Operating Manual

for

Model 601 2nd Order SQUID Gradiometer System

By:

Tristan Technologies, Inc.
San Diego, California
USA

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WARRANTY

Tristan Limited Warranty

Tristan Technologies, Inc. warrants this product for a period of twelve (12) months from date of original shipment to the customer. Any part found to be defective in material or workmanship during the warranty period will be repaired or replaced without charge to the owner. Prior to returning the instrument for repair, authorization must be obtained from Tristan Technologies, Inc. or an authorized Tristan service agent. All repairs will be warranted for only the unexpired portion of the original warranty, plus the time between receipt of the instrument at Tristan and its return to the owner.

This warranty is limited to Tristan products that are purchased directly from Tristan, its OEM suppliers, or its authorized sales representatives. It does not apply to damage caused by accident, misuse, fire, flood, acts of nature, failure to properly install, operate or maintain the product in accordance with the printed instructions provided.

This warranty is in lieu of any other warranties, expressed or implied, including merchantability or fitness for purpose, which are expressly excluded. The owner agrees that Tristan's liability with respect to this product shall be as set forth in this warranty, and incidental or consequential damages are expressly excluded.

Table of Contents

1. SYSTEM Overview

The model 601 Second Order SQUID Gradiometer System (block-diagram is presented in Figure 1.1) has been designed and built by Tristan Technologies, Inc for JTM/University of Michigan. The system includes the following basic components:

- Liquid Helium Dewar
- Single Channel LTS SQUID Gradiometer Probe
- SQUID Control System
- Liquid Helium Level Sensor

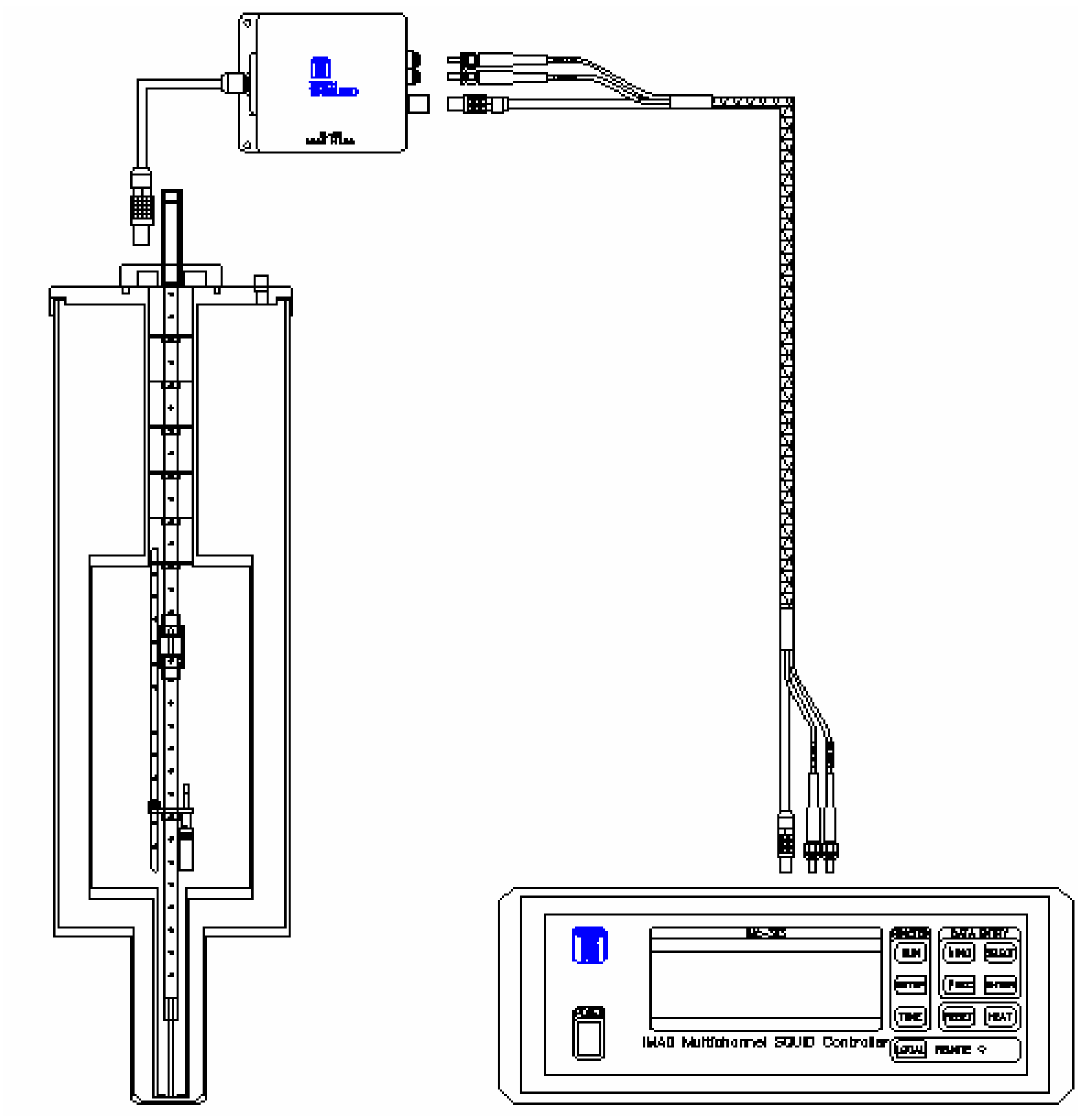

Figure 1.1 System Block Diagram

1.1 INITIAL INSPECTION

All Tristan instruments and equipment are carefully inspected and packaged at Tristan prior to shipment. However, if a unit is received mechanically damaged, notify the carrier and the nearest Tristan representative or the factory in San Diego, California. Keep the shipping container and packing material for the carrier and insurance inspections.

WARNING

THE PROBE IS THE MOST FRAGILE COMPONENT OF THE SYSTEM AND SHOULD BE HANDLED AS SUCH. DAMAGE IS MOST EASILY AVOIDED BY ALWAYS SUPPORTING THE PROBE PROPERLY WHEN IT IS OUT OF THE DEWAR AND BY TAKING CARE NOT TO BUMP THE PROBE INTO OTHER OBJECTS.

If the unit does not appear to be damaged but does not operate to specifications, contact the nearest Tristan representative or the Tristan factory and describe the problem in detail. Please be prepared to discuss all surrounding circumstances, including installation and connection detail. After obtaining authorization from the Tristan representative, return the unit for repair along with a tag to it identifying you as the owner. Please enclose a letter describing the problem in as much detail as possible.

1.2 REPACKING FOR RETURN SHIPMENT

If it is necessary to return the system, repack the unit in its original container with the original packaging materials. If the original packing materials are not available consult a Tristan representative for advice on shipping your system as safely as possible.

WARNING

THE DEWAR MUST BE SHIPPED UPSIDE DOWN. SHIPPING THE DEWAR IN ANY OTHER ORIENTATION WILL RESULT IN DAMAGE NOT COVERED IN THE TRISTAN LIMITED WARRANTY. TAKE CARE TO CLEARLY MARK WHICH SIDE IS UP ON THE DEWAR CRATE WHEN SHIPPING.

WARNING

DAMAGE WHICH OCCURS DURING SHIPPING AND/OR CUSTOMS INSTPECTION IS NOT COVERED BY THE TRISTAN LIMITED WARRANTY. WHEN SHIPPING TO TRISTAN, ALWAYS INSURE EQUIPMENT FOR FULL REPLACEMENT VALUE. CONTACT A TRISTAN REPRESENTATIVE IF ASSISTANCE IS REQUIRED IN DETERMINING THE FULL REPLACEMENT VALUE.

1.3 RETURN FROM CUSTOMERS OUTSIDE THE U.S.A.

To avoid delays in customs clearance of equipment being returned, contact the nearest Tristan Technologies representative for complete shipping information and necessary customs requirements. Failure to do so can result in significant delays.

1.4 SYSTEM COMPONENTS

QTY 1: Dewar Model BMD-9 (Serial Number 131)
QTY 1: Cryogenic Storage Baffle Set
QTY 1: Probe Model BMP-601 (Serial Number 140)
QTY 1: AMI Liquid Helium Level Sensor (13″ active length)
QTY 1: dc SQUID (Serial Numbers A52.12)
QTY 1: iMC-303 SQUID Controller (Serial Number 001060)
QTY 1: CC-60 Six meter Composite Cable
QTY 1: iFL-301-L Flux-Locked Loop (Serial Number 001112)
QTY 1: PC to iMC-303 SQUID Controller Interface Applications Disk
QTY 1 : System Manual
QTY 1: iMAG® LTS Multi-Channel SQUID System Manual
Third Party Manufacturers Component Manuals

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2. CRYOGENIC SYSTEM

The cryogenic system is composed of a liquid helium dewar, single channel probe, custom length cryogenic cable and second order gradiometer detection coil. (These components are showin in figures 2.1 through 2.4)

Figure 2.1 Model BMD-9 Liquid Helium Dewar

Figure 2.2 Model BMP-9 Single Channel Probe

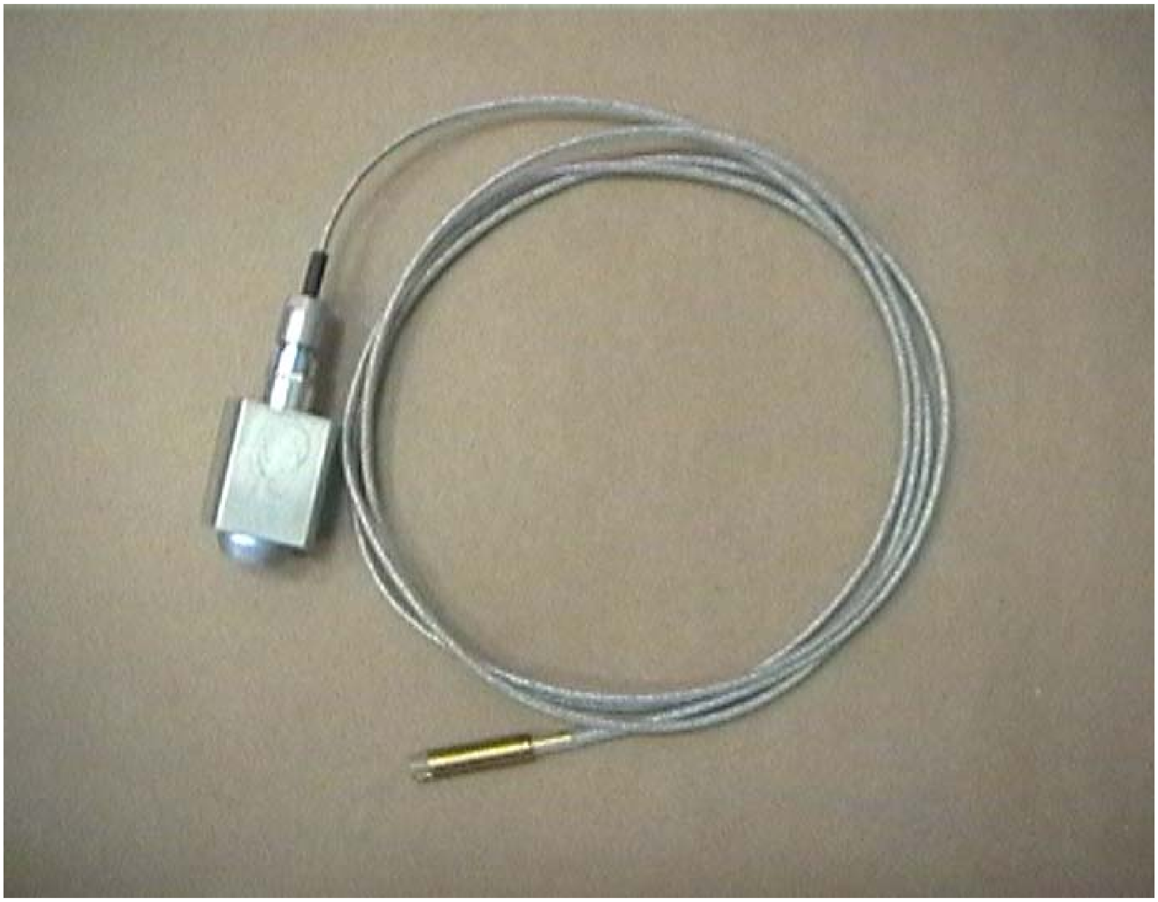

Figure 2.3 Custom Length Cryogenic Cable

Figure 2.4 Second Order Gradiometer Detection Coil

The dewar performance data are summarized in Table 2.1.

Dewar Volume	9 L
Dewar Gap Cold	< 9 mm
Dewar Only Boiloff	3.2 L/day

Table 2.1 Summary of Dewar Performance

2.1 NORMAL INSTALLATION AND OPERATION

2.1.1 PROBE INSTALLATION (WARM DEWAR)

- Inspect dewar and verify internal cavity is free from ice, moisture, or other contaminants.

WARNING

CONTAMINANTS COULD RESULT IN INCORRECT MEASUREMENTS OR PROBE DAMAGE!

- Verify that probe tail is lowered to maximum length.
- Verify dewar top plate o-ring is in place.
- Carefully lower probe assembly into dewar cavity. Align orientation markings, if any.
- Attach probe top plate to dewar with 8-32 X 1 $^{1}/_{4}$ screws.

2.1.2 HELIUM TRANSFER

- Verify helium level in storage dewar and BMD-9 dewar.
- Open transfer port at top of probe.
- Transfer observing all standard cryogenic handling and safety procedures.
- Observe transfer levels. Note: Dewar capacity is 9 liters.
- After transferring, plug the transfer port after allowing sufficient vent time.
- Verify all connectors at top of probe are free from ice and moisture before making cable connections.

2.1.3 PROBE REMOVAL

- Disconnect Flux-Locked Loop from top of probe.
- Observe all cryogenic handling and safety procedures.
- Remove probe attachment screws.
- Carefully lift probe straight out of the dewar. Rotate probe back and forth to prevent freezing in place.
- Immediately place the bottom of the probe in a plastic bag (garbage bags work well for this) to limit condensation accumulation.
- Insert storage baffles into dewar assembly.

2.1.4 DEWAR WARM – UP

Fiberglass dewars such as the one supplied with this system should never be allowed to warm up by simply letting all the helium evaporate. If this is allowed to happen and the inside fiberglass warms to near room temperature, helium gas will diffuse through the dewar walls and soften the vacuum space of the dewar.

To prevent this, you should wait for about one to four hours after the helium level has reached 0% and then remove the probe from the dewar. Place the probe inside a tight-fitting plastic bag to prevent excessive condensation of moisture. Turn the dewar upside down to pour out the remaining helium. Then let the dewar warm up to room temperature (leave the neck tube open). If this procedure is used, it will be necessary to make sure that any water which condenses in the dewar is removed prior to using the system again. This can be done by wiping it out using a rag on the end of a rod or by blowing room-temperature air into the tail of the dewar.

WARNING

DO NOT BLOW HOT AIR INTO THE DEWAR AS THIS MAY CAUSE FAILURE OF THE EPOXIED JOINTS.

2.2 SAFETY PRECAUTIONS FOR HANDLING CRYOGENIC LIQUIDS

The potential hazards of handling liquid helium stem mainly from the following properties:

WARNING

1. **THE LIQUID IS <u>EXTREMELY</u> COLD (HELIUM IS THE COLDEST OF ALL CRYOGENIC LIQUIDS).**
2. **THE ULTRA-LOW TEMPERATURE OF LIQUID HELIUM CAN CONDENSE AND SOLIDIFY AIR.**
3. **VERY SMALL AMOUNTS OF LIQUID HELIUM ARE CONVERTED INTO LARGE VOLUMES OF GAS.**
4. **HELIUM IS NOT LIFE SUPPORTING.**

2.2.1 EXTREME COLD—COVER EYES AND EXPOSED SKIN

Accidental contact of liquid helium or the cold gas that results from its rapid evaporation may cause a freezing injury similar to a burn. Protect your eyes and cover the skin where the possibility of contact exists. Eye protection should always be worn when transferring liquid helium.

2.2.2 KEEP AIR AND OTHER GASES AWAY FROM LIQUID HELIUM

The low temperature of liquid helium or cold gaseous helium can solidify another gas. Solidified gasses and liquid, particularly solidified air, can plug pressure-relief passages and foul relief valves. Plugged passages are hazardous because of the continual need to vent the helium gas which evolves as the liquid continuously evaporates. Therefore, always store and handle liquid helium under positive pressure and in closed systems to prevent the infiltration and solidification of air or other gases. Do not permit condensed air on transfer tubes to run down into the container opening.

2.2.3 KEEP EXTERIOR SURFACES CLEAN TO PREVENT COMBUSTION

Atmospheric air will condense on exposed helium-cooled piping. Nitrogen, having a lower boiling point than oxygen, will evaporate first from condensed air, leaving an oxygen-enriched liquid that may drip or flow to nearby surfaces. Areas and surfaces upon which oxygen-enriched liquid can form, or come in contact with, must be cleaned to oxygen-clean standards to prevent possible ignition of grease, oil, or other combustible substances. Leak-testing solutions should be selected carefully to avoid mixtures which can leave a residue that is combustible. When combustible type foam insulations are used, they should be carefully applied to reduce the possibility of exposure to oxygen-enriched liquid which could, upon impact, cause explosive burning of the foam.

2.2.4 PRESSURE-RELIEF DEVICES MUST BE ADEQUATELY SIZED

While most cryogenic liquids require considerable heat for evaporation, liquid helium has a very low latent heat of vaporization. Consequently, it evaporates very rapidly when heat is introduced or when liquid helium is first transferred into warm or partially-cooled equipment. Even minor deterioration of the vacuum in the helium container can result in significant evaporation. Pressure relief devices for liquid helium equipment must, therefore, be of adequate capacity to release helium vapor resulting from such heat inputs, and thus, prevent hazard due to excessive pressure. This system has been designed to safely vent the evolving helium gas in the event of any reasonable failure mode.

WARNING

DO NOT MAKE ANY MODIFICATIONS TO THIS SYSTEM WHICH MIGHT AFFECT ITS ABILITY TO VENT HELIUM GAS IN THE EVENT OF AN EMERGENCY SUCH AS LOSS OF VACUUM IN THE DEWAR VACUUM SPACE.

If transfer lines can be closed off at both ends so that a cryogenic liquid or the related cold gas can become trapped between the closed ends, a pressure-relief device must be provided in that line to prevent excessive pressure build-up.

2.2.5 KEEP EQUIPMENT AREA WELL VENTILATED

Although helium is nontoxic, it can cause asphyxiation in a confined area without adequate ventilation. Any atmosphere which does not contain enough oxygen for breathing can cause dizziness, unconsciousness, or even death. Helium, being colorless, odorless, and tasteless cannot be detected by the human senses and will be inhaled normally as if it were air. Without adequate ventilation, the expanding helium can displace air and result in an atmosphere that is not life-supporting. The cloudy vapor that appears when liquid helium is exposed to the air is condensed moisture, not the gas itself. The issuing helium gas is invisible. Liquid containers should be stored in large, well ventilated areas.

If a person becomes groggy or loses consciousness when working around helium, get them to a well ventilated area immediately. If breathing has stopped, apply artificial respiration. If a person loses consciousness, summon a physician immediately.

2.3 GENERAL INFORMATION

- Transfer helium with probe inserted.
- Do not touch coils at bottom of probe.
- When probe is removed from dewar, carefully place flat on "V" blocks for support.

3. Sensors and Control Electronics

3.1 SENSOR INITIAL PERFORMANCE TEST

The sensor and control electronics system is composed of a LTS dc SQUID, liquid helium level sensor, flux-locked loop, fiber-optic connecting cable and cryogenic control unit. (These components are showin in figures 2.1 through 2.9)

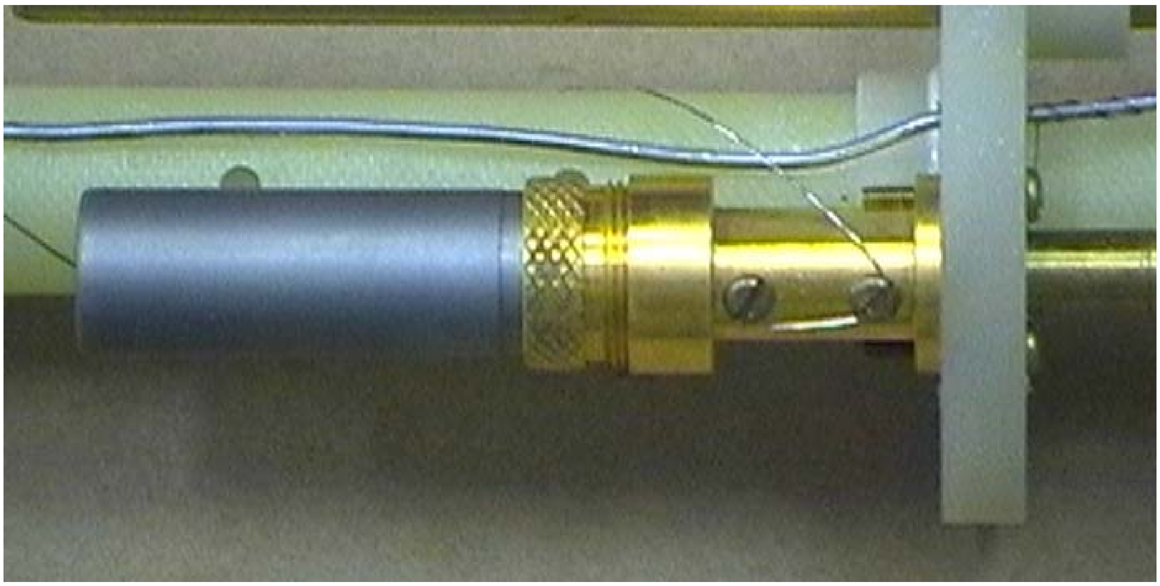

Figure 2.5 Model LSQ/20 LTS dc SQUID

Figure 2.6 Liquid Helium Level Sensor

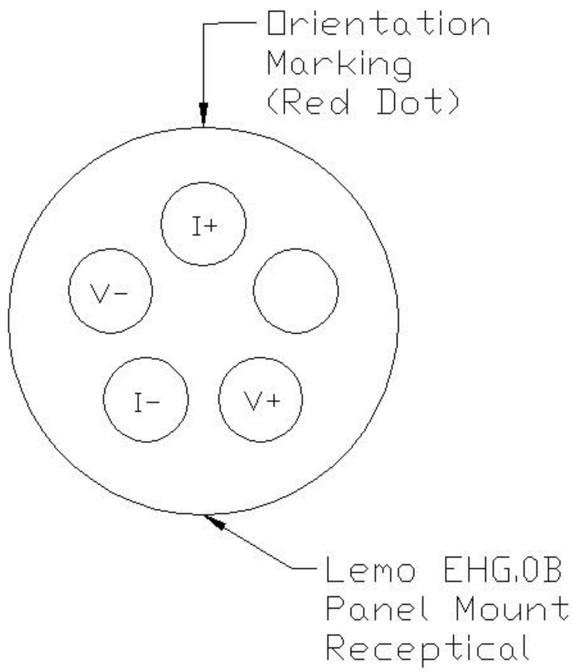

Figure 2.7 Level Detection Diagram

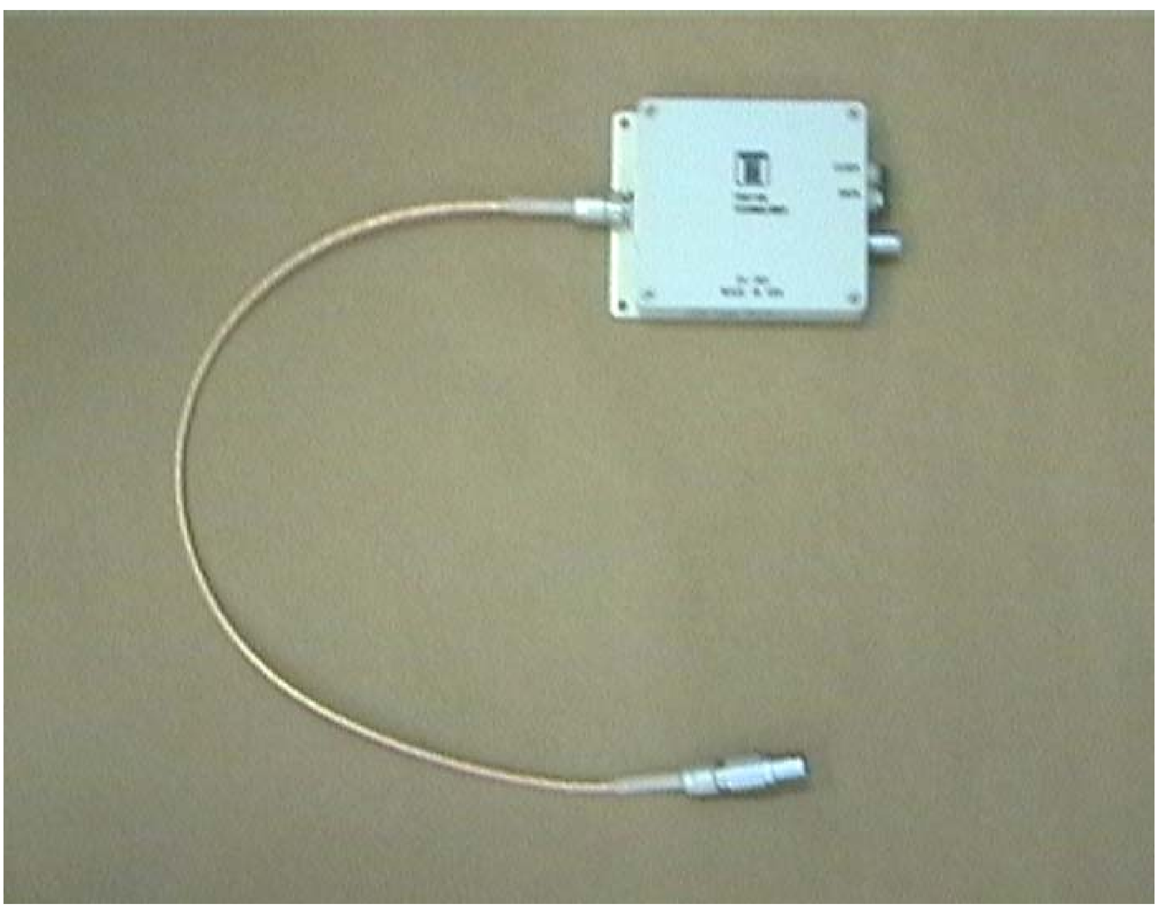

Figure 2.8 Model iFL-301-L Flux-Locked Loop

Figure 2.9 Model CC-60 Fiber Optic Composite Connecting Cable

Figure 2.10 Model iMC-303 Cryogenic Control Unit

The LTS SQUIDs used in this system have been tested at Tristan Technologies. Tables 3.1 presents the test results containing data for the open input loop SQUIDs.

SQUID Serial Number	A52.12
Bias Current	29.05 μA
SQUID Gain	0.727 V/Φ_o
Signal Mag	0.200 mV
Modulation Coil Coupling	1.52 μA/Φ_o
Input Coil Coupling	0.192 μA/Φ_o
Input Coil Inductance	1.89 μH
Current Limit	>23 mA
1/f Noise Corner Frequency	< ½ Hz
100 Hz No Load Noise	3.12 μΦ_o /√Hz
100 Hz No Load Noise	3.39 x 10^{-31} J/Hz
100 Hz Noise w/ 3.67 μH Load	2.82 μΦ_o /√Hz
100 Hz Noise w/ 3.67 μH Load	2.77 x 10^{-31} J/Hz

Table 3.1 Open Input SQUID Test

The SQUID has also been tested with attached pick-up coil at Tristan Technologies. The pick-up coil is configured as a second order dB_z/dz gradiometer and was balanced to 0.42%. Below are the test results for the SQUID parameters of and noise spectral densities on gain x100 (see Figures 3.1 through 3.4 and Table 3.2). To carry out the measurements, the pick-up coils were shielded using lead foil in a mu-metal shield.

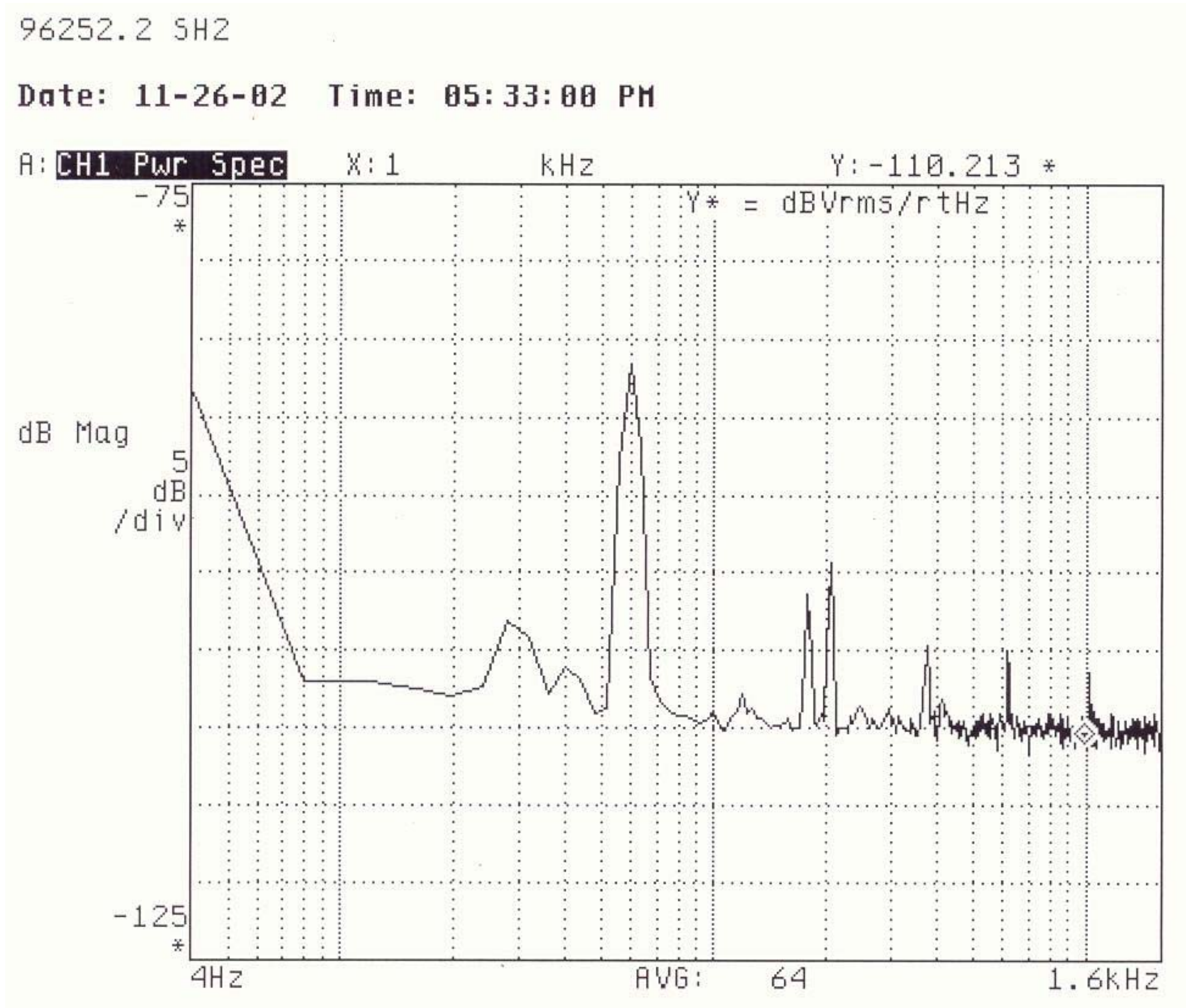

Figure 3.1 Low Frequency Spectrum

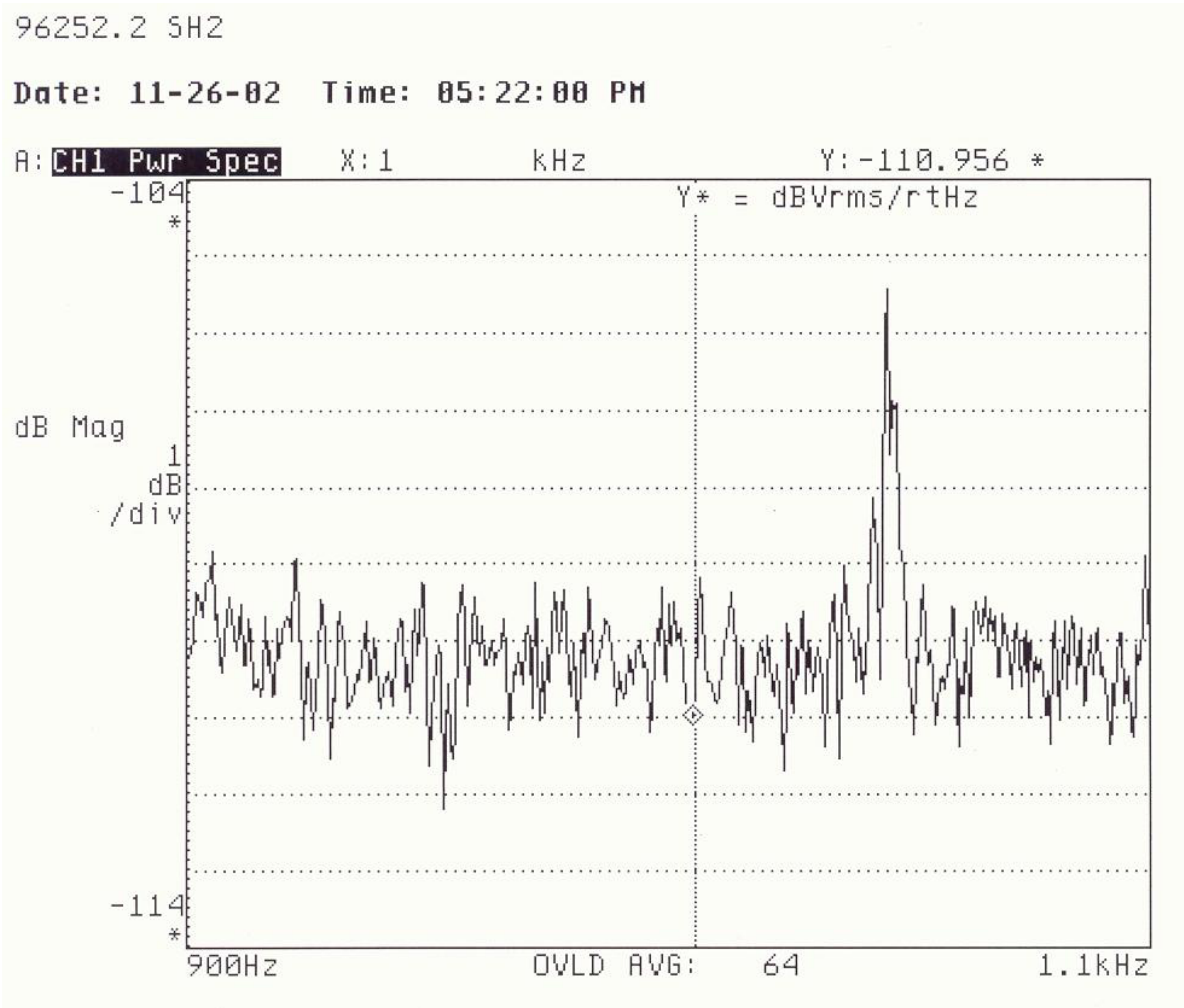

Figure 3.2 White Noise Spectrum

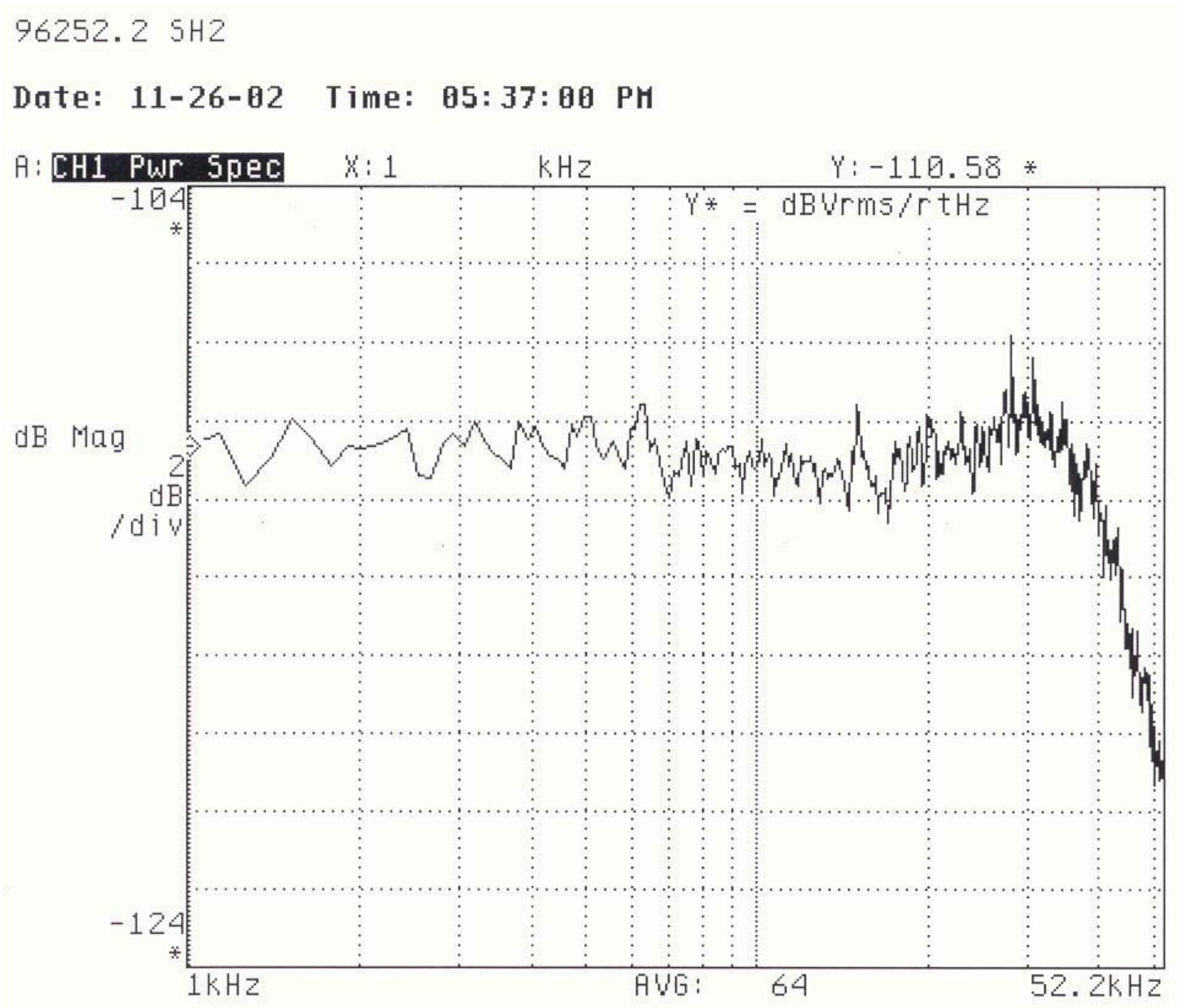

Figure 3.3 High Frequency Spectrum

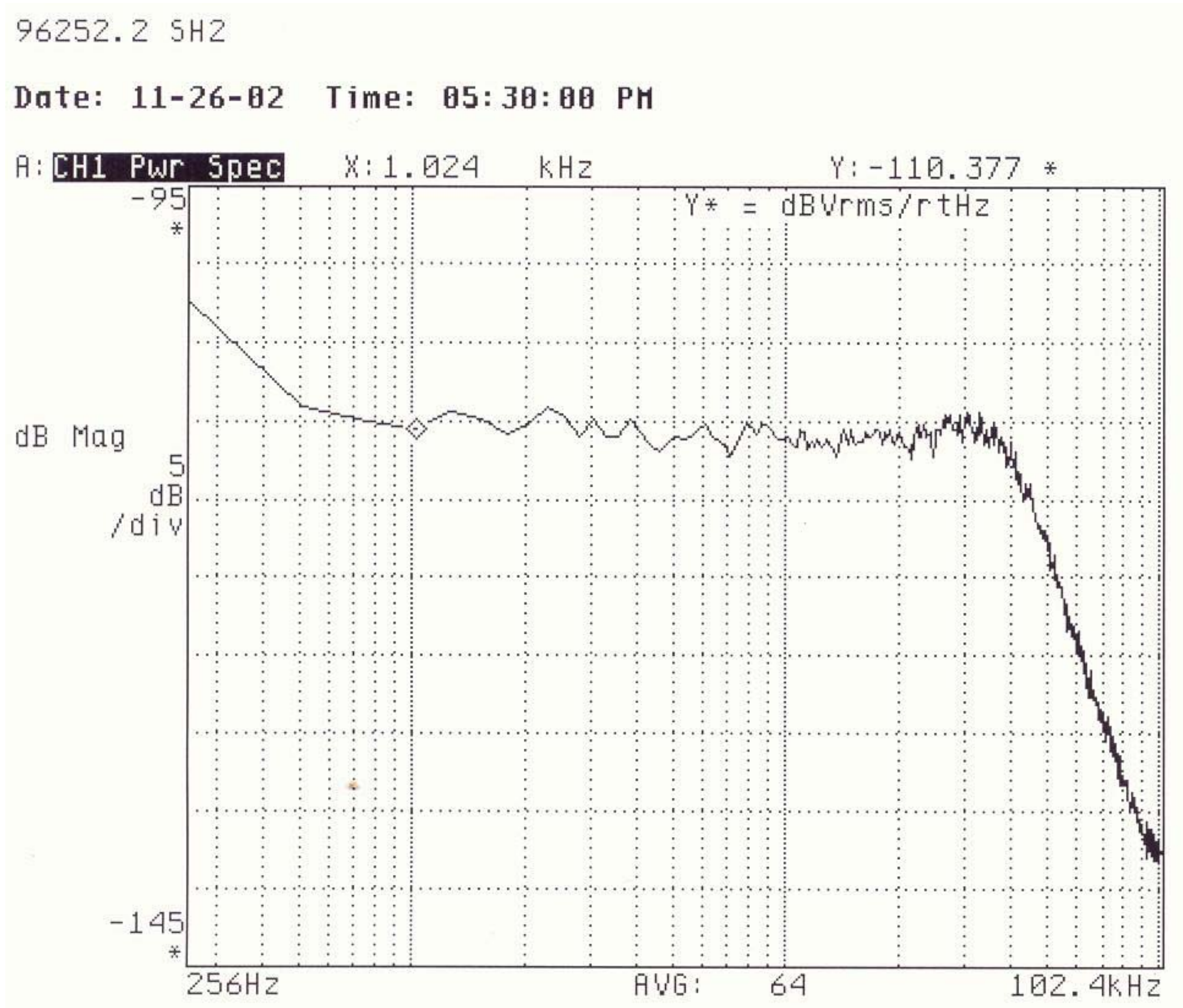

Figure 3.4 Full Spectrum

1kHz Noise @ gain x100 dBV$_{rms}$/sqrtHz	Sensitivity Gain x100 fT/sqrtHz@1khz
-110.5	9.67

Table 3.2 Summary of Noise and Sensitivity

3.2 FIELD CALIBRATION

The calibration procedure for the system sensors is presented below. The calibration is intended to provide the user with a meaningful conversion from the measured voltage output to appropriate physical properties being measured. The coil configuration is shown in Figure 3.5 and the turn origin locations are recorded in Table 3.3.

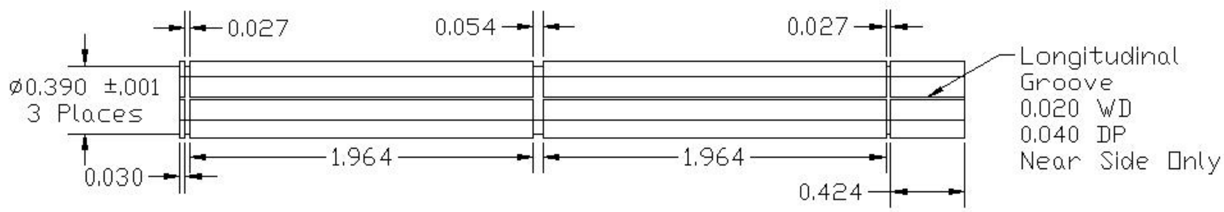

Figure 3.5 Coil Design

Turn	Diameter m	X m	Y m	Z m	Polarity
1	.01	.00000	.00000	.00000	+
2	.01	.00000	.00000	.00015	+
3	.01	.00000	.00000	.00030	+
4	.01	.00000	.00000	.00045	+
5	.01	.00000	.00000	.05045	-
6	.01	.00000	.00000	.05060	-
7	.01	.00000	.00000	.05075	-
8	.01	.00000	.00000	.05090	-
9	.01	.00000	.00000	.05105	-
10	.01	.00000	.00000	.05120	-
11	.01	.00000	.00000	.05135	-
12	.01	.00000	.00000	.05150	-
13	.01	.00000	.00000	.10150	+
14	.01	.00000	.00000	.10165	+
15	.01	.00000	.00000	.10180	+
16	.01	.00000	.00000	.10195	+

Table 3.3 Turn Origin Coordinates

3.2.1 CALIBRATION TECHNIQUE

A SQUID channel produces a voltage which is proportional to the change in flux threading the pick-up coil for that channel. The flux induced in the pick-up is due to the combined flux generated by the (generally) complex magnetization, shape and position of the sample. In this calibration procedure, a second coil is used as the sample. The physical dimensions and current of this coil are also known. By also knowing the relative placement of the coil below the pick-up coil, the mutual inductance M can be calculated. The flux induced by the current I in the calibration coil is given by

$$\Phi_{pick-up} = M \times I_{calib}$$

The pick-up coil is configured as a second order gradiometer to cancel the effect of uniform magnetic fields. Thus the signal is due to the net flux threading the pick-up coil set and is due to non-uniformity in the field generated by the sample. The calculation of this net flux is in general difficult because it depends upon the particular details of the source of the magnetic field, and is thus model dependent.

It has become conventional to characterize the net flux induced in a particular gradiometer coil configuration by an average magnetic field applied to the area of one sense of the pick-up coil set; that is, by calculating what uniform magnetic field, applied to just one polarity or sense of the pick-up coil set, would give the observed signal. This technique then yields a means of converting an observed signal to a quantity which characterizes the mean magnitude of the induced field (change) at the pick-up coil site. This technique does not require knowledge of the details of the magnetization of the sample.

If A is the area of one polarity of the pick-up coil set, and V_{calib} is the observed signal due to the calibration current, then the calibration ratio (Volts/Tesla) can be calculated as

$$V/T = \frac{V_{calib} \times A}{\Phi_{pick-up}}$$

With this conversion ratio, the user can convert an observed (change in) voltage signal to an *effective* (change in) magnetic field. It excludes the details of the sample magnetization, and the particular field gradient sensitivity of the channel.

3.2.2 CALIBRATION PROCEDURE

The following steps describe the calibration procedure to be used on each channel. The system has been calibrated at Tristan. However, if some changes are made in the internal circuitry of the sensors, or to check the calibration, the user can utilize this procedure for the system re-calibration.

Coil Mounting. The calibration coil should be mounted on a x-y scanning stage. It should be oriented with its axis vertical and with as small separation between the coil and probe surface as is convenient. Typically, a coil center to probe tail surface distance of 2 mm is suitable. The coil leads should be tightly twisted and exit downward away from the probe. The purpose of the scanning stage is to locate the coil centered directly below the appropriate channel pick-up coil. This is done be scanning the x and y axes and observing the position of the coil center from the data; for present configuration this is the extremum (maximum or minimum, depending upon the polarity) of the observed signal. The calibration and the pick up coils should be on the same axis.

The coil separation Z is defined as the following:

Z = B + D + C,

where B (see Table 3.3) is the distance between the dewar's inside bottom and the closest coil of the pick up coil set, D (see Table 2.1) is the dewar tail separation, C is the distance between the calibration coil and the dewar's outside bottom (see Figure 3.6).

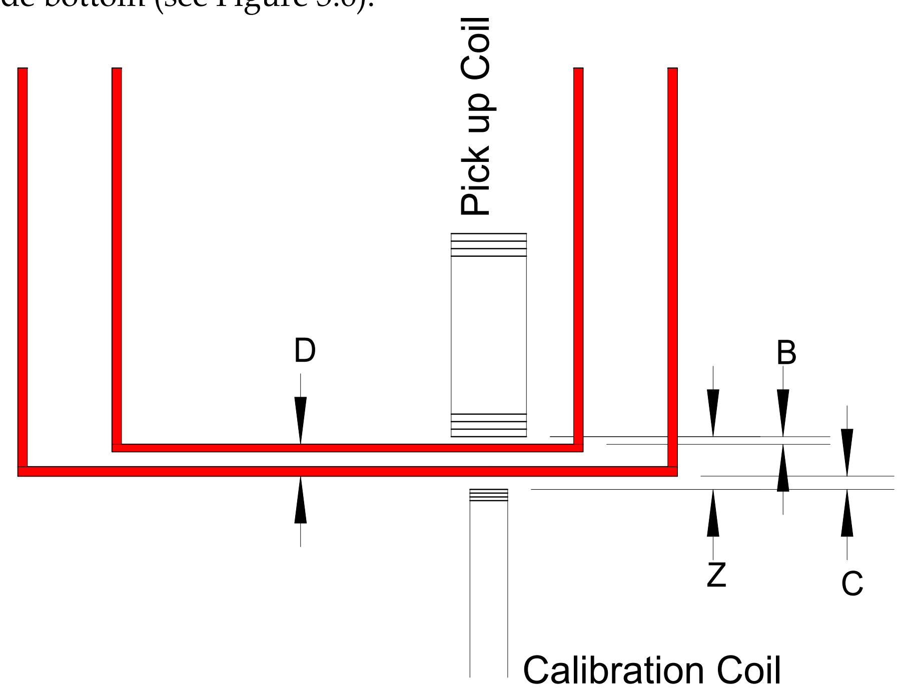

Figure 3.6 Relative position of pick up coil, calibration coil and dewar tail

The calibration coil is placed 1 - 2 mm below the dewar's bottom, and Z is calculated corresponding to this position.

Calibration Current. Because the stage can induce a signal as it is scanned, it is suggested that an AC current be used in the calibration coil. The AC frequency should be chosen away from other potential noises in the local environment (such as the line frequency). A wave form generator or output from a lock-in-detector with appropriate resistor in series can be used to drive the coil. The drive current should be verified by measuring with a laboratory ammeter or by measuring a voltage output from a resistor in series with the calibration coil. Feed the voltage output across this resistor into oscilloscope to check if the signal is sinusoidal. The circuit as shown in Figure 3.14 can be used to drive I_{calib}.

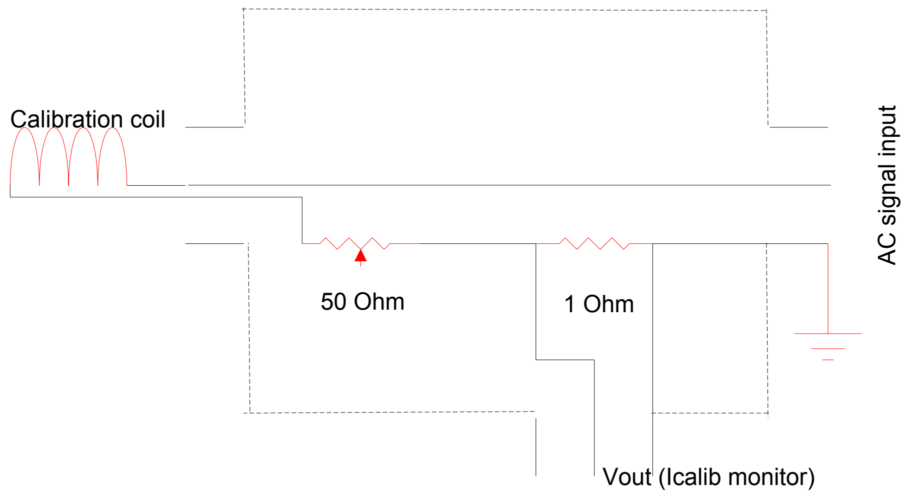

Figure 3.7 Calibration coil circuit

Scan Calibration Coil and V_{calib} Determination. To determine the appropriate calibration coil position for each channel, secure the coil to a x-y table. Apply the required AC signal (I_{calib}) to the calibration coil. Read the SQUID voltage output from the SQUID controller using a lock-in-detector and extracting the peak in-phase lock-in signal. The extremum (polarity depends on particular channel configuration) voltage output is located by moving the table first in the X direction, then in the Y direction. The peak signal, where the calibration coil is centered is defined as V_{calib}. **I_{calib} and V_{calib} are both measured in *peak* values or in *rms* values**.

Mutual Inductance. The diameter, the position, and the number of turns of the calibration coil and the pick-up coil set are needed. For a given separation and orientation (assumed to lie in parallel planes), the mutual inductance can be calculated. Table 3.3 provides the pick-up coil turn positions for use in the calculation.

Area. The area of one sense or polarity of the pick-up coil is used. For JTM/University of Michigan, A is $100\pi x10^{-6}$ m^2.

Calculate V/T. The following formula is used to obtain the V/T (volts per Tesla) ratio.

$$V/T = \frac{V_{calib} \times A}{I_{calib} \times M}$$

Use of Conversion ratio. The conversion of an observed voltage signal to an effective magnetic field should be used with caution. It is important to understand the method for obtaining this ratio, and hence its applicability.

3.2.3 SUMMARY OF THE SYSTEM CALIBRATION

Calibrated Tesla Per Volt gain x100
1.62 x10^-9

Table 3.19 Summary of system calibration