TRISTAN TECHNOLOGIES, INC

Magnetic and Cryogenic Device solutions

Non-Bio Systems Information Brochure

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System information

The components of a SQUID magnetometer (Fig. 2) typically consist of the following: a detection coil, which senses changes in the external magnetic field and transforms them into an electrical current; an input coil which transforms the resulting current into a magnetic flux in the SQUID sensor; electronics which transform the applied flux into a room temperature voltage output; and acquisition hardware and software for acquiring, storing and analyzing data. Both the SQUID amplifier and the detection coils are superconducting devices. Thus some type of refrigerant (liquid helium or liquid nitrogen) or refrigeration device (cryocooler) is needed to maintain the SQUID and detection coil in the superconducting state. Additional signal conditioning electronics may be needed to improve signal-to-noise.

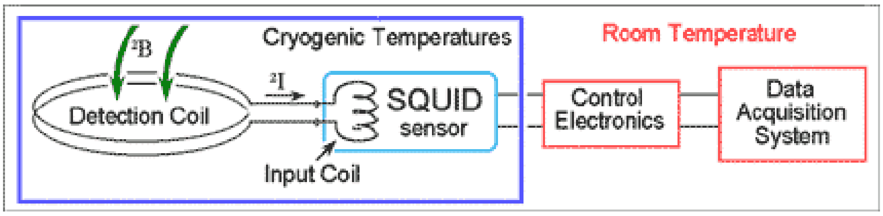


Figure 2: Block diagram of a SQUID magnetometer

The SQUID sensor and electronics package can be considered as a black box that acts like a magnetic field-to-voltage converter and amplifier with extremely high gain. In addition, it offers extremely low noise, high dynamic range, excellent linearity, flat phase response and a bandwidth that can extend from dc to beyond 100 kHz, capabilities that no other single sensor offers.

The type of SQUID sensor and detection coil configuration is dependent on what is to be measured. Tristan's SQUID measurement systems make use of either Tristan's LSQ/20 LTS dc SQUID sensor or the HTM-8 HTS dc SQUID sensor. The input coil for an LTS SQUID is normally fabricated from flexible superconducting NbTi wire. The inherent anisotropic nature of HTS SQUIDs requires that the input coils be planar. Typically HTS magnetometers are available only as pure magnetometers.

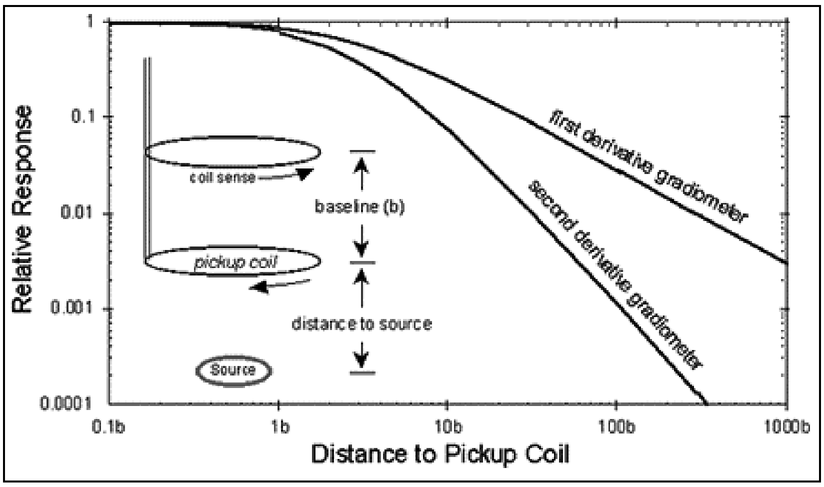


Figure 3: Response of gradient coils relative to magnetometer response (1/r3 suppressed)

Another factor to be considered is the detection coil configuration. Conceptually, the easiest input circuit to consider for detecting changes in magnetic fields is a pure magnetometer (Fig. 2). However, magnetometers are extremely sensitive to all magnetic signals in the environment. This may be acceptable if one is measuring ambient fields. However, if the magnetic signal of interest is weak, then environmental magnetic interference may prevent measurements. If the signal source is close to the detection coil, then a gradiometer coil may allow a weak signal to be measured. Figure 3 shows the relative noise rejection for 1st and 2nd derivative gradiometers. The figure insert shows a first order gradiometer, consisting of two coils connected in series but wound in opposite senses, and separated by a distance “b”, called the gradiometer baseline. A uniform magnetic field (e.g., from a distant environmental source) would couple equal but opposite quantities of flux into the two coils, resulting in zero net flux in the gradiometer, or zero signal. However, signal sources that are close to the lower coil (relative to the baseline, or separation between coils) would couple significantly more flux into the lower coil than into the upper coil; this would result in a net flux in the gradiometer and hence the signal would be detected.

For objects objects that are close (relative to the gradiometer baseline), the gradiometer acts as a pure magnetometer, while rejecting more than 99% of the magnetic signals coming from distant objects. In essence, the gradiometer acts as a “compensated” magnetometer.

Normally, SQUID magnetometers (and gradiometers) map the axial (BZ) component of the magnetic field. Obviously, using three sensors, it is possible to monitor all three vector components of the magnetic field. Additional channels of SQUID sensors can be used to provide reference channels for electronic balancing. Portions of the reference magnetometer responses are summed electronically with the detection coil(s) output to reject common mode signals from distant noise sources. Electronic balancing can be used to create an HTS axial gradiometer from two HTS magnetometers.

Tristan and its key personnel have produced a number of measurement systems for a variety of applications. Some of them are listed here:

- Tristan has 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.
- 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.
- 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.

1. 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

2. Geophysical Applications include oil and mineral exploration, pollutant monitoring, magma flow measurements, rock magnetometry, magnetic anomaly detection, etc.

Figure a: Tristan HTS SQUID gradiometer in flight

3. Non-Destructive Test & Evaluation (NDE)

NDE scanning systems are used for defect detection, corrosion measurement, magnetic microscopy, etc. Some examples of SQUID NDE include:

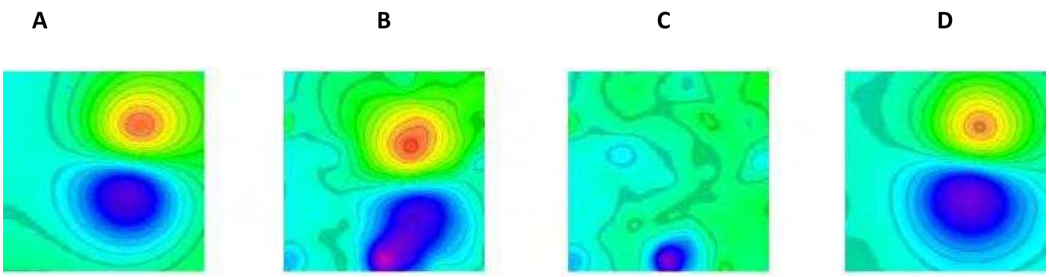
Intrinsic currents measurements, such as:

- 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:

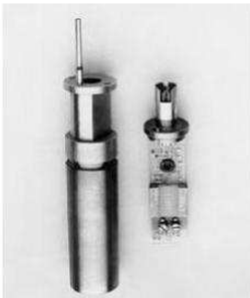
- cyclic stress (strain)
- simultaneous dc & ac magnetic fields

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



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.

Figure b: Tristan non-magnetic dewars **Model 607 magnetometer**



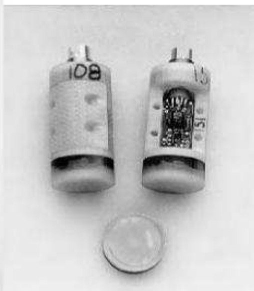


Figure c: iMAG® Electronics and laboratory probes **LTS SQUID sensor** **HTS SQUID sensor**

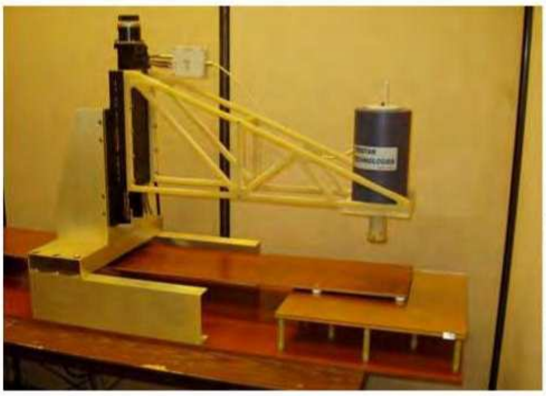


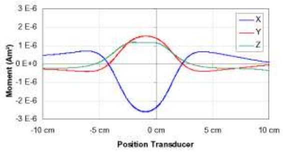
Figure d: SMM-701 NDE scanning system **Model SMM-770 Scanning SQUID Microscope**

DRM-300 Rock Magnetometer

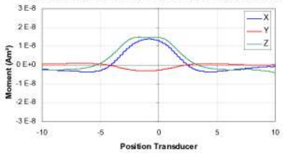
The Tristan model DRM-300 is a compact and easy to use SQUID magnetometer system for measurement of remnant magnetization of geophysical samples. The use of SQUID technology allows unparalleled sensitivity. Closed cycle refrigeration eliminates the need to transfer liquid helium. Its small footprint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

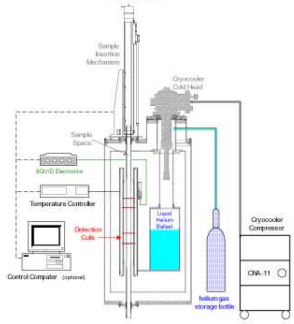
Options

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

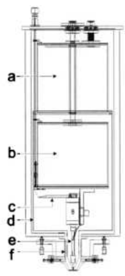
Applications

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*

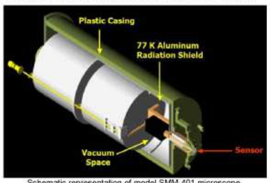
Magnetic microscopy image of a 1 mm by 2 cm by 1 cm slice of martian meteorite ALH84001, overlayed on top of a visual photo of the same slice. The colors give the field intensity, with red and yellow (blue) corre-sponding to upward (downward) magnet-ization. The fusion crust on the upper left side of 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).



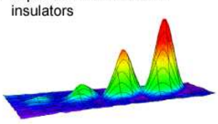
Schematic representation of model SMM-401 microscope.

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

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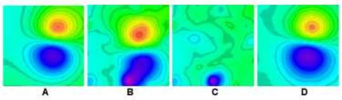
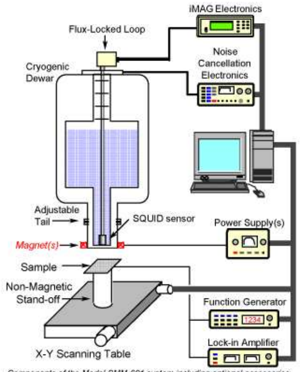
Model SMM-601 Scanning SQUID Microscope with dc and ac biasing magnets

- 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 x 10^{-11} 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

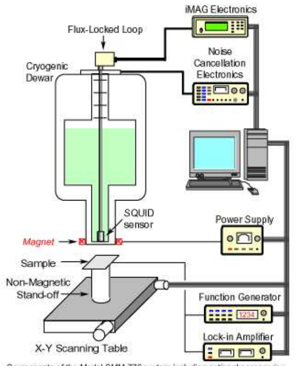
- insulators, ferrous and non-ferrous metals to detect cracks, voids and corrosion
- nanoparticle distributions
- flux-motion in HTS materials

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 x 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.

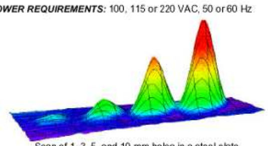
CRYOGENIC HOLD TIME: Time between refills of liquid nitrogen is typically 3 days

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

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770/303

TRISTAN TECHNOLOGIES

Magnetometers for Geophysics

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.

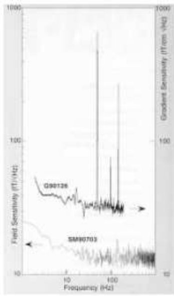
The basic geophysical measurement system offered by Tristan is the model G377. It measures all three vector components of the Earth's magnetic field (B_X, B_Y, B_Z). The small size and portability of the model G377 makes it convenient for field use. It can also be supplied with different size dewars 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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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)

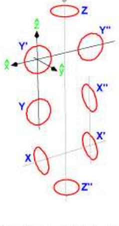
TENSOR CONFIGURATION

- 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:

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



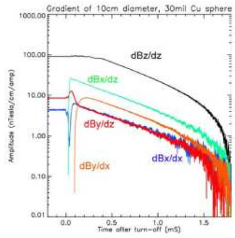
where a, b, and c are the coil-to-coil center spacings.

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.)

TRISTAN TECHNOLOGIES

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SQUID iMAG

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.

SYSTEMS

TRISTAN TECHNOLOGIES

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

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).

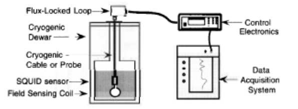

Fig. 1. Typical magnetometer system

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 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		$Bz, \frac{dB_z}{dz}$ 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		$Bz, \frac{dB_z}{dz}$ 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.

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SQUID iMAG

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**

CRYOGENIC PROBES for the laboratory

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.

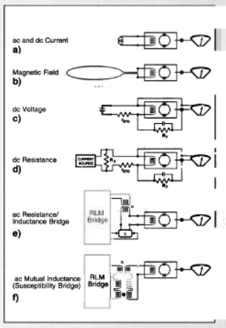
In all Tristan probes, construction materials are non-magnetic and carefully selected to minimize conduction of heat into the cryogenic bath. All probes are shielded against rf interference and other electrical transients that may affect the SQUID operation. A room temperature O-ring seal allows pumped 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.

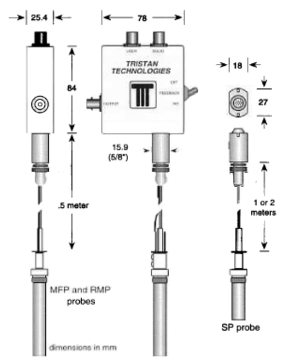


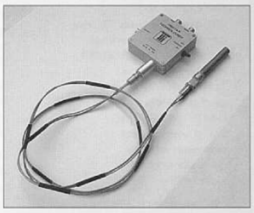
TECHNICAL FEATURES

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

MULTICHANNEL CONTROLLER

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.

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.

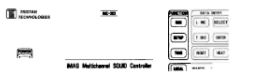
COMPOSITE CABLE

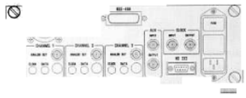
Tristan's advanced design provides superior radiofrequency (rfi) rejection and allows for long cable runs, even in hostile environments. It is a simple matter to locate the FLL inside a shielded room and operate it using an iMAG Multichannel Controller located outside the room.

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.

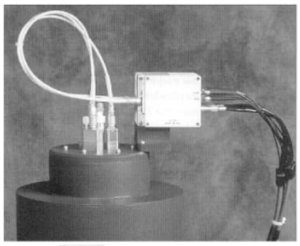
Flux Lock-Loop (Model iFL-301)

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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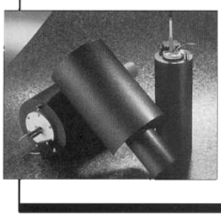
SQUID iMAG

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.

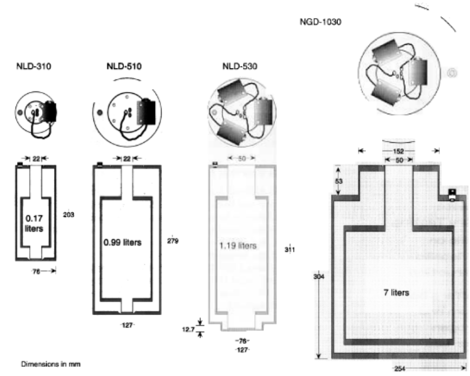
CONSTRUCTION TECHNIQUES AND MATERIALS

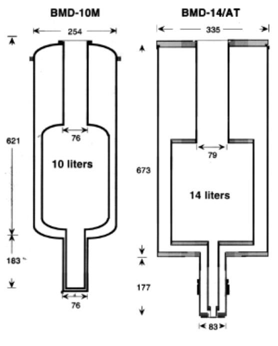
All Tristan dewars incorporate fully tested design concepts and are assembled with the highest standards of workmanship. They are leak tested after each phase of their construction and are cycled between room temperature and liquid nitrogen temperature to assure long-term reliability. A complete series 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

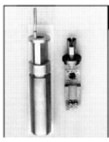
Tristan offers several configurations of low-noise SQUID sensors which serve as the heart of our iMAG SQUID systems.

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:	$< 5 \times 10^{-31}$ J/Hz
	$< 5 \times 10^{-6}\ \Phi_0/\sqrt{Hz}$
$1/f$ 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

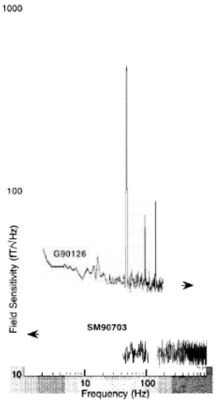
Besides the standard LSQ/20, Tristan can supply LTS sensors with longer niobium shield cans such as that supplied with the MFP and RMP probes (see Probe Data Sheet for details). We can also supply the bare sensor chip for specialized applications.

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.

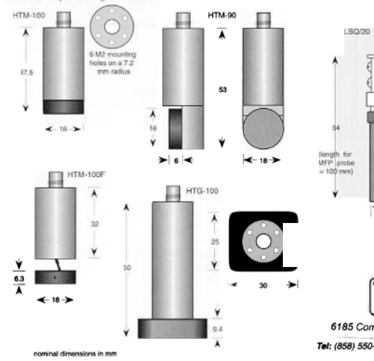
Tristan's HTS sensors are available in a wide variety of configurations. The standard HTS magnetometer sensor is available in a 90° mounting (Model HTM-90) or in a flexible end piece (Model HTM-100F). The flexible section can be as long as 15 cm without degrading performance. Pickup coil dimensions other 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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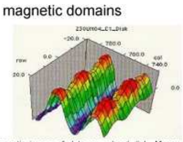
Ultra-high Resolution Scanning Magnetic Microscope

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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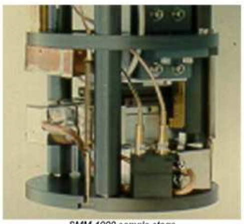


SMM-1000 sample stage

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: 1×10^{-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.

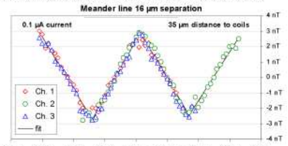
SAMPLE SCANNING RANGE: 5 mm x 5 mm in x-y directions.

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



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