops.

The measurement sequence is generally repeated one or more times to improve accuracy.

Excluding the ultrasound portion, it typically takes less than 10 minutes to make a BLS measurement and determine hepatic iron concentration.



Schematic of Major Subsystems

Applications

The most relevant applications of Biomagnetic Liver Susceptometry (BLS) are related to iron overload diseases such as hereditary hemochromatosis and siderosis caused by blood transfusions. To date, the following applications have been demonstrated:

- Monitoring iron overload in patients with transfusional siderosis (genetic ß-thalassemia major and sickle cell disease, or other transfusion dependent anemias) for the onset or intensification of chelation therapy and during this therapy
- Assessment of iron overload in patients scheduled for Interferon alfa therapy in viral liver infections such as Hepatitis B or C
- Assessing iron overload in patients with ß-thalassemia scheduled for bone marrow transplantation (BMT) or monitoring iron overload after BMT during iron depletion therapy
- Assessment of the long-term efficacy of different iron chelators under study
- Diagnosis of hereditary hemochromatosis and assessment of the degree of iron overload in known hereditary hemochromatosis
- Monitoring liver iron concentration in the initial assessement and long term phlebotomy therapy of hereditary hemochromatosis

SQUID iMAG

SYSTEMS

TRISTAN TECHNOLOGIES

- Laboratory Applications
- Biomagnetic Measurements
- Geophysical Exploration
- Non-Destructive Evaluation
- Magnetic Microscopy
- Custom SQUID Systems

Tristan offers a variety of fully configured system packages based on the iMAG® series of SQUID components. These range from basic single-channel magnetometer systems to instruments for specific applications. They include systems for biomagnetism, geophysical exploration, nondestructive testing of materials, magnetic microscopy and studies of rock magnetism. For applications that require applied fields, Tristan can supply persistent superconducting magnets, permanent magnet structures with custom-designed field profile shapes and built-in copper magnets for ac fields. Tristan's SQUIDs are available in both high temperature (HTS) 77 K and low temperature (LTS) 4.2 K versions. Standard product data sheets and application sheets are available for many of these complete systems. Contact your Tristan products representative with your specific system needs.

The basic SQUID system consists of an input circuit connected to a SQUID sensor, a dewar to provide the cryogenic environment, SQUID control electronics and possibly a data acquisition system (Fig. 1).

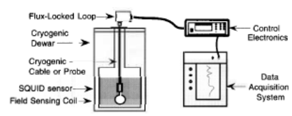


Fig. 1. Typical magnetometer system

Tristan offers complete systems or individual components, according to your needs. Tristan also supplies the basic components that can be combined to form the basis of a SQUID measurement system. Specific information on individual components can be found on their respective data sheets.

SQUIDS

Model LSQ/20 LTS dc SQUID Sensor
Model HTM-100 HTS Magnetometer
Model HTG-100 HTS Gradiometer
Model HTo-100 HTS miniMAG

PROBES

Model SP Standard Cryogenic Cable
Model RMP External Feedback Probe
Model MFP Multi-Function Probe
NLI series of dewar inserts for HTS SQUID sensors

ELECTRONICS

Model iFL-301-L (LTS Flux-Locked Loop)
Model iFL-301-H (HTS Flux-Locked Loop)
Model iMC-303 Cryogenic Control Unit
Model RLM ac Impedance Bridge

DEWARS

BMD series for liquid helium (LTS) systems
NLD series for liquid nitrogen (HTS) systems

TRISTAN LABORATORY SYSTEMS

Tristan offers the most complete line of SQUID measurement systems available. These systems can be combined with either user- or Tristan-supplied cryogenics to give you the most versatile measurement capabilities possible.

For laboratory applications, the LTS SQUID system can be configured to measure a wide variety of electromagnetic signals. HTS SQUIDs are available as pure magnetometers and planar gradiometers. Typical sensitivities that can be achieved with Tristan SQUID systems are listed below:

a)	Current:	10^{-12} amp/√Hz
b)	Magnetic Fields:	10^{-15} tesla/√Hz
c)	dc Voltage:	10^{-14} volt
d)	dc Resistance:	10^{-12} Ω
e)	Inductance:	10^{-12} henry
f)	Magnetic Moment:	10^{-10} emu

Model BMS Basic Measuring Systems: The Model BMS-H is a HTS SQUID system capable of measuring magnetic fields approaching 30 femtotesla/√Hz (1 fT = 10^{-15} tesla). Typically, this system is used in conjunction with a NLD series Dewar. The BMS-H can also be supplied with a planar gradiometer coil with a gradient sensitivity better than 100 fT/cm√Hz or a miniMAG sensor with spatial resolution <100 μm.

The Model BMS-L is a LTS SQUID system capable of measuring small electric currents with a better than than 7 × 10^{-13} ampere/√Hz. With a simple pickup coil, it also can be used for the detection of magnetic fields as small as 1 fT.

Model PMS Picovolt Measuring System: This cryogenic dc voltage amplifier with a gain of 10^8 and a rms noise of less than 10^{-13} volts/√Hz is used for measurements of very small voltages and resistances.

Model MPS Multi-Purpose Measurement System: This system is a low impedance ac bridge system for extremely sensitive resistance and inductance measurements. Resolutions of 10^{-10} ohm and 10^{-13} henry are readily obtained. The Model MPS also has the combined capabilities of the BMS and PMS systems and allows a wide range of both ac and dc measurements to resolutions approaching 0.001% on single or multiple samples.

Specialty Components: Tristan also provides a number of additional accessories for use in configuring iMAG SQUID-based systems. These include variable temperature cryostats (0.05 K – 800 K), room-temperature and low-temperature X-Y scanning stages, LTS superconducting motors, mu-metal magnetic shields, dewars, dewar stands, transfer tubes and other accessories.

TRISTAN MAGNETOMETER SYSTEMS

For measurements of external magnetic fields, Tristan offers both liquid helium and liquid nitrogen SQUID measurement systems. Series 600 LTS systems are designed for the researcher who desires ultimate performance from a low to medium channel count SQUID magnetometer or gradiometer system. The series 700 HTS magnetometers offer researchers interested in HTS (liquid nitrogen) SQUIDs a number of convenient platforms to perform magnetic measurements.

model	type	channels	orientation	noise
601	LTS		$B_z, \frac{dB_z}{dz}$ or $\frac{d^2B_z}{dz^2}$	l0 fT/√Hz
603	LTS	3	$\frac{dB_x}{dz}, \frac{dB_y}{dz}, \frac{dB_z}{dz}$	< 10 fT/√Hz
606	LTS	3 + 3	$\frac{dB_x}{dz}, \frac{dB_y}{dz}, \frac{dB_z}{dz}; B_x, B_y, B_z$	< 10 fT/
612	LTS		$\frac{dB_z}{dz}$	15 fT/√Hz
701	HTS		$B_z, \frac{dB_z}{dz}$ or $\frac{dB_x}{dz}$	< 90 fT/√Hz <100 fT/cm√Hz
703	HTS	3	$B_x, B_y, B_z, \frac{dB_z}{dz}, \frac{dB_x}{dz}$	< 90 fT/√Hz <100 fT/cm√Hz

With the use of discrete detection circuits, Tristan LTS SQUID systems can operate in magnetic fields exceeding 9 tesla and sample temperatures ranging from mK to well above room temperature. Tristan HTS SQUIDs can operate in fields that can exceed 0.1 tesla.

TRISTAN CUSTOM SQUID SYSTEMS

Tristan has supplied a wide variety of unique SQUID-based instrumentation for Laboratory, Biomagnetic, Geophysical, and Non-Destructive Evaluation (NDE) measurements. If your needs are unique, contact us to discuss your particular requirements. Tristan's scientists and engineer's 20+ years of experience and an ever-increasing quest for refinement of its product line, ensures that Tristan can manufacture the ideal SQUID system to suit your needs.

Specifications subject to change without notice.

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SQUID iMAG

CRYOGENIC PROBES for the laboratory

FEATURES

- Easy to Install
- Multiple Measurement Capability
- Immersion or Vacuum Operation

Tristan manufactures three basic SQUID probes for general laboratory use. These probes are used to interface the SQUID sensors to the flux-locked loops and provide the basic capability for a variety of ultrasensitive measurements such as:

- Magnetic Fields and Field Gradients
- Static Magnetic Moment and Susceptibility
- Electric and Magnetic Fluctuations
- dc Voltage and Resistance
- Low Frequency ac Resistance and Self-inductance
- Low Frequency Mutual Inductance and Susceptibility

Tristan's cryogenic probes and cables are the heart of any SQUID based measurement system. They provide a flexible transmission line running from room temperature to either 4 K or 77 K with plug-in connectors at each end. Without restrictions of a rigid probe, a variety of installation options are available.

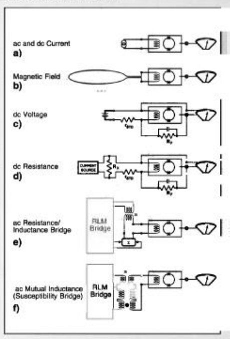
In all Tristan probes, construction materials are non-magnetic and carefully selected to minimize conduction of heat into the cryogenic bath. All probes are shielded against rf interference and other electrical transients that may affect the SQUID operation. A room temperature O-ring seal allows pumped dewar operation. Probes are available separately for upgrading older SQUID systems or for expanding the capabilities of a more recently purchased system.

The Model SP Cryogenic Cable is the probe of choice for simple current and magnetic field measurements. Used with the Model DSQ/20 low temperature (LTS) dc SQUID sensor, measurements shown in Fig 1a & 1b are possible. Used with the Model HTM-100 high temperature (HTS) dc SQUID sensor, measurement configurations shown in Fig 1b are possible.

The Model MFP Multi-Function Probe is the most versatile LTS SQUID probe offered. It combines full picovoltmeter, magnetometer, and ac bridge capabilities in a compact, easy-to-use design. The Model MFP can be used in any of the configurations shown in Fig. 1.

The MFP probe includes additional room temperature circuitry located in a vacuum sealed housing. The longer LSQ/20M SQUID sensor housing accommodates a cryogenic terminal board with the resistance and mutual inductance standards required for voltage and impedance measurements. Its great versatility makes this the recommended probe when a variety of applications are required.

The Model RMP is designed for ac measurements (Fig. 1e & 1f) and configurations requiring external feedback, but not a standard resistor.

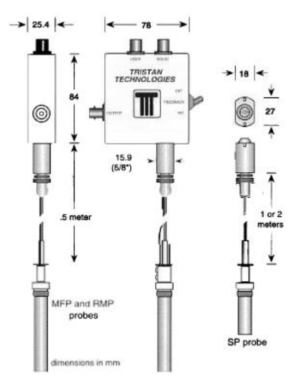


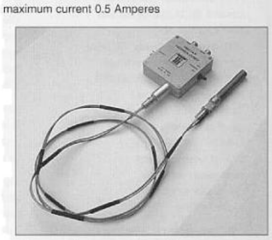
TECHNICAL FEATURES

Model SP: Working Temperature: 0 – 77 K (Sensor dependent)

Model RMP: Working Temperature: 0 – 7 K (LSQ/20M sensor only)
Standard Mutual Inductance: 0.6 μH (nominal)
Input Impedance: capacative at non-zero frequencies with Z = 1/20 j ω
Current Leads: rf decoupled floating pair, maximum current 0.5 Amperes

Model MFP: Working Temperature: 0 – 7 K (LSQ/20M sensor only)
Standard Resistor: 30 μΩ (nominal)
Standard Mutual Inductance: 0.6 μH (nominal)
System Voltage Gain: 10^8 (nominal)
Noise/√Hz: $(V^2)^{1/2} \leq \sqrt{10^{-26} + 5 \times 10^{-25} R^2_{source} + 4k_{Boltzmann} R_{source} T_{source}}$
Input Impedance: capacitive at non-zero frequencies with Z = 1/20 j ω
Current Leads: rf decoupled floating pair, maximum current 0.5 Amperes





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SQUID iMAG

SQUID ELECTRONICS

Features:

- Easy Setup
- Manual and Auto-Tuning of All SQUID Parameters
- Multichannel Capabilities
- Single Controller for LTS and HTS SQUIDs
- Digital and Analog Outputs
- Fiber-Optic Communication Avoids Inductive Pickup and Cross-talk

Tristan's iMAG© SQUID electronics have been designed for the user who wants performance and flexibility. Microprocessor-driven hierarchical front panel menus allow fast setup for both LTS and HTS SQUID sensors. Multiple slew rates, gains and bandwidths allow the user to fine tune the measurement process. Individual tuning of each channel gives optimum performance in multichannel configurations. When you need the best in SQUID electronics, look to the iMAG© series to satisfy your needs.

MULTICHANNEL CONTROLLER

The Model iMC-303 iMAG SQUID controller forms the basis of a powerful and flexible measurement system. Its three channel capability accommodates nearly all laboratory SQUID applications without incurring the cost or complexity of eight-channel designs. A unique feature of the Tristan controller is its ability to simultaneously control both LTS and HTS devices. For the experienced user, the Tristan Multichannel Controller offers complete manual control of all SQUID parameters, including bias level, modulation amplitude, "skew" level, dc flux level in the SQUID (offset), heater and integrator reset. All parameters are easily adjusted using the membrane keypad and a convenient menu-driven interface. Users who want a fully automated system will use the one-touch tuning capability that rapidly and reliably optimize the level of all critical parameters.

High-resolution A/D convertors and the standard IEEE-488 bus make the iMAG controller ideal for use with computerized data acquisition. Use the rear-panel BNC connectors to monitor the high-level analog outputs. A "fourth channel" input allows you to synchronously digitize your own signal along with the three SQUID signals using the controller's internal A/D converter. LabView™ software drivers are also available.

FLUX-LOCKED LOOP

iMAG FLLs are offered in both HTS and LTS versions. The LTS version uses an advanced bias reversal technique that effectively reduces low-frequency noise in HTS SQUIDs without introducing noise spikes in the output spectrum. The less-expensive LTS FLL provides slightly higher frequency response.

The Model iFL-301 series iMAG flux-locked loops (FLLs) provide superior performance under a wide range of operating conditions. The Tristan design locates the FLL as close as practical to the SQUID sensors and eliminates the need to run low-level or high-frequency leads over long distances. A short cable connects the FLL to the probe or cryogenic cable, allowing the compact FLL to be conveniently mounted near the dewar, but out of the way of the liquid cryogen transfers. Connection to the iMC-303 controller is via a composite cable.

COMPOSITE CABLE

Tristan's advanced design provides superior radiofrequency (rfi) rejection and allows for long cable runs, even in hostile environments. It is a simple matter to locate the FLL inside a shielded room and operate it using an iMAG Multichannel Controller located outside the room.

The connection between the controller and flux-locked loop(s) is via the CC Series composite cables. Low level dc power and the high-level analog output are the only electrical connections required between the FLL and the Multichannel Controller. The high-frequency clock signal and digital control signals are all supplied via the composite cable's optical fiber.

This cable is offered in both 6 (Model CC-6) and 20 meter (Model CC-20) lengths. Custom lengths are available.

IMC-303 SQUID CONTROLLER

iMAG Controller (Model iMC-303)

Number of Channels: 3 SQUID channels that interface to both HTS and LTS Flux Locked-Loops (FLLs). The controller can operate any combination of LTS or HTS SQUIDs simultaneously using the appropriate FLLs. An auxiliary channel is supplied for synchronous data acquisition (see below)

Auxiliary I/O: One auxiliary analog input (10 kΩ impedance, 50 kHz BW) is provided for 16-bit digitizing of a user-supplied signal for synchronous acquisition or event triggering. Maximum output signal is 4.5 V FS. Gain is selectable to be ×1, ×2, ×5, ×10, ×20 or ×50.

User Interface: Interactive user interface via large LCD display and membrane keypad. Special function keys and menu-driven software provide friendly operating and setup environment.

Remote Interfaces: Both IEEE-488 and RS-232 remote control interfaces are standard. All control settings may be input and all instrument data may be output via these interfaces. Total maximum data rate via the IEEE-488 interface is 16 bits at 20 kHz for a single channel, or 5 kHz for all three SQUID channels plus the auxiliary channel.

Analog Outputs: 4 analog outputs (600Ω) provided on the back panel for the 3 SQUID channels and the auxiliary analog input.

Autotune: Autotuning of all SQUID parameters is accomplished by single button push. All adjustments may also be made manually or via the remote interfaces.

FLL Reset: Any channel may be reset manually or automatically at any user selectable output voltage.

Bandwidth & Gain: Selectable bandwidths of 5 Hz, 500 Hz, 5 kHz & 50 kHz. (4-Pole Butterworth response). Selectable gains of (1, 2, 5, 10, ..., 500) corresponding to full-scale outputs ranging from approximately 500 Φ_0 to 1 Φ_0.

Master/Slave: Multiple control units (up to 10) can be configured to operate more than 3 SQUID sensors. A clock input and output are provided so that a master clock can be used to drive all FLLs.

Dimensions: 321 mm wide, 121 mm high, 300 mm deep (12.6" wide, 4.8" high, 11.8" deep); 6.1 kg (13.5 lbs).

Power Req. 100 to 125, 200 to 240 Volts AC, 50 or 60 Hz. DC power (±12 V) is available as an option. Operating voltage should be specified at time of order.

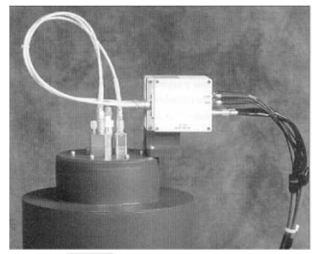
Flux Lock-Loop (Model iFL-301)

Two versions of the flux-locked loop are available, one for HTS sensors and one for LTS sensors. The HTS FLL has a 25 kHz maximum bandwidth (selectable to be 250 Hz from the iMC-303 controller) and uses high-frequency bias reversal to minimize low-frequency noise intrinsic to the HTS sensors. This bias reversal does not increase the white noise of the sensors or add any spikes within the specified bandwidth. The LTS FLL has a 50 kHz bandwidth (selectable to be 500 Hz from the iMC-303 controller) and uses no bias reversal since it is not required by the LTS sensors. Wider bandwidths on both LTS and HTS loops are available on special order.

All FLL functions are controlled remotely by the iMAG iMC-303 Controller. The FLLs connect to the iMC-303 via a composite cable. To minimize rfi, even when using very long cables, all high-frequency signals are transmitted by optical fiber between the FLL and Controller.

Dimensions: 77 mm wide, 77 mm high, 16 mm deep (3" wide, 3" high, 0.6" deep); 190 gm (6 oz).

Specifications subject to change without notice.



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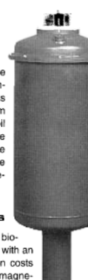
SQUID iMAG

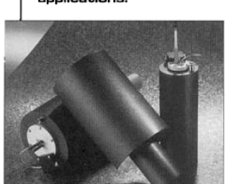
DEWARS



FEATURES

- Low Boil-Off
- Close Tail Spacing
- Standard and Custom Designs
- Complete Factory Testing
- Metallic or Non-Metallic Construction

Tristan offers both liquid helium and liquid nitrogen dewars for use in SQUID magnetometry and other applications that require magnetically transparent dewars. Tristan dewars are built in a variety of sizes and materials for both general and special purpose applications.



Tristan takes special pride in the innovative design and construction techniques it has developed. The use of SQUID magnetometers for biomagnetic or non-destructive testing and evaluation (NDE) measurements requires that magnetic signals from a subject at room temperature be coupled to a superconducting pickup coil in the liquid reservoir of the dewar. It is essential to use nonmagnetic materials and to have the smallest possible spacing between the cryogenic reservoir and the outside of the dewar. Tristan's development of adjustable tail dewars have allowed tail gaps to be less than 2 mm.

BMD Series Liquid Helium Dewars

Tristan's BMD-10 is a fiberglass dewar designed for biomagnetism and NDE. The BMD-10M variant is supplied with an upper aluminum housing to reduce weight, construction costs and increase reliability. Intended for use with Tristan magnetometer probes, they provide a spacing of less than 10 mm between room temperature and the liquid helium. The BMD-10 typically uses 2 liter/day of liquid helium. The larger BMD-14 series offers longer hold times and room for multi-channel detection coils. Custom dewars with different size necks, tails, helium reservoirs or in–vacuum detection coils are available.

NLD Series Liquid Nitrogen Dewars

Specifically designed for use with HTS SQUID sensors, Tristan offers a wide assortment of standard dewar designs. These include tailed dewars with close access to the sensors , multi-channel dewars, hand-held dewars that operate in any orientation and larger dewars with more than 30-day hold times. Cryogenic inserts are available to mount the SQUID sensors rigidly in the dewar and provide any performance features required of the application. Custom dewars with different size necks, tails, or cryogen reservoirs can be special ordered.

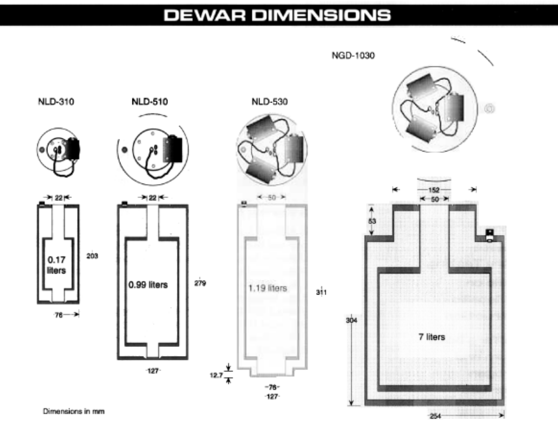
CONSTRUCTION TECHNIQUES AND MATERIALS

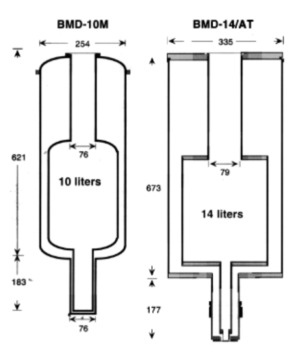
All Tristan dewars incorporate fully tested design concepts and are assembled with the highest standards of workmanship. They are leak tested after each phase of their construction and are cycled between room temperature and liquid nitrogen temperature to assure long-term reliability. A complete series of tests is made at operating temperature including measurements of the equilibrium boil-off rate. A factory test report is supplied with each dewar.

The use of super-insulation and one or more vapor-cooled shields totally eliminates the need for liquid nitrogen in the BMD series. Tristan's own computer analysis is used to calculate the optimum layer density of super-insulation in each temperature region and the insulation is carefully applied by hand to maintain this density, even in those difficult regions such as corners, close-spaced tails, or regions where overlap occurs. Also computed are the number and position of the required vapor-cooled shields and, for custom dewars, the predicted cryogen boil-off rate.

For dewar applications requiring unusual geometries, precise tolerances, or extra strength, Tristan uses its own fiber-epoxy laminate that is shaped in custom molds and cured at elevated temperature and pressure. When operation in magnetically noisy environments is anticipated, a nonmagnetic, eddy current shield can be built into the dewar to attenuate high frequency fields.

DEWAR DIMENSIONS





OPTIONS AND ACCESSORIES

- Insert for single or multiple SQUID sensors.
- Coil-in-Vacuum dewars
- Adjustable tail option for liquid helium and NLD-500 series dewars. This option can allow tail spacings less than 2 mm from liquid helium or nitrogen to room temperature.

- ±90° Tilt Option for NLD series 310 & 510 dewars.
- Custom designed low-pass (eddy current) filters and rfi shields.
- Mechanical anchoring of the helium reservoir to the outside dewar case is available for applications where mechanical vibrations and relative motion may introduce noise.
- Liquid helium or nitrogen level gauge.
- Flexible metal transfer tubes.

Specifications subject to change without notice.

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SQUID iMAG

Features:

- All Thin-Film Devices
- Niobium-Aluminum Tri-layer Process for Robust LTS Devices
- YBCO Step-edge and Bicrystal Junctions for Robust HTS Devices
- Symmetric Modulation Coils Eliminate Inductive Loading of Output

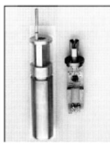
Tristan offers several configurations of low-noise SQUID sensors which serve as the heart of our iMAG SQUID systems.

Address your magnetic sensing applications with the latest technology in both high-temperature and low-temperature superconductivity.

dc SQUID SENSORS

The **low-temperature (LTS) SQUIDs** run in liquid helium and are fabricated using a niobium/aluminum all thin-film tri-layer technology that combines durability with high sensitivity. They feature symmetric integral signal and modulation coils that eliminate output variations with varying input loads. The niobium-shielded package comes with screw terminals ready to accept your custom input circuit. Tristan can also provide thin-film integrated LTS SQUID magnetometers with state-of-the-art performance. The Tristan Model LSQ/20 can be used with the Model SP Cryogenic Cable for ultrasensitive measurements of current (< 0.7 pA/√Hz) and magnetic field (< 1 fT/√Hz). In conjunction with the Model RMP and MFP Cryogenic Probes, it can measure a much wider range of electromagnetic properties in magnetic fields as high as 9 tesla—see Tristan's Cryogenic Probe data sheet for more information.

The **high-temperature (HTS) SQUIDs** run in liquid nitrogen at 77 K and are offered in magnetometer or gradiometer configurations. They feature YBCO pick-up coils patterned on the chip and a tough passivation layer for protection from moisture and oxygen. All HTS iMAG sensors use a common connector to attach them to the Model SP Cryogenic Cable; they may be easily interchanged to provide alternative pick-up coils and different sensitivity levels. We can guarantee magnetometer performance better than 90 fT/√Hz. For customers who need even lower noise levels and performance in magnetic fields, we can provide sensors with world-record noise performance; contact us for the latest specifications and pricing.



LTS Sensors

Input coil inductance:	1.8 μH
Noise level:	< 5 × 10^{-31} J/Hz
	< 5 × 10^{-6} Φ_0/√Hz
1/*f* knee:	nominal 0.5 Hz
Input coil sensitivity:	0.2 μA/Φ_0
Temperature range:	0 – 7 K

HTS Sensors

Noise (HTM-100):	< 90 ft/√Hz
(HTo-100):	< 10 pT/Hz
(HTG-100):	< 100 fT/cm √Hz
1/*f* knee:	nominal 10 Hz
Operating Temperature:	77 K
Operating field:	0 ≥ 100 mT

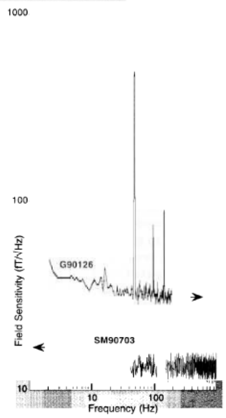
Besides the standard LSQ/20, Tristan can supply LTS sensors with longer niobium shield cans such as that supplied with the MFP and RMP probes (see Probe Data Sheet for details). We can also supply the bare sensor chip for specialized applications.

The 2 μH input impedance of the LSQ/20 allows easier matching of input circuits. Unlike asymmetric coil designs, the symmetric coil design of the LSQ/20 avoids inductive coupling of unwanted signals. Additionally, it exhibits no sensitivity variations with changing input impedances.

Tristan's HTS sensors are the first commercial devices to operate in both ambient and kilogauss environments. Step-edge junctions ensure uniform response independent of sensor orientation, avoiding the Fraunhofer-like diffraction behavior seen in many monolithic bicrystal junction devices.

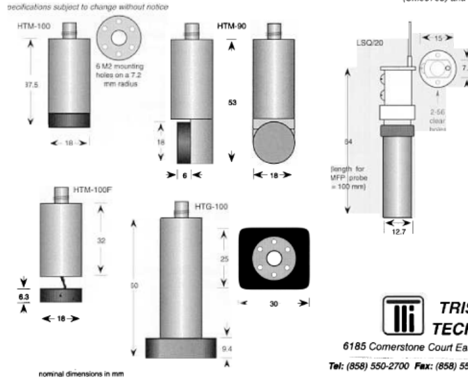
Tristan's HTS sensors are available in a wide variety of configurations. The standard HTS magnetometer sensor is available in a 90° mounting (Model HTM-90) or in a flexible end piece (Model HTM-100F). The flexible section can be as long as 15 cm without degrading performance. Pickup coil dimensions other than the standard 8 mm × 8 mm are also available. The HTo-100 MiniMAG has a 50 μm × 50 μm pickup coil and is well suited for magnetic microscopy. The HTM-400's large 16 mm × 16 mm detection area gives it the highest sensitivity on any available HTS sensor. Tristan's gradiometers are available in either dB_Z/dx (shown below) or dB_X/dz configurations.

Integral heaters on all Tristan sensors (LTS and HTS) allows normalization of the sensor without having to warm the entire experiment above the critical temperature. If your measurements require special configurations or higher performance, contact Tristan directly or your Tristan representative.



Actual performance of HTM-400 magnetometer (SM90703) and HTG-100 gradiometer (G910126

specifications subject to change without notice



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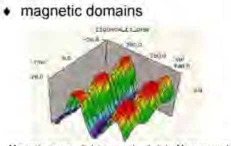
Ultra-high Resolution Scanning Magnetic Microscope

The Tristan model SMM-1000 Scanning Magnetic Microscope performs micron level non-destructive analysis of surface and sub-surface material properties using an array of small SQUID magnetometers. It can be used to image diverse objects such as:

- micro-current distributions
- vortex motion in superconductors
- traces on a circuit board or multi-chip module
- weak electric currents in semiconductors
- integrated circuits
- magnetic domains



Magnetic image of data on a hard disk. Measurements were made at a vertical standoff of 30 microns. The bit spacing is 10 microns and the inter-track spacing is 15 microns (courtesy UCSD)

Besides measuring magnetic fields, the SMM-1000 can also be configured to detect:

- transient magnetic properties
- magnetic susceptibility
- magnetic hysteresis

Model SMM-1000 Scanning SQUID Microscope

- The SMM-1000 uses a proprietary integrated circuit that incorporates an array of Superconducting Quantum Interference Devices (SQUIDs) to map the magnetic field from small samples. The use of liquid helium SQUIDs provides a 100 fold improvement in sensitivity over other magnetic detectors and allows high-resolution mapping of electric currents and magnetic sources located beneath the surface of the sample.
- It is a fully featured measurement system that allows the user to extract a magnetic image of the object being measured over the entire dc – 10 kHz frequency range. Its flat phase response allows both in-phase and quadrature information to be obtained without distortion. Additional detection channels can be supplied to speed data acquisition rates.
- It allows computer controlled scans of objects over a large (5 x 5 mm) area with 0.17 μm stepping capability. The user has the ability to preprogram the scan coordinates.
- Automated setup and computer control makes measurements rapid and repeatable. System software provides the ability to control the critical system components, acquire data from the SQUID sensor, and analyze the data to determine the magnetic properties of the sample being measured. The use of open architecture software allows the user to modify and customize nearly all aspects of operating including image processing.

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SMM-1000 sample stage

System Operation

The SMM-1000 achieves micron resolution by the use of small (14 μm) detection coils and narrow gap between the coils and the object(s) being scanned.

The sample is mounted inside an exchange gas can at the lower end of a cryogenic probe. This houses all of the cryogenic portions of the SMM and, during a measurement, is filled with a small amount of helium gas. The sample is placed on the sample stage and the probe can attached. Then the SMM Probe is lowered into the liquid helium dewar. After the sample stage has cooled to 4.2 Kelvin, measurements can begin. When finished, it is possible to warm up the microscope, mount a sample, and cool it back to helium temperature in as little as two hours.

Detail of SMM sensor tip showing nine 14 μm detection coils

System Components

The standard model SMM-1000 includes a single channel SMM probe (Magnetic Detection Subsystem) and iMAG® SQUID Electronics, sample position measurement and control Subsystem, liquid helium dewar with vibration Isolation stand, probe warm-up and gas-handling station, computer control console, and complete software package for system control, data acquisition and data analysis. The model SMM-1000 can be supplied with additional capabilities to extend its measurement capabilities.

Specifications subject to change without notice

OPTIONS AND ACCESSORIES

Additional Detection Channels: The model SMM-1000's measurement capabilities can be extended to multi-channel capabilities. Additional vertical (B_z) measurement sites can be installed to reduce measurement time. The standard distance between the coils is 50 μm. Coils may be located 100 μm, 150 μm, or 200 μm apart at no extra charge. Other coil diameters and configurations are available as options.

Applied Field Capability: This option generates a vertical (B_z) dc magnetic field on the sample. This allows magnetic susceptibility measurements on insulators, conductors and ferrous materials to be performed.

Variable Sample Temperature: The standard measurement temperature is 4.2 K. The variable temperature option allows sample temperature to be varied between 2 K and 100 K.

SPECIFICATIONS

SENSOR: Low temperature superconducting quantum interference device (SQUID) operating at 4.2 K

SPATIAL RESOLUTION: 1 μm for single dipole sources

SENSITIVITY: 1 x 10^{-10} tesla/√Hz (100 pT/√Hz)

OPERATING BANDWIDTH: dc - 10 kHz. Measurements can be made at any frequency. Bandwidths above 10 kHz are available.

CRYOGENIC COOLING: To avoid low frequency noise below 200 Hz, the system uses liquid helium to cool the sensor.

CRYOGENIC HOLD TIME: Time between refills of liquid helium is typically 3 days. Longer hold times available upon request.

SAMPLE SCANNING RANGE: 5 mm x 5 mm in x-y directions.

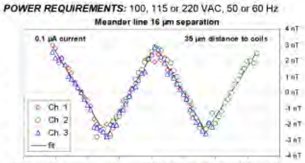
SAMPLE LIFTOFF: Optical readout, adjustable with minimum approach of 0.1 μm.

SCAN STEP SIZE: Adjustable with minimum step size of 0.17 μm.

SCANNING TECHNIQUE: Computer controlled raster scan, up to 10 mm/min scan rate

POWER REQUIREMENTS: 100, 115 or 220 VAC, 50 or 60 Hz

Meander line 16 μm separation



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