

User's Manual

Model 8404

AC/DC Hall Effect Measurement System

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NOTE: The CE document shown here applies only to those systems which were purchased with the CE option.



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We: Lake Shore Cryotronics, Inc.
575 McCorkle Blvd.
Westerville, OH 43082 USA

hereby declare that the equipment specified conforms to the following Directives and Standards:

Application of Council Directives..... **2006/95/EC LVD**
2004/108/EC EMC

Standards to which Conformity is declared **EN-61010-1:2010**
 Overvoltage II
 Pollution Degree 2
EN 61326-1:2013
 Class A
 Annex B

Model Number..... 8404


Scott Ayer

1/17/2014

Director of Quality and Compliance
Position

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Chapter 1: Introduction

1.1 General

Many contemporary semiconductor and electronic materials are being developed for applications including photovoltaic and thermoelectric materials, new display technologies, organic electronics, and high power devices. These materials possess electronic properties that are becoming increasingly difficult to measure. In fact, current electronic transport property measurement systems cannot measure many of these materials due to their low charge carrier mobilities and the high temperatures needed to characterize high power devices. A new methodology is necessary to characterize these materials.

Traditionally, the DC field measurement technique has been sufficient to measure materials with mobilities down to approximately $1 \text{ cm}^2/\text{V s}$. However, the emerging class of photovoltaic (solar cell), thermoelectric and organic electronic materials are characterized by low mobilities that are difficult, if not impossible, to measure. It is challenging to extract the diminishingly small Hall voltage from the background noise that is produced by such materials using DC field techniques. In order to close the gap between traditional DC field measurement techniques and these low mobility materials, Lake Shore and Toyo have joined in an international partnership. This collaboration has resulted in the 8400 Series Hall effect measurement system (HMS), with an AC field Hall measurement option capable of measuring mobilities down to $0.001 \text{ cm}^2/\text{V s}$, allowing you to measure low mobility materials with ease. For those involved in exploration of solar cells, organic electronics and other novel materials, this offers a significant breakthrough in research productivity.

The 8400 Series HMS can provide a full range of Hall measurements on van der Pauw samples. The standard system is capable of DC field measurements and has a resistance range from $0.5 \text{ m}\Omega$ to $10 \text{ M}\Omega$. An assortment of options including AC field capability, variable temperature assemblies, high resistance, and low resistance are available to broaden your measurement opportunities and simplify experimental processes. The 8400 Series HMS provides a robust platform to which you can add new features as your material measurement needs evolve.

1.1.1 An International Collaboration

Together, Lake Shore Cryotronics, Inc. and Toyo Corporation in Japan have served the scientific community for nearly a century. And, for nearly fifty years combined, both companies have provided high performance Hall effect measurement systems to researchers in academia, national labs and industry so that they can measure the electronic and magneto-transport properties of the novel electronic materials they are developing. While not widely understood or utilized elsewhere, the AC measurement technology offered in the Model 8404 has been adapted from techniques proven in Japan over 15 years. Lake Shore and Toyo Corporation have now combined the unique strengths of both company's products and jointly developed a new AC and DC field Hall effect measurement system with resultant performance that is unparalleled in the industry.

1.2 Features

- *Integrated software:* define samples and create measurement profiles from the Windows® menu-driven interface
- *Ergonomic workstation:* in addition to housing all of the integrated electronics, the workstation offers a convenient tabletop and drawer to store sample cards and other convenience items
- *AC field Hall measurement option:* measure Hall mobilities down to $0.001 \text{ cm}^2/\text{Vs}$ —lower than ever possible using traditional DC field Hall measurement techniques
- *High Resistance Option:* widens range to $0.5 \text{ m}\Omega$ to $200 \text{ G}\Omega$
- *Easy sample access:* for ease of sample exchange, modules slide forward out of the magnet gap
- *Storage:* while not in use, conveniently and safely store variable temperature bodies and sample inserts within close reach
- *Settable magnet gap:* guarantees precise gap spacing, ensuring repeatability and reproducibility
- *Future expansion:* more than just a Hall effect measurement system, the robust platform allows you to add new features as your material measurement needs change
- *Temperature-dependent measurements:* measure samples from 10 K to 1273 K with an optional closed cycle refrigerator and oven, or take dedicated 77 K measurements with an optional single-point LN_2 body

1.3 Fields of Study

The 8400 Series HMS combines the best of both DC and AC field Hall measurement methodologies to facilitate the broadest range of research applications. Optional variable temperature modules and measurement platforms extend the utility of your HMS by allowing you to configure your system to meet your specific needs.

AC field, variable field, and temperature dependent magnetotransport measurements provide a means for you to understand fundamental processes in solid state physics and materials science. In addition to the AC field measurement and variable temperature options, the 8400 Series HMS allows you to compare material properties measured using the Hall effect, to properties derived from electronic transfer characteristics.

1.3.1 Photovoltaic and Thermoelectric Applications

Photovoltaic (solar cell) and thermoelectric materials are often characterized by low mobilities. This characteristic makes them difficult or impossible to measure using traditional DC field Hall methods. The 8400 Series HMS with AC field Hall measurement option makes it possible to characterize these materials with ease.

1.3.2 Organics

The AC field measurement option of the 8400 Series HMS provides an opportunity, not easily realized until now, to reliably measure the Hall effect in low mobility organic electronics. These materials are the basis for printable and flexible electronic devices, as well as organic light emitting diodes and organic solar cell materials.

1.4 Materials

- *Solar cells:* OPVs, a-Si, uSi, CdTe, CuInGaSe (CIGS)
- *Organic electronics:* OTFTs, Pentacene, Chalcogenides, OLEDs
- *Transparent conducting oxides:* InSnO (ITO), ZnO, GaZnO, InGaZnO (IGZO)
- *III-V semiconductors:* InP, InSb, InAs, GaN, GaP, GaSb, AlN based devices, high electron mobility transistors (HEMTs) and heterojunction bipolar transistors
- *II-VI semiconductors:* CdS, CdSe, ZnS, ZnSe, ZnTe, HgCdTe
- *Elemental semiconductors:* Ge, Si on insulator devices (SOI), SiC, doped diamond
- *SiGe based devices:* HBTs and FETs
- *Dilute magnetic semiconductors:* GaMnAs, MnZnO
- *Other conducting materials:* Metal oxides; organic and inorganic conductors
- *Magnetoresistors (MR):* MR, Giant-MR, Tunneling-MR, and Colossal-MR devices
- *High temperature superconductors*

1.5 Direct and Derived Measurements as a Function of Field and Temperature

- Hall voltage
- Resistivity
- Hall coefficient
- Carrier type/concentration/density
- Hall mobility
- Magnetotransport
- Shubnikov-de Haas oscillations (SdH)

1.6 System Application Software

Along with sophisticated hardware, you get fully integrated HMS software, which is Windows® graphic menu-driven interface for system operation, data acquisition, and analysis.

The menu structure and navigation functions make the platform easy to use. The software controls magnetic field, sample temperature, and sample excitation while delivering a comprehensive collection of measurement capabilities. The sample module ID feature automatically recognizes attached hardware and configures the software accordingly.

You can define and save specifications and experimental configurations, as well as record and display data in laboratory and SI units for further analysis. Real-time feedback of processed data can be displayed in graphical and tabular format. With the software's SQL reporting capabilities, data and plots can be printed or exported directly to a Microsoft Excel® spreadsheet as well as PDF or Microsoft Word® documents.

1.6.1 Performs Both van der Pauw and Hall Bar Measurements

To measure sample sheet resistivity, the 8400 Series HMS supports both van der Pauw and Hall bar measurement geometries. The Hall bar method uses one dimensional current flow approximation. You can also measure samples with gated Hall bars to account for gate bias—important for measurement of device-level material. Measure Hall density in a channel as a function of gate voltage and, as you change the gate voltage, create more or fewer carriers.

The system's program mode makes it easy to conduct gated Hall bar measurements. You can, for instance, set up a loop with varying temperatures and gate voltages and easily perform a Hall measurement using the software.

1.6.2 Toolbox with Resistance Utility

Through the software's toolbox, you have complete control over the measurement parameters and can change them in real time. When combined with environmental settings like temperature, experimental parameters can be quickly determined.

In addition to standard Hall measurements, the software's toolbox enables you to perform resistance measurements at the start of an experiment. This is a very useful tool when you need to do a quick and initial check of a sample, to determine usable current, for instance. Once that's known, you can then proceed with experimentation to determine further integrity of the sample.

1.6.3 Advanced Programming Functions

The system easily supports variable temperature measurements, enabling you to start and end at your convenience. But the software also enables you to perform time loops, so you can set the system up to repeat Hall measurements according to a pre-set schedule for unattended experiments throughout the day. You can also program it to insert a resistance measurement into a sequence of Hall measurements.

Commands enable you to "Go to Temperature," "Go to Field," and "Go to GBV" (gate bias voltage). You can also program it to "Wait," that is, start a measurement then have the system pause and settle before continuing. This way, you have the flexibility to automate and customize your experiment procedure.

1.7 Parameters to Consider When Selecting Your Configuration

A variety of measurement options are available to enable you to configure the Model 8404 system for best performance with your samples and their characteristic properties.

1.7.1 Mobility Range

Mobility is one of the most important and commonly derived electronic transport properties measured in a Hall effect measurement system, as it is often directly related to the material performance in an electronic device. The type of magnet field, whether DC or AC, along with the integration of precision electronics and software determines the low mobility range you will be able to measure in your HMS.

The 8400 Series HMS combines the best of both DC and AC field measurement capabilities. The result of which is the widest mobility range of any commercially available HMS. The system comes standard equipped with the traditional DC field method, capable of measuring mobilities down to $1 \text{ cm}^2/\text{V s}$. While sufficient to measure a wide range of materials, the DC field method is not capable of measuring the emerging class of photovoltaic (solar cell), thermoelectric and organic electronic materials that are characterized by very low mobilities. For these applications, the 8400 Series HMS is available with a unique AC field measurement option that extends your mobility measurement capabilities down to $0.001 \text{ cm}^2/\text{V s}$.

1.7.2 Resistance Range

Along with Hall mobility and other sample parameters, resistance measurements are one of the fundamental building blocks that define the capabilities and performance specifications of your 8400 Series HMS. In order to enable measurement of the broadest range of materials, it is critical that your system be capable of measuring a very wide range of resistances.

Like the mobility range, the 8400 Series HMS offers the widest possible resistance range. The system takes great care in controlling low currents and small voltages present in electron transport systems. While the standard system is capable of measuring resistances from $0.5 \text{ m}\Omega$ to $10 \text{ M}\Omega$, resistance measurement options allow you to measure resistances all the way down to $10 \text{ }\mu\Omega$ and as high as $200 \text{ G}\Omega$ when working in DC fields. The high end is limited to $8 \text{ G}\Omega$ when working in AC field. This wide resistance range ensures you can study the broadest range of materials.

1.7.3 Magnet Configuration

The magnet is one of the key components of any Hall effect measurement system. It determines, in part, what kind of measurements you will be able to perform. The 8400 Series HMS comes equipped with a 100 mm (4 in) 76 mm (3 in) electromagnet capable of taking variable DC field Hall measurements to 1.67 T and AC field measurements to 1.18 T . The standard configuration is optimized to both maximize field strength and ensure uniformity of the field over your sample area. Optional pole cap diameters are available to allow you to configure the field and uniformity to your specific requirements. The magnet can also be configured for axial optical access to accommodate lasers and other optical devices.

The Model EM4-CSA electromagnet used in the Model 8404 has a magnet pole adjustment feature that takes the guesswork out of setting a consistently repeatable pole gap. It is equipped with spacers allowing you to adjust your gap within a defined set of distances without the use of any measurement tools. You'll no longer need to be concerned with ensuring repeatability when changing between pole gaps.

1.7.4 Temperature Range

While measurements at room temperature are sufficient in many cases, transport properties can change significantly as the temperature varies. Measuring a sample at variable temperatures allows carriers to be identified by their excitation energies and provides clues to the dominating scattering mechanism in materials. For materials intended for applications requiring variable temperature ranges, testing the materials at these temperatures can determine if they're suitable for such applications. The 8400 Series HMS is designed to control temperature and magnetic flux to produce accurate, reliable Hall effect and electronic transport measurements.

The 8400 Series HMS is available with a variety of temperature options to further extend the functionality of your system. A single point LN₂ body is available if you only need to measure samples at room temperature and at 77 K. An optional closed cycle refrigerator (CCR) body is available for taking measurements from 15 K to 400 K, and an optional oven extends your temperature measurement capabilities from 305 K to 1,273 K. The 8400 Series HMS is field configurable, so while any of these temperature options can be configured with your system at time of order, they can also be added in the field at any time.

1.7.5 Additional Measurement Options

The 8400 Series HMS is not just a Hall effect measurement system. Additional measurement options include gate bias and magnetoresistance. Your system can be configured with these options at time of order, or you can upgrade in the field at any time. This flexibility preserves your investment, allowing you to keep up with the rapidly changing landscape of characterization measurements. Additional future upgrades are also in development.

1.8 Safety

This section provides safety precautions to be taken for cryogenics, as well as ESD precautions. Finally, this section also provides images with definitions of the safety symbols used on the product.

1.8.1 Handling Liquid Helium and Liquid Nitrogen

Helium and nitrogen are colorless, odorless, and tasteless gases. When properly cooled, the gases liquify. Liquid nitrogen (LN₂) is used with the 8400 Series HMS. Although not explosive, there are certain safety considerations for handling LHe and LN₂.

Operate all cryogenic containers (Dewars) in accordance with manufacturer instructions. Safety instructions are normally posted on the side of each Dewar. Keep cryogenic Dewars in a well-ventilated place, protected from the weather, and away from heat sources. FIGURE 1-1 shows a typical cryogenic Dewar.

Transfer LHe and LN₂ and operate storage Dewar controls in accordance with manufacturer/supplier instructions. During transfer, follow all safety precautions written on the storage Dewar and recommended by the manufacturer.



Helium and nitrogen gases generated by their liquid forms are potential asphyxiants and can cause rapid suffocation without warning. Store and use liquid helium and liquid nitrogen in an adequately ventilated area. **DO NOT** vent the container in confined spaces. **DO NOT** enter confined spaces where gas may be present unless area is well-ventilated. If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.



Liquid helium and liquid nitrogen can cause severe frostbite to exposed body parts. **DO NOT** touch frosted pipes or valves. For frostbite, consult a physician immediately. If a physician is unavailable, warm the affected parts with water that is near body temperature.

Two essential safety aspects of handling LHe are adequate ventilation and eye and skin protection. Although helium and nitrogen gases are non-toxic, they are dangerous because they replace air in a normal breathing atmosphere. Liquid helium is an even greater threat because a small amount of liquid evaporates to create a large amount of gas. Store and operate cryogenic Dewars in open, well-ventilated areas.

When transferring LHe and LN_2 , protect eyes and skin from accidental contact with liquid or the cold gas issuing from it. Protect eyes with full face shield or chemical splash goggles; safety glasses (even with side shields) are inadequate. Always wear special cryogenic gloves (Tempshield Cryo-Gloves® or equivalent) when handling anything that is, or may have been, in contact with the liquid or cold gas, or with cold pipes or equipment. Wear long sleeve shirts and cuffless trousers long enough to prevent liquid from entering shoes.

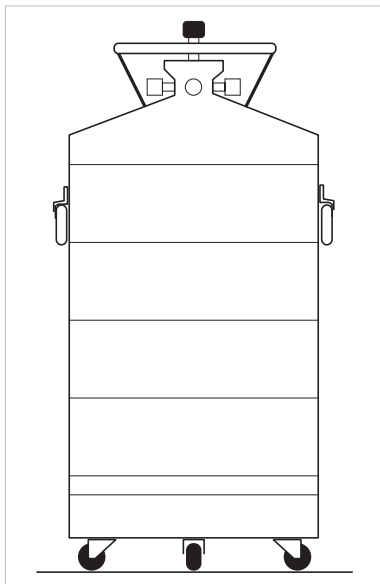


FIGURE 1-1 Cryogenic storage Dewar

1.8.1.1 Recommended First Aid for LHe and LN_2 Exposure

Post an appropriate material safety data sheet (MSDS) obtained from the manufacturer/distributor at every site that stores and uses LHe and LN_2 . The MSDS specifies symptoms of overexposure and first aid.

If a person exhibits symptoms of asphyxia such as headache, drowsiness, dizziness, excitation, excessive salivation, vomiting, or unconsciousness, remove to fresh air. If breathing is difficult, give oxygen. If breathing stops, give artificial respiration. Call a physician immediately.

If exposure to cryogenic liquids or cold gases occurs, restore tissue to normal body temperature (98.6°F) by bathing it in warm water not exceeding 105 °F (40 °C). Do not rub the frozen part, either before or after rewarming. Protect the injured tissue from further damage and infection and call a physician immediately. Flush exposed eyes thoroughly with warm water for at least 15 min. In case of massive exposure, remove clothing while showering with warm water. The patient should not drink alcohol or smoke. Keep warm and rest. Call a physician immediately.

1.8.2 Electrostatic Discharge

Electrostatic discharge (ESD) may damage electronic parts, assemblies, and equipment. ESD is a transfer of electrostatic charge between bodies at different electrostatic potentials caused by direct contact or induced by an electrostatic field. The low-energy source that most commonly destroys electrostatic discharge sensitive devices is the human body, which generates and retains static electricity. Simply walking across a carpet in low humidity may generate up to 35,000 V of static electricity.

Current technology trends toward greater complexity, increased packaging density, and thinner dielectrics between active elements, which result in electronic devices with even more ESD sensitivity. Some electronic parts are more ESD sensitive than others. ESD levels of only a few hundred volts may damage electronic components such as semiconductors, thick and thin film resistors, and piezoelectric crystals during testing, handling, repair, or assembly. Discharge voltages below 4000 V cannot be seen, felt, or heard.

1.8.3 Identification of Electrostatic Discharge Sensitive Components

The following are various industry symbols used to label components as ESD sensitive.



FIGURE 1-2 Symbols indicating ESD sensitivity

1.8.4 Handling Electrostatic Discharge Sensitive Components

Observe all precautions necessary to prevent damage to ESDS components before attempting installation. Bring the device and everything that contacts it to ground potential by providing a conductive surface and discharge paths. As a minimum, observe these precautions:

- De-energize or disconnect all power and signal sources and loads used with unit
- Place unit on a grounded conductive work surface
- Technician should be grounded through a conductive wrist strap (or other device) using 1 M series resistor to protect operator
- Ground any tools, such as soldering equipment, that will contact unit. Contact with operator's hands provides a sufficient ground for tools that are otherwise electrically isolated.
- Place ESD sensitive devices and assemblies removed from a unit on a conductive work surface or in a conductive container. An operator inserting or removing a device or assembly from a container must maintain contact with a conductive portion of the container. Use only plastic bags approved for storage of ESD material.

Do not handle ESD sensitive devices unnecessarily or remove them from the packages until they are actually used or tested.

1.8.5 Equipment Safety
Symbols

	Direct current (power line)		Equipment protected throughout by double insulation or reinforces insulation (equivalent to Class II of IEC 536—see Annex H)
	Alternating current (power line)		
	Alternating or direct current (power line)		CAUTION: High voltages; danger of electric shock; background color: yellow; symbol and outline: black
	Three-phase alternating current (power line)		
	Earth (ground) terminal		CAUTION or WARNING: See included documentation; background color: yellow; symbol and outline: black
	Protective conductor terminal		
	Frame or chassis terminal		CAUTION: Hot surface
	On (supply)		
	Off (supply)		

FIGURE 1-3 Safety symbols

1.8.6 Sample Insert
Specific Warning
Symbol



See section 4.3.1.2 for a warning related to the sample insert connections.

Chapter 2: System Overview

2.1 General

This chapter describes the major components of the 8400 Series Hall effect measurement system (HMS). It also illustrates and establishes a vocabulary for the major components. Finally, it provides the basic theoretical concepts upon which Hall measurements are made and upon which the system operates.

2.2 Major Components

This section is intended as a reference for identifying various components, operator interfaces and controls called out in later chapters. An 8400 Series HMS comprises the measurement platform, sample management components, instrument console, computer, and system software. FIGURE 2-1 shows an overall view of the full system. Each major component is detailed in the following sections.

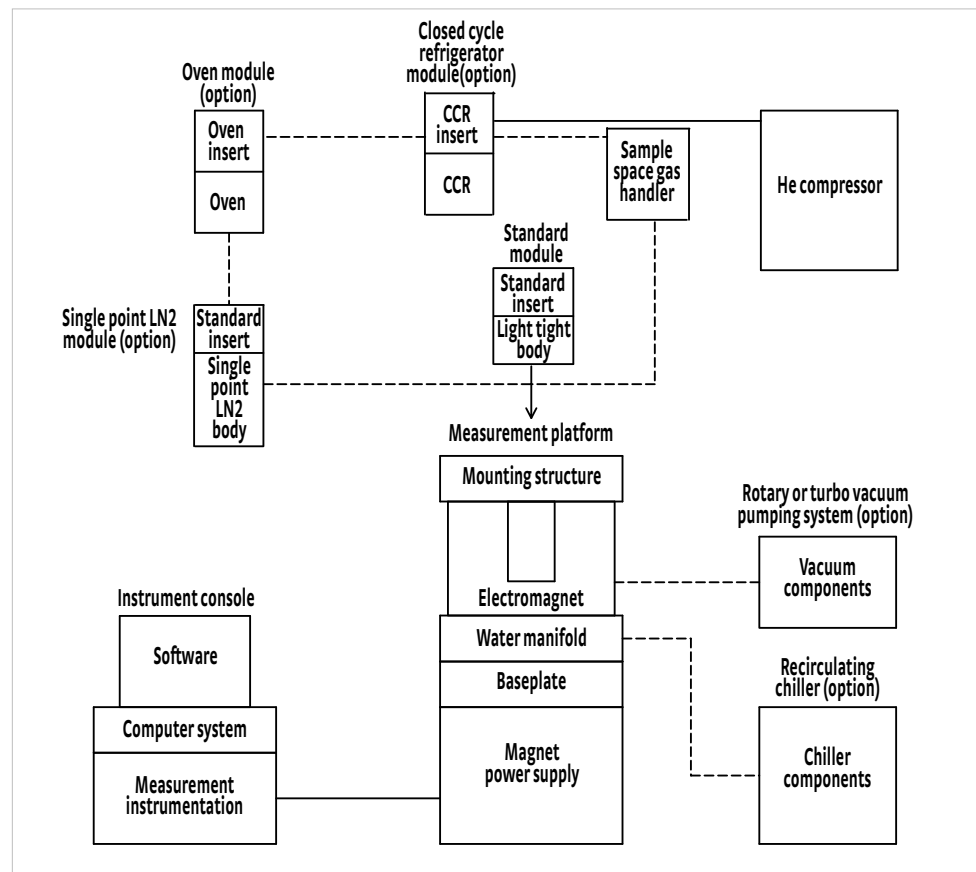


FIGURE 2-1 8400 Series Hall effect measurement system major components

2.2.1 Measurement Platform

The measurement platform provides the magnetic field and serves as the support for the sample management components. Major components of the measurement platform include the electromagnet, magnet power supply and the magnet console and mounting structure. FIGURE 2-2 illustrates the measurement platform components.

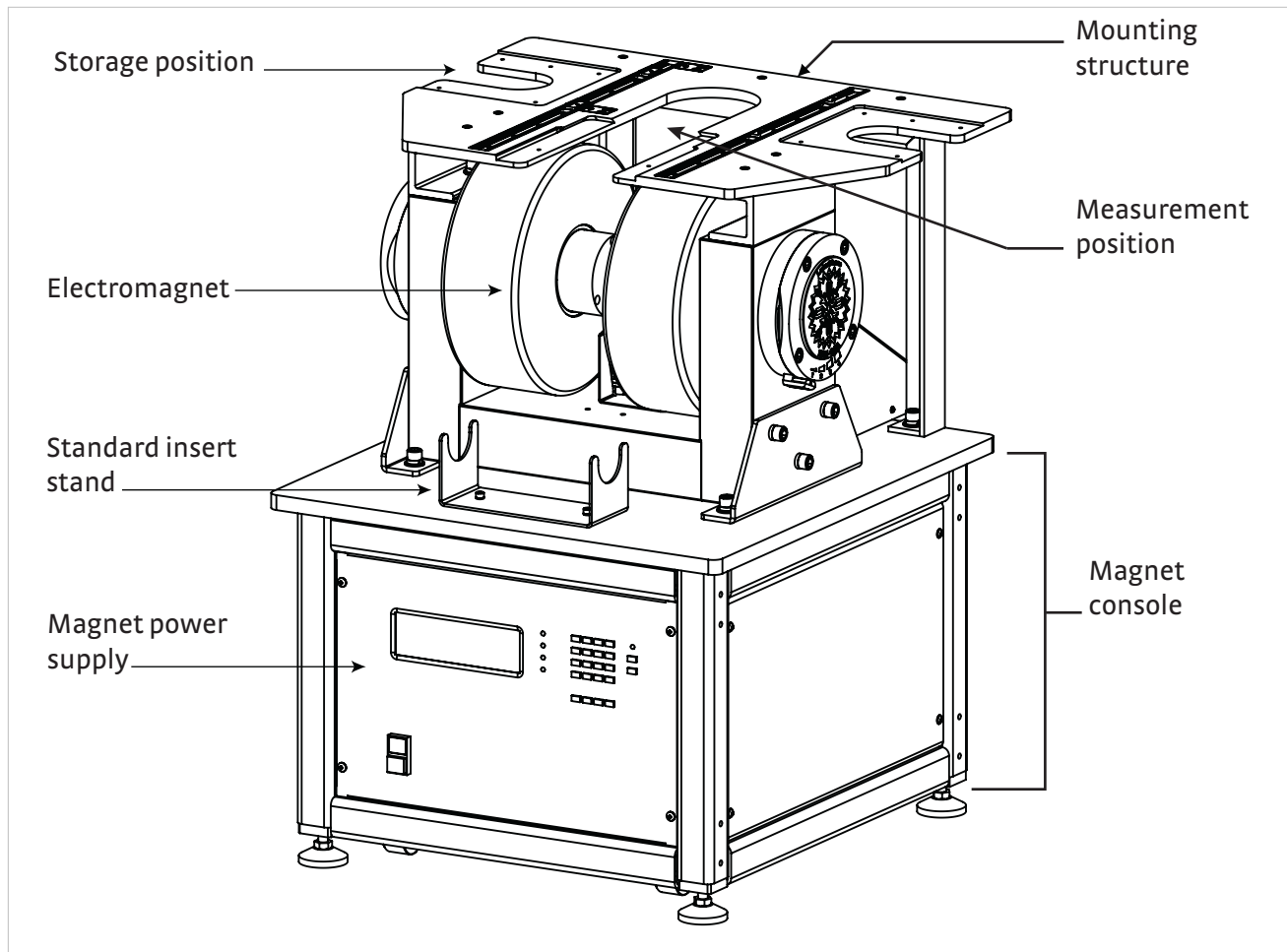


FIGURE 2-2 *Measurement platform*

2.2.1.1 Magnet

The Model EM4-CSA electromagnet provides bipolar, variable DC magnetic field of up to 1.67 T in the standard Model 8404 configuration. It is also capable of producing full amplitude (up to 1.18 T RMS) AC fields of up to 100 mHz in frequency when the Model 84030 AC field Hall measurement option is added. The magnet's settable gap can be changed easily to accommodate optional sample modules of different widths. Standard pole caps with 50 mm (2 in) tip diameter were chosen for the best combination of field strength and uniformity at the sample. The EM4-4PB high uniformity option provides pole caps with a larger 100 mm (4 in) tip diameter for applications that require higher uniformity. The Model 84060 option provides line of sight optical access through the pole and pole cap. Optical access sample modules must be ordered separately. Major components of the electromagnet include the magnet c-frame, water cooled coils, magnet poles, pole adjusters, pole caps, electrical connections and plumbing. FIGURE 2-3 shows the electromagnet.

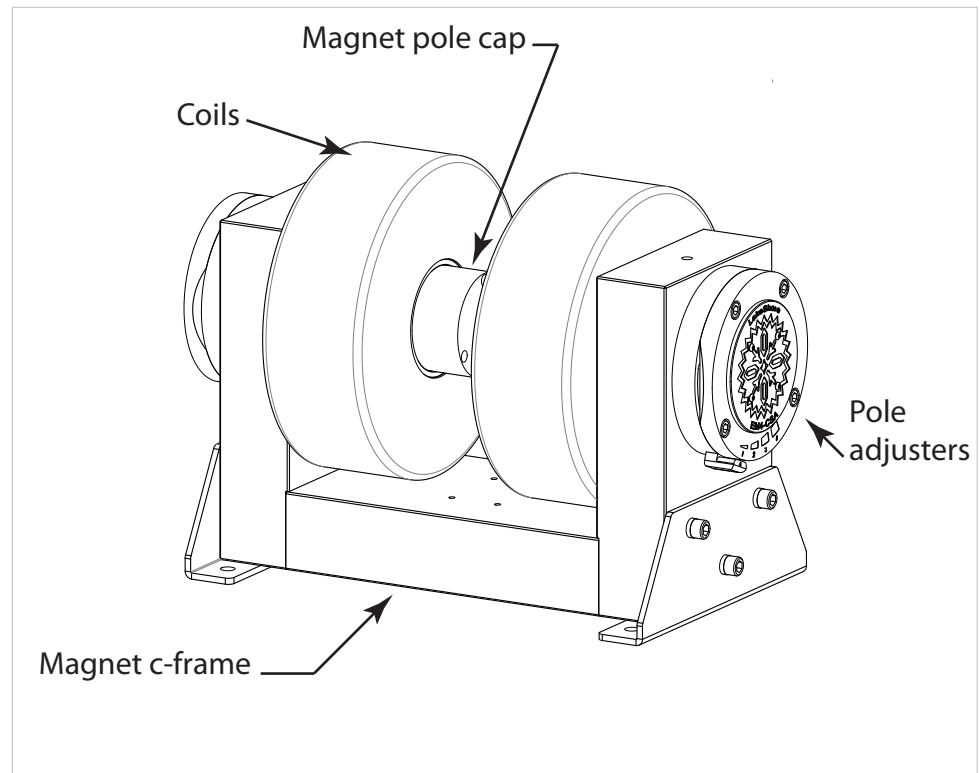


FIGURE 2-3 EM4-CSA

2.2.1.2 Power Supply

The electromagnet power supply is a linear, bipolar current source providing true 4-quadrant output, eliminating the need for external switching or operator intervention to reverse current polarity when changing the polarity of the field in the electromagnet. The power supply is capable of supplying $\pm 70\text{ A}/\pm 35\text{ V}$. Its output architecture relies on low noise linear input and output stages. The linear circuitry of the power supply permits operation with less electrical noise than switch-mode electromagnet power supplies, and it allows greater resolution and finer detail in results drawn from data taken during high sensitivity experiments. The power supply supports both the DC field and AC field Hall measurement methods. It is water cooled via the internal water manifold of the Model 8404.



FIGURE 2-4 Magnet power supply

2.2.1.3 Magnet Console and Mounting Structure

The magnet console and mounting structure is a welded frame structure that houses the magnet power supply, electromagnet, sample module, and variable temperature option body.

2.2.2 Sample Management

The sample management components provide a controlled measurement environment for the sample or device under test (DUT). They also provide the electrical and optional optical interface for the sample. This section describes and illustrates the standard Model 8404 sample management components or sample module which include the light tight body, standard insert and sample card. Other modules are also available as part of the temperature options described in section 2.3.1.1 through section 2.3.1.4.

2.2.2.1 Light Tight Body

The light tight body serves as a support for the standard insert, allows for consistent sample alignment, and provides a light tight, draft free environment for the sample. It is designed to fit a 25 mm (1 in) magnet air gap for the highest possible field in the Model 8404. It is also compatible with all standard and optional sample cards. Optional optical access is available; refer to section 2.3.3.6 for more information. FIGURE 2-5 shows the light tight body.

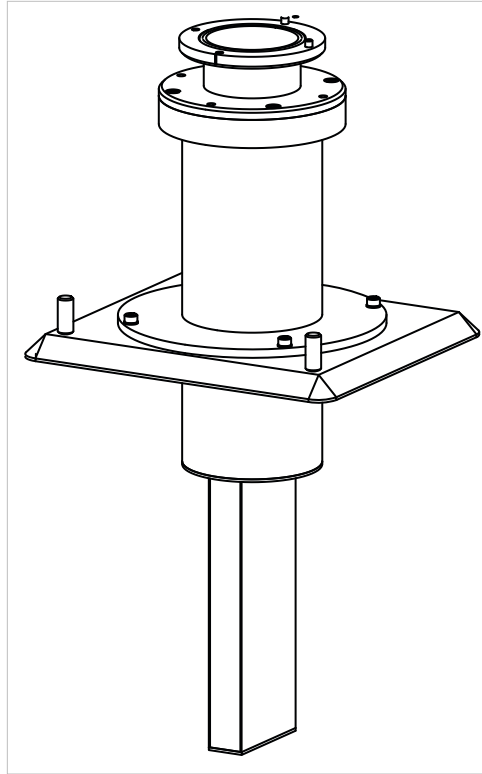


FIGURE 2-5 *Light tight body*

2.2.2.2 Standard Insert

The standard insert provides physical mounting and electrical connection to the sample card. The standard insert is compatible with the standard light tight body and optical access body for operation at room temperature and the optional Model 84015 single point LN₂ body for operation near 77 K. It includes eight triaxial connectors for guarded signals to the sample for resistance measurements up to 200 GΩ depending on your system's configuration. Its circular connector contains temperature monitor leads, insert identification, and safety interlock. The standard insert is compatible with a variety of standard and optional sample cards depending on whether it is used with the light tight body or single point LN₂ body option. Temperature monitoring is available when purchased with the Model 840-VTA or Model 841-STM options.

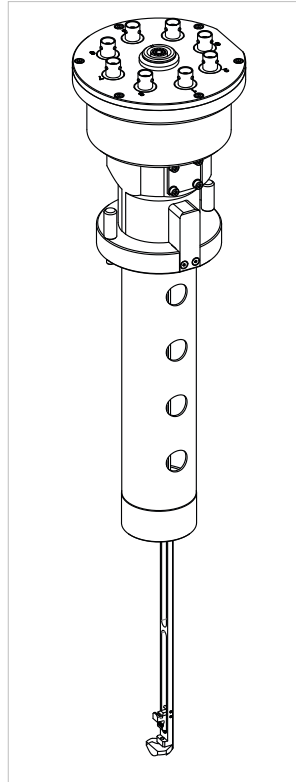


FIGURE 2-6 *Standard insert*

2.2.2.3 Sample Mounting Kit

The sample mounting kit that comes standard with the HMS includes five 10 mm solder pad sample cards (one with a platinum (PT) temperature sensor and four without the sensor) and sample mounting accessories. The interchangeable, plug-in sample cards facilitate fast, easy, and flexible sample mounting, exchange and storage. The included 10 mm solder pad sample cards provide a mounting position for square samples up to 1 cm on a side. They also provide solder pads for six signal and two gate bias connections for sample lead wires. All of the included cards are compatible with the light tight body, single point LN₂ body and optical access body. A Model 840-VTA option or Model 841-SMT option is required for temperature monitoring. Other optional sample cards are described in section 2.3.4.



FIGURE 2-7 Solder pad sample card for 10 mm samples

2.2.3 Instrument Console

Standard instrument console components include the Keithley 2182A voltmeter, the Model 6220 current source, and the Model 776 buffered Hall effect matrix. The instrument console is fully assembled, wired and tested at Lake Shore before shipment. The computer, keyboard, and monitor are placed on the desktop working surface. FIGURE 2-8 shows the instrument console.

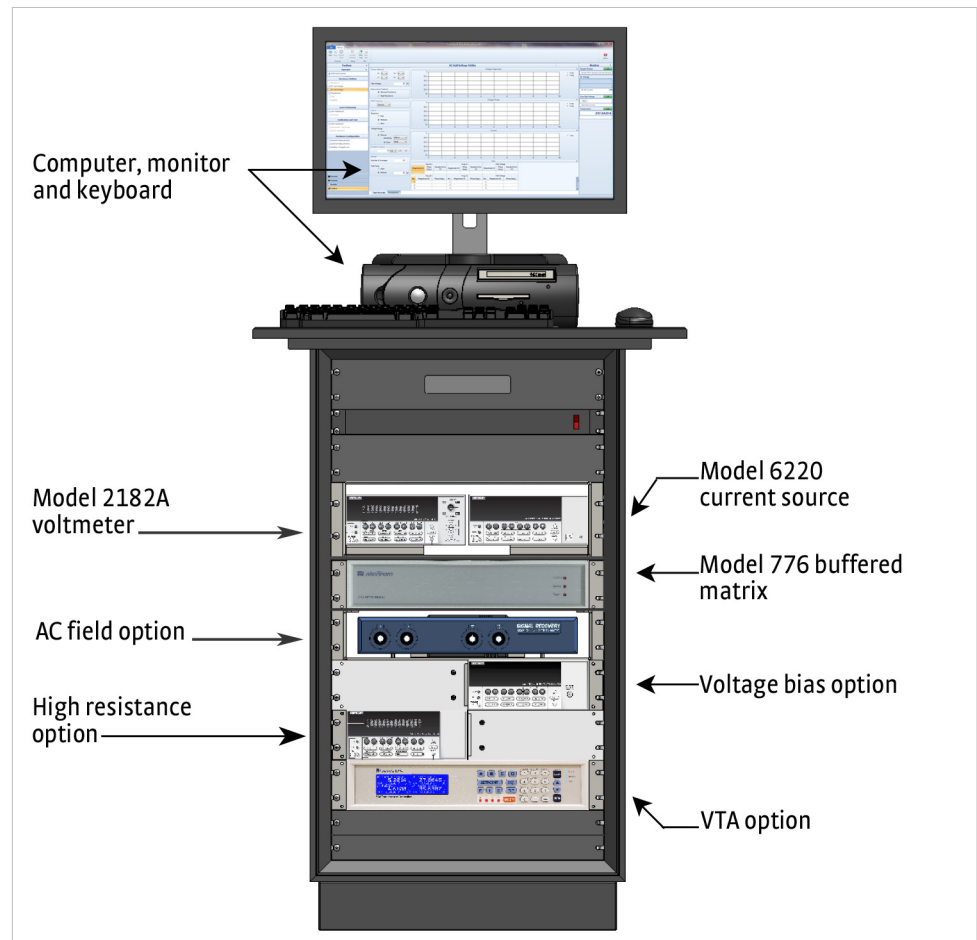


FIGURE 2-8 Instrument console

2.2.4 Computer and Monitor

The Model 8404 is shipped with a Windows™ 7 computer and a wide screen monitor.

2.2.5 System Software

The system software is described in detail in the Software Manual for the 8400 Series AC/DC Hall Effect Measurement System.

2.3 Configurations, Options, and Accessories

This section describes and illustrates the optional components of the Model 8404. A wide selection of modules and other options make it possible to configure the Hall system to meet a variety of specific measurement applications.

2.3.1 Temperature Options

The Model 8404 can be equipped with several temperature options to provide an environment for your sample that is suitable to your measuring needs. This section gives an overview and illustrates the modules as well as the support structures and instrumentation that can be added to your system to facilitate various measurements.

2.3.1.1 Model 84015 Single Point LN₂ Body

The Model 84015 single point LN₂ body is a light tight support for the standard insert. It provides for consistent sample alignment, and its structure allows you to fill it with liquid nitrogen to take measurements at a fixed point, near 77 K. The Model 84015 is compatible with the 10 mm sample cards, and the sample rotation option. This option is field installable.

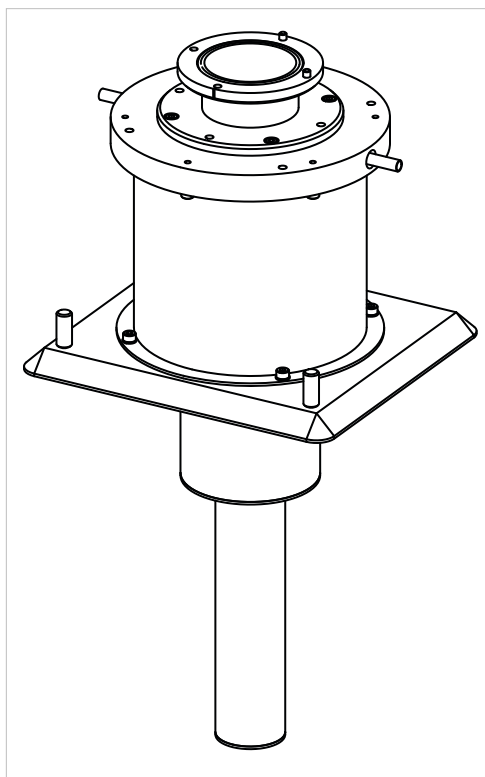


FIGURE 2-9 Single point LN₂ body

2.3.1.2 Model 84016 Closed Cycle Refrigerator (CCR) with CCR Insert

The Model 84016 CCR provides a variable temperature sample space with a range of 15 K to 400 K depending on configuration. It also serves as a support for the CCR insert allowing consistent sample alignment, sample rotation, and a light tight environment for the sample. Low pressure helium exchange gas creates the thermal link between the CCR and sample, so the sample insert can be removed without warming the entire CCR. The CCR and included compressor offer convenient, cryogen free operation. The CCR is sized to fit a 50 mm (2 in) magnet air gap. The Model 84016 is compatible with both AC and DC field operation, but AC field will cause eddy current heating of the sample space when the CCR is operating at low temperatures. This increases the temperature of the option by approximately 5 K to 10 K.

The Model 84016 CCR insert provides physical mounting, temperature monitoring and electrical connection to the sample. It includes six triaxial connectors for guarded signals to the sample, supporting resistance measurements up to 200 G Ω depending on system configuration. Its circular connector contains temperature monitor leads and auxiliary feedthrough pins. The insert provides a mounting position for samples up to 12 mm x 15 mm x 3 mm. Six reusable solder posts are provided for connection to the sample lead wires.

The Model 84016 requires the Model 840-VTA option to provide temperature electronics, cabling and sample space gas handling. A TPS-FRG option or equivalent is required to maintain vacuum in the CCR during operation for thermal insulation (Model 840-VTA and Model TPS-FRG can be shared with the Model 84017 oven if both are ordered). A regulated source of helium gas is also required but not included.

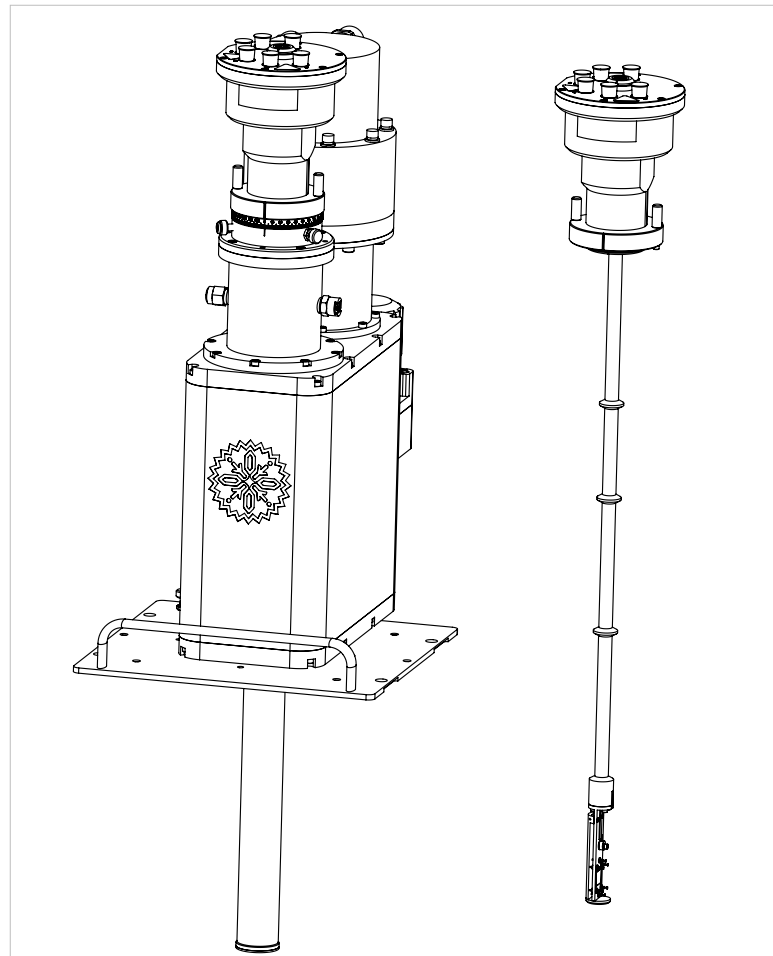


FIGURE 2-10 Left: CCR with the CCR insert installed; Right: CCR insert

2.3.1.3 Model 84016-O Optical Access CCR Module

An optical access version of the Model 84016 is also available as Model 84016-O. The CCR includes transparent windows to allow optical access to the top side of the sample. Features are similar to the Model 84016, and the two share the sample insert. The base temperature of the option will increase slightly because of the additional radiation entering the sample space through the optical windows. The optical version also requires a Model 84060 optical access magnet option and a larger magnet gap.

2.3.1.4 Model 84017 Oven with Oven Insert

The Model 84017 oven provides a variable temperature sample space with a range of 373 K to 1273 K (100 °C to 1000 °C). It also serves as a support for the oven insert allowing consistent sample alignment, sample rotation, and a light tight environment for the sample. Low pressure argon exchange gas creates the thermal link between the oven and sample. The oven is sized to fit a 50 mm (2 in) magnet air gap. The Model 84017 is compatible with both AC and DC field operation. The oven also can be operated with the sample in vacuum or air with reduced operating range, and with additional customer supplied hardware.

The Model 84017-I oven insert provides physical mounting, temperature monitoring and electrical connection to the sample. It includes triaxial connectors for signals to the sample supporting resistance measurements up to approximately 100 M Ω depending on sample and substrate. Its circular connector contains temperature monitor leads, insert identification and safety interlock. The insert provides a mounting position for square samples up to 1 cm on a side. Four movable probes are provided for point contact to the sample.



As temperature is increased, the effect of leakage current becomes more prominent and can limit the accuracy of higher resistance sample measurements. This effect can be considered as a resistor R_L in parallel with the sample R_S , with the typical values of R_L as shown below.

Temperature	R_L
Room (~22 °C / 295 K)	100 G Ω or greater
500 °C / 773 K	100 M Ω or greater
800 °C / 1073 K	1 M Ω or greater
1000 °C / 1273 K	100 K Ω or greater

TABLE 2-1 Typical values

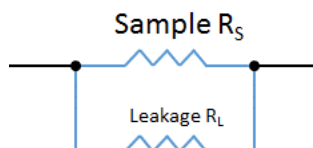


FIGURE 2-11 Leakage current

More specific data can be found in the quality control data provided on the system computer.

The Model 84017 requires the Model 840-VTA option to provide temperature electronics, cabling and sample space gas handling. A Model PS-E2M, Model TPS-FRG, or equivalent is required to maintain vacuum in the oven during operation for thermal insulation (the Model 840-VTA and the Model TPS-FRG can be shared with the Model 84017 oven if both are ordered). A regulated source of argon gas is also required, but not included.

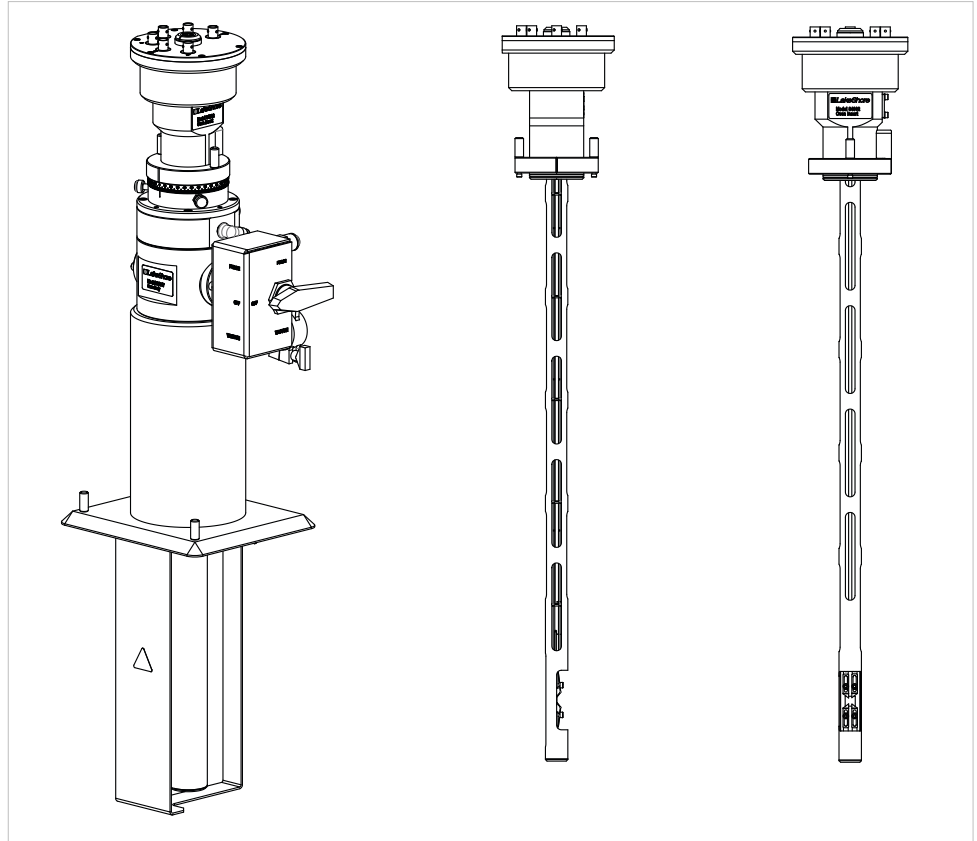


FIGURE 2-12 Left: Model 84017 oven with the oven insert installed; Middle and Right: Oven insert

2.3.1.5 Model 840-VTA: Variable Temperature Control Option

The Model 840-VTA control option provides temperature control functionality. It includes the Model 336 temperature controller, and a rack mount to install the Model 336 into your instrument console. The sample space gas handler portion of the Model 840-VTA controls the gas/vacuum environment at the sample space during a Hall measurement. He or Ar gas supplies are regulated to provide 0.5 psi positive pressure to the sample space, when required. An integrated venturi-type vacuum source also allows for evacuation of the sample space prior to backfilling with the selected gas. The Model 840-VTA option is compatible with the CCR module and the oven module, and it provides all the functionality of the Model 841-STM for the standard insert. FIGURE 2-13 shows an example of the Model 336 with settings for a HMS configuration.



FIGURE 2-13 Model 336: sample space temperature shown under Input C

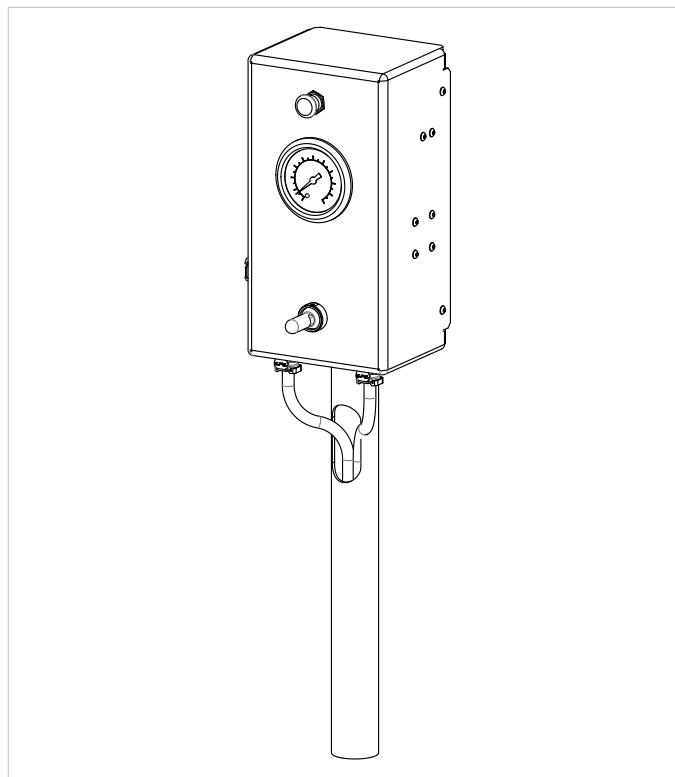


FIGURE 2-14 Sample space gas handler

2.3.1.6 Model 841-STM Sample Temperature Monitor Using Model 336

The Model 841-STM provides a means to monitor the temperature of the sample using the standard insert. This option is not necessary if you have the Model 840-VTA option; however, if there is a possibility you will need to upgrade to the Model 840-VTA option in the future consider this over the Model 842 STM (using the Model 218, section 2.3.2). This option includes the Model 336 temperature controller, rack mount, and associated cable, and it is field installable.

2.3.2 Magnet/Field Options

This section describes and illustrates the magnet options.

2.3.2.1 Model 845-FM DC Field Monitor

The DC field monitor provides real time measurement of the field for ASTM compliance. This option includes the Model 475 with a probe, and electromagnet mounting bracket, rack mount kit for the Model 475, associated cables, and software support. FIGURE 2-15 shows the Model 475.

Magnetic field



FIGURE 2-15 Model 475 gaussmeter

2.3.2.2 Model 84060 Optical Access Magnet Option

The Model 84060 provides a 6.35 mm (1/4 in) diameter optical access through the magnet poles of the Model EM4-CSA electromagnet. Optical pole caps with a 100 mm (4 in) tip diameter and 6.35 mm (1/4 in) optical access holes are also provided. This option is required for compatibility with the Model 84006 room temperature optical access body and the Model 84016-O CCR.

2.3.2.3 Model EM4-4PB High Uniformity Option

The high uniformity option exchanges the standard pole caps to provide a 100 mm (4 in) magnet gap for higher field uniformity. This option is field installable.

2.3.3 Sample Measurement Options

This section describes the sample measurement options.

2.3.3.1 Model 84030 AC Field Hall Measurement

The AC field Hall measurement option provides your system the ability to optimize measurements of samples with very low Hall voltages, which are typical of low mobility samples. The option includes the Ametek 7230 lock-in amplifier, rack mount, associated cables and software support. This option is field installable.

2.3.3.2 Model 84031 High Resistance Measurement

The high resistance measurement option expands the resistance range of the standard system up to 200 G Ω (8 G Ω if you are using the AC field option). The high resistance option comes with the Keithley 6514 and associated cables, rack mount kit and software support. This option is field installable.

2.3.3.3 Model 84033 Low Resistance Measurement

The low resistance measurement option provides optimized low noise measurement for low resistance samples. This option uses the standard Keithley 6220+2182A delta mode that comes with the standard system; additional software support is provided.

2.3.3.4 Model 84032 Gate Bias

The gate bias option provides bias voltage (up to 100 V) for gated Hall measurements, gated IV curves and FET device characterization. This option includes the Keithley 6487, rack mount, associated cables, and software support. This option is field installable.

2.3.3.5 Model 84010 Sample Rotation

The Model 84010 sample rotation adds 0° to 360° rotation to the light tight body and the to the single point LN₂ body. This option only supports the 10 mm sample cards. This option is field installable. FIGURE 2-16 shows the sample rotation stage.

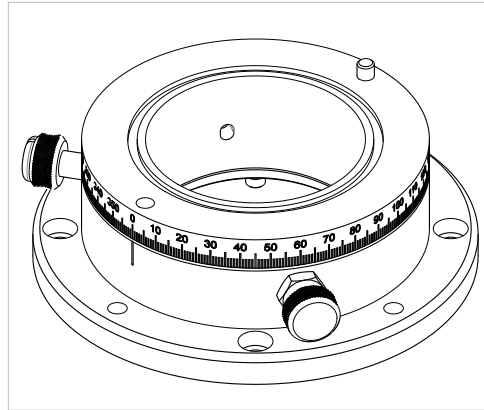


FIGURE 2-16 Sample rotation stage

2.3.3.6 Model 84006 Room Temperature Optical Access Body

The room temperature optical access body includes a single 6.35mm (1/4 in) diameter opening to allow optical access to the top side of the sample. Features are otherwise similar to the standard light tight body, and the two share the standard insert. The body is compatible with room temperature operation, only. The body requires a Model 84060 optical access magnet option, but it operates at the standard 25 mm magnet gap.

2.3.4 Sample Cards and Accessories

This section describes the various sample cards for use with the standard insert. The 10 mm cards are compatible with the single point LN₂ body option and the sample rotation option. The 50 mm cards are compatible with the room temperature light tight enclosure.

2.3.4.1 Model 840930 Sample Mounting Kit with Sample Temperature Sensor

This kit contains five 10 mm solder pad sample cards; one card comes with a platinum temperature sensor. The kit also contains miscellaneous mounting accessories. The Model 840930 should be ordered as a replacement for the sample mounting kit for use with the standard insert.

2.3.4.2 Model EMP-HP-SC-10-S Sample Mounting Kit

The sample mounting kit contains five 10 mm solder pad sample cards and miscellaneous mounting accessories.

2.3.4.3 Model EMP-HP-SC-10-P Prober Pin Sample Card for 10 mm Samples

The prober pin sample card uses prober pin-type mounting for samples up to 10 mm x 10 mm. These are compatible with the standard insert, the Model 840-VTA 841-STM, 84010, 84015 and 84006. The card comes with a platinum temperature sensor.

2.3.4.4 Model 840911 Prober Pin Sample Card for 50 mm Samples

The prober pin sample card uses prober pin-type mounting for samples up to 50 mm x 50 mm. This card is only compatible with the standard sample insert and the Model 840-VTA and 841-STM. The card comes with a platinum temperature sensor.

2.3.5 General Accessories

This section describes miscellaneous options.

2.3.5.1 Model 840950 Floor Mounting Hardware Kit

The floor mounting hardware kit is used to mount the system to the floor and to reduce the amount of unwanted movement of the system after installation. The kit includes hardware for the instrument console and the measurement platform. These must be installed according to local codes by qualified personnel.

2.3.5.2 QMSA® Software Option

In order to use the QMSA results, you may need to purchase additional QMSA® software, available from Lake Shore (part number 750QMSA).

2.3.6 Pumps and Chillers

This section describes the pumps and chillers available for the 8400 Series HMS.

2.3.6.1 Rotary Pump for Oven Option (PS-E2M)

The rotary pump is an oil-filled roughing pump suitable for evacuating the vacuum insulation space of the oven option to provide thermal insulation. The rotary pump includes a mist filter.

2.3.6.2 Compact Turbo Pumping System for the CCR or Oven (TPS-FRG)

The turbo pump is suitable for evacuating the vacuum insulation space of the CCR. The turbo pump option components include the controller, turbo pump, oil free dry scroll backing pump, vacuum gauge, and vent valve. The TPS-FRG will also operate with the oven option. You do not need to buy the rotary pump if you have the turbo pump.

2.3.6.3 Water Chiller for Magnet/Magnet Power Supply (RC-EM7)

A recirculating system can be used to help with water sanitation, flow rate and temperature control. A recirculating system is also helpful if you are concerned with the expense incurred with water usage. The chiller features a CFC-free refrigeration system. The refrigeration system utilizes a hermetically sealed compressor and a hot gas bypass system of temperature control. This system eliminates on/off cycling and premature wear of the compressor. This chiller is sized to operate a Model 8404 without the optional Model 84016 CCR.

2.3.6.4 Water Chiller for Magnet/Magnet Power Supply/CCR Compressor (RC-EM10)

A recirculating system can be used to help with water sanitation, flow rate and temperature control. A recirculating system is also helpful if you are concerned with the expense incurred with water usage. The chiller features a CFC-free refrigeration system. The refrigeration system utilizes a hermetically sealed compressor and a hot gas bypass system of temperature control. This system eliminates on/off cycling and premature wear of the compressor. This chiller is sized to operate a Model 8404. with the optional Model 84016 CCR.

2.4 DC Field Hall Effect Measurements

Mobility is one of the most important and commonly derived electronic transport properties of semiconductor materials. The mobility can often be directly related to the performance of the material in an electronic device. When measured over a range of temperatures, the change in mobility provides insight into the transport mechanism of the material. Measuring the mobility in samples from a material that was produced by different methods yields information to grade material performance as an electronic device and to optimize production methods.

Hall measurement systems use a material's Hall effect to determine Hall mobility. The Hall measurement is also used to determine the associated properties of carrier concentration, resistivity, and carrier type. Use of DC field Hall measurements is well established, and there are established industry standards for carrying out the measurements (section 2.8).

The Model 8404 can provide a full range of Hall measurements on both Hall bar and van der Pauw samples. It can perform full standards-based measurements when necessary, or a smaller subset when desired. The traditional Hall effect may be the only measurement needed when measuring well-behaved semiconductors.

Other methods are used to determine mobility especially when the mobility is low or hard to derive. The Model 8404 offers its unique AC field Hall effect measurement option (section 2.5) to extend the mobility range of the system.

2.4.1 DC Field Hall Nomenclature

This section provides an explanation of the naming conventions and nomenclature used in this manual and in the system software. The units used for the quantities defined here, and conversion between common systems of units can be found in section 2.4.2.

Hall mobility (μ_H) is the ratio of the Hall coefficient (R_H) to the resistivity (ρ):

$$\mu_H = \frac{R_H}{\rho}$$

Hall coefficient (R_H) is the Hall voltage (V_H) times the thickness (t) divided by the current (I) and magnetic field (B).

$$R_H = \frac{t V_H}{I B}$$

Hall voltage is the most critical measurement needed in order to determine the Hall coefficient. Later sections will describe the exact methods used in the Model 8404 to get the best possible measurement of the Hall voltage. The Hall voltage contains other information about the electrical transportation properties of the material. For instance, the sign of the Hall voltage is positive if the carriers in the material are holes, and it is negative if the carriers in the material are electrons.

Hall voltage (V_H) is the ratio of the current (I) and field (B) to the thickness (t), density of free carriers (n) and electronic charge (e) in many materials.

$$V_H = \frac{I B}{t n e}$$

The previous two equations relating the Hall voltage to the carrier density and Hall coefficient to Hall voltage can be used to derive the relationship between the Hall coefficient and carrier density. This result assumes a model using free electron gas or spherical energy bands for the semiconductor:

$$R_H = \frac{1}{n e}$$

The Hall factor (h_f) is the correction term used when this assumption is not realized. With the correction term, the relationship between the Hall coefficient and carrier density should be modified to include the correction term, the Hall factor (h_f):

$$R_H = \frac{h_f}{n e}$$

This same Hall factor is also the ratio of the Hall mobility to the drift mobility. Drift mobility is defined as the carrier velocity per applied electric field.

Although the Hall factor can be calculated, the calculation can be difficult and often only represents an approximation. Absent of any better information, it is reasonable to use a Hall factor of 1. This manual will assume the Hall factor is 1, but the 8400 Series software will allow the user to enter a Hall factor and use the Hall factor to calculate results.

Resistivity (ρ) is used to derive Hall mobility, but it is also an important transport property. Resistivity (ρ) is the shape independent expression of resistance (R) derived by canceling the area (A) through which the current flows, and the length (L) along which the current flows.

$$\rho = \frac{R A}{L}$$

In FIGURE 2-17, the area is the width (w) times the thickness (t), so the equation for resistivity becomes:

$$\rho = \frac{R w t}{L}$$

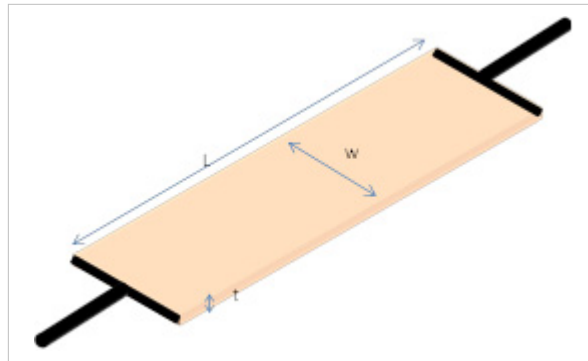


FIGURE 2-17 Resistivity

Following Ohm's Law, resistance (R) is the ratio of voltage (V) to current (I).

$$R = \frac{V}{I}$$

Sheet resistivity (ρ_{sheet}) can be calculated even when the thickness of a sample is unknown at the time of the measurement. If the resistance (R) of the sample is measured, then sheet resistivity is the resistivity divided by thickness.

$$\rho_{sheet} = \frac{R w}{L}$$

The SI units of (ρ_{sheet}) are V/A . It is not $V/\text{square meter}$ or any other length, but simply the resistance of any size square ($w = L$ in the above equation) of the material when the current is flowing uniformly along the length of the sample.

Sheet Hall coefficient ($R_{H\text{sheet}}$) can also be calculated even when the thickness of a sample is unknown at the time of the measurement.

$$R_{H\text{sheet}} = \frac{V_H}{I B}$$

Voltage measurement notation ($V_{ij,kl}$): four lead measurements are used to measure resistance (for resistivity), or Hall voltage. The most common measurement is to apply a current through two leads and measure the voltage difference between the other two leads.

The notation used for a voltage measurement is ($V_{ij,kl}$). This means the current source is connected with positive source on contact i and negative source on contact j. The voltage is measured between positive contact k and negative contact l. An example would be $V_{12,43}$ (FIGURE 2-18). This means when the current source is connected between positive contact 1 and negative contact 2, the voltage difference can be measured between positive contact 4 and negative contact 3. Likewise, the notation used for a resistance measurement is $R_{ij,kl}$. It is defined as $V_{ij,kl}/I$, where I is the current between contacts i and j.

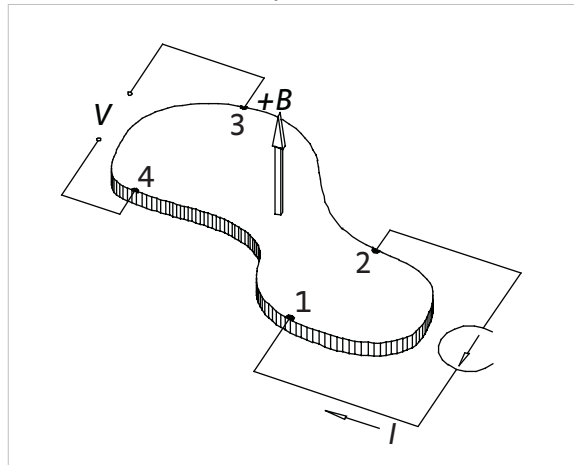


FIGURE 2-18 *Measuring voltage*

2.4.2 DC Field Hall System of Units

Hall measurement and magnetoresistance measurements commonly use two systems of units: the SI system and the laboratory system. The laboratory system is a hybrid system, combining elements of the SI, emu, and esu unit systems. TABLE 2-2 lists the most common quantities, their symbols, and their units in both systems, and the conversion factor between them. The SI units are a unified set of units. The equations in this manual are written with SI units, unless explicitly stated otherwise. This greatly simplifies calculations and extraneous factors in equations.

Quantity	Symbol	SI	=Factor X	Laboratory
Carrier concentration	n, p	m ⁻³	10 ⁻⁶	cm ⁻³
Charge	q, e	C	1	C
Current	I	A	1	A
Hall coefficient	R _H	m ³ /C	10 ⁶	cm ³ /C
Sheet Hall coefficient	R _{Hsheet}	m ² /C	10 ⁴	cm ² /C
Magnetic induction ¹	B	T	10 ⁴	G
Mobility	μ _H	m ² /V·s	10 ⁴	cm ² /V·s
Electric potential ²	v	V	1	V
Resistivity	ρ	·Ω	10 ²	·Ω·cm
Sheet resistivity	ρ _{sheet}	Ω/□	1	Ω/□
Resistance	R	·Ω·	1	·Ω·

To use this table, 1 SI unit = (factor) × 1 laboratory unit. For example, 1T = 10⁴ G

1. Magnetic induction is also called magnetic field

2. Electric potential is also called voltage

TABLE 2-2 Unit systems and conversions

2.4.3 DC Field Hall Measurement Overview

This section provides an overview of DC field Hall voltage and resistivity measurements. Section 2.4.4 describes methods to optimize the Hall voltage measurement, and to approximate the ideal measurement as closely as possible.

2.4.3.1 Hall Voltage

When the combination of a magnetic field and a flowing current in a material produces a new voltage, the Hall voltage, it is called the Hall effect. The Hall effect is illustrated in FIGURE 2-19 and can be explained as a long thin material with a current, I, flowing along the length. The current, I, is the total charge per second and is related to the velocity (V_x) by $I = neV_x w t$, where n is the volume concentration of the carriers in the material and V_x is the velocity of the carriers. If a static (DC) magnetic field is present in the z direction (into the plane of the paper in FIGURE 2-19), then there is a force on the charges given by $-eV_x B$. This force, called the Lorentz force, pushes the carriers along the curved lines in FIGURE 2-19.

Since no current can flow through the boundary, the charges build up on the edges of the material and creates the Hall voltage across the width of the material. When the force from the Hall voltage exactly balances the Lorentz force, no more carriers hit the edge of the material. The force from the Hall voltage is eV_H/w , where w is the width of the sample. Setting this equal to the Lorentz force gives

$$V_H = \frac{I B}{t n e}$$

The Hall voltage can be either positive or negative. If the Hall voltage is positive, the carriers in the material are holes. If the Hall voltage is negative, the carriers are electrons.

The result that the Hall voltage is proportional to the magnetic field is the basis for Hall magnetic field sensors. In our application, we turn this around and use the Hall effect and the known magnetic field to study the properties of the materials.

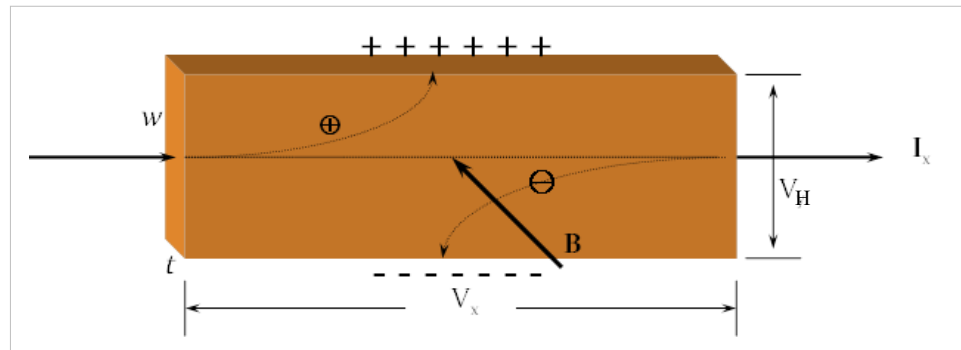


FIGURE 2-19 Hall effect

2.4.3.2 Resistivity

The resistivity of a material does not depend on the size or shape of the sample. It also does not depend on the position of electrical contacts used in the measurement. The fact that resistivity is independent of these properties complicates the measurement. Over the years, many protocols have been developed to meet these requirements, the most common being for van der Pauw (section 2.4.5.3.2).

2.4.4 Hall Measurement Optimization

The measured components of mobility, Hall voltage, and resistance (for resistivity), are captured in much the same way. An excitation current is passed through the sample creating a voltage proportional to the desired quantity. In the case of Hall voltage, magnetic field is also a necessary part of the process. In the ideal case, the desired voltage is large compared to unwanted voltages, measurement errors, and background noise. In reality, this is seldom the case. In many materials the unwanted signals can be as large as, or larger than the desired voltage.

This section identifies several factors that must be considered when optimizing a Hall measurement to separate the desired signals from the unwanted signals. It then references various sections within the manual that explains these factors. Many of the factors involve significant trade offs in sample preparation complexity, equipment cost, and measurement time. This section also highlights many of the features of the Model 8404 to help optimize Hall measurements for a wide variety of samples, along with the dominant error sources that make them necessary.

2.4.4.1 Sample Type and Structure

A simple, square van der Pauw sample structure is the most common structure, and it is adequate for most materials. Section 2.4.5.1 describes how some more complex van der Pauw structures can reduce uncertainty especially when it is difficult to control the exact contact size and location. Similar information for Hall bar samples is given in section 2.4.6.1. The Model 8404 supports two of the most common sample types: van der Pauw and Hall bar. There are significant advantages and disadvantages to each type as described in section 2.4.5.4 and section 2.4.6.4.

2.4.4.2 Contact Type

Contact quality can have a profound impact on measurement uncertainty as described in section 2.10. The Model 8404 supports both fixed (soldered) and optional, movable (probe pin) sample contacts in the standard sample insert. Variable temperature options only offer one: fixed contacts on the CCR, and movable contacts on the oven. Features have been included in the 8400 Series software to evaluate and possibly improve contacts before measurement.

2.4.4.3 Resistance Method

The resistance methods available in the Model 8404 are described in this section. For the best measurement performance, choose a method that matches the sample's contact-to-contact resistance.

The **standard resistance method** is sufficient for routine resistance measurements between 0.5 mΩ and 10 MΩ.

The optional **high resistance method** is preferred when sample resistance is above the standard resistance range, because it can reduce measurement uncertainty in two ways. It adds an electrometer grade buffer in series with the voltage leads to ensure that the measured voltage is not attenuated by the input impedance of the voltmeter. The high resistance method also includes driven guards to the signal leads, and a current meter. This reduces uncertainty caused by current leakage, which is a common problem when very low current is being used to measure high resistance.

The optional **low resistance method** (section 2.7.3.3) is preferred when sample resistance is below the standard resistance range, because it has a lower voltage measurement noise floor. Frequently, when the sample resistance is low, the desired voltage is low. The lower voltage measurement noise floor of the low resistance option allows the Model 8404 to measure samples with resistance as low as 10 μΩ

Lead and contact resistance can be a problem when measuring medium to low resistance samples. All of the measurement protocols associated with Hall measurements use 4-lead measurement techniques to reduce the effect of lead resistance on the desired voltage (section 2.8).

2.4.4.4 Excitation Current

Setting an appropriate excitation current can be a little more complicated than it may first appear. The goal is clear: set a current high enough that the desired voltage is large compared to the unwanted signals. However, setting a current too high can have adverse effects on the measurement, and it can potentially damage the sample. High current can generate enough power to heat the sample. It can also create a voltage that is above the linear region of the sample contacts. Both of these problems can be observed in the results of the ohmic check feature (section 2.10.2).

2.4.4.5 Current Accuracy

Current source accuracy is as important as voltmeter accuracy when making current-dependent measurements such as resistivity or Hall voltage. The Keithley 6220 current source was specifically chosen for the 8400 Series HMS because of its accurate and stable current output. Current source accuracy does not add any significant uncertainty when using the standard resistance method. System wiring and routine sample mounting techniques also contribute little to the overall uncertainty.

More care must be taken when operating with the high resistance option. As current decreases and sample resistance increases, even small errors become significant. Current setting accuracy, current leakage in the cables, and current leakage through contamination such as residual flux on the sample card can impact accuracy and repeatability of measurements.

The Model 84031 high resistance option adds an electrometer grade current meter to help monitor any current errors that may be present in the system during low current measurements. Larger than expected disagreement between the current source and current meter is a strong indicator that there is contamination or another source of leakage in the system. The current meter reading is used for calculations when it is in use.

2.4.4.6 Current Reversal

Hall voltage measurements suffer from all of the unwanted voltages present in typical resistance measurements, in addition to those that arise in the presence of magnetic field (section 2.4.4.9).

Unwanted contributions present in all measurements of this type include thermoelectric voltage, offset voltage and offset current. Thermoelectric voltage (V_{th}) is generated any time there is a thermal gradient across dissimilar metals. It is almost always present in the sample contacts, as well as system wiring and connections. Offset voltage (V_{os}) in the voltmeter is the voltage read on the meter when the inputs are shorted (0V). One other unwanted measurement contribution is offset current (I_{os}) in the current source. This is the current produced when the source is set to zero output. I_{os} creates an unwanted voltage when it passes through the sample's resistance:

$$V_{I_{os}} = I_{os} R_{sample}$$

The desired voltage is proportional to the excitation current magnitude and polarity. The unwanted signals mentioned above are not proportional to current. Current reversal, available in the standard 8400 Series HMS, provides a straight forward method for separating the desired signals from the undesired signals. In some measurements, current reversal can be turned off to shorten measurement time, but it is only recommended for quick screening of samples.

2.4.4.6.1 Nernst Effect Voltage (V_N)

If a temperature gradient exists across the sample, then electrons tend to diffuse from the hot end of the sample to the cold end of the sample. This diffusion current is affected by magnetic field, producing a Hall voltage. The phenomenon is known as the Nernst or Nernst-Ettingshausen effect. The resulting voltage is designated V_N and is proportional to magnetic field, but not to external current.

Since this voltage is independent of current, when a magnetic field is present the voltage is eliminated by current reversal.

2.4.4.6.2 Righi-Leduc Voltage (V_R)

The Nernst (diffusion) electrons also experience an Ettingshausen-type effect since their spread of velocities result in hot and cold sides on the sample; consequently, they set up a transverse thermoelectric voltage, known as the Righi-Leduc voltage, V_R . The Righi-Leduc voltage is also proportional to magnetic field, but not to external current. Since this voltage is independent of current, the voltage is eliminated by current reversal when a magnetic field is present.

2.4.4.7 Field Magnitude

Manual DC field magnitude setting is available in the standard Model 8404. The Hall voltage is proportional to the magnetic field. This would seem to imply that the larger the magnetic field, the larger the Hall voltage, and therefore, the easier the measurement. However, this is not always the case. Some materials show a nonlinear Hall voltage. For example, a magnetic material produces a part of the Hall voltage proportional to the magnetic field and another part of the Hall voltage proportional to the magnetization of the material. There are other instances of nonlinear Hall effect; therefore, it is good practice to measure the Hall voltage using at least two magnetic fields to confirm the linearity of the Hall measurement. If these measurements confirm linearity, then the higher field measurement is typically the better measurement.

2.4.4.8 Field Accuracy

Field accuracy of the standard Model 8404 is sufficient for most applications. Field accuracy is based on system calibration, and it must be re-calibrated each time you change the pole caps or gap. For compliance to ASTM standard F76 the Model 845-FM field monitor option is offered. For the 8400 Series HMS, the system assigns the field value from a calibration table. Calculations are made based on these field values; however, to comply with ASTM field accuracy and measurement requirements, the field monitor option allows you to specifically measure the field, instead of using the field assigned. Particularly at low fields, the field reading can be improved by adding the DC Field monitor option.

2.4.4.9 Field Reversal

Hall voltage is proportional to the magnetic field magnitude and polarity. Some unwanted signals are not proportional to field. This allows a straight forward method for separating the desired signals from those undesired signals—field reversal. DC field reversal is available via the hardware (bipolar power supply) and software in the standard Model 8404. In some measurements, field reversal can be turned off to shorten the measurement time, but it is only recommended when doing quick screening of samples.

The misalignment voltage V_M is the largest of these unwanted voltages. V_M is caused by the misalignment of the contacts. Its magnitude is proportional to the physical asymmetry of the sample contacts, the sample resistance, and the excitation current.

In the ideal case, V_H is expected to be zero when field (B) is zero.

$$V_H = \frac{R_H I B}{t}$$

When misalignment voltage is accounted for in a positive field measurement, the measured voltage (V_+) is:

$$V_+ = V_H + V_M$$

If field is reversed the measured voltage (V_-) is:

$$V_- = -V_H + V_M$$

The desired voltage changes sign, but the unwanted voltage does not change sign. The field reversed voltage VFR is calculated by subtracting the negative field voltage (V_-) from the positive field voltage (V_+) and dividing by 2.

$$V^{FR} = \frac{V_+ - V_-}{2}$$

Several other unwanted voltages depend on the sample temperature, temperature gradients and magnetic field. Many can be eliminated by a combination of current and field reversal, but others cannot. One example that cannot be eliminated in one of these ways is the Ettingshausen effect voltage (section 2.4.4.9.1).

2.4.4.9.1 Ettingshausen Effect Voltage (V_E)

Even if no external transverse temperature gradient exists, the sample can set up its own. The Lorentz force shunts slow (cool) and fast (hot) electrons to the sides in different numbers and causes an internally generated thermoelectric voltage. This phenomenon is known as the **Ettingshausen effect**. V_E is proportional to both current and magnetic field.

This voltage is also present in the final measured voltage. The system measures the sum of the Hall voltage and the Ettingshausen effect voltage. The user must determine if the Ettingshausen voltage is small for their samples.

2.4.4.10 Geometry Averaging

Measurement uncertainty can result if a sample is not homogeneous. By definition, for a homogeneous sample, the voltage $V_{ij,kl}$ that is measured is equal to the voltage $V_{kl,ij}$ measured with the current and voltage leads interchanged. For non-homogeneous samples, the best approximation that can be made is to average these two voltages. In Hall measurements, this is called **geometry averaging**. It can be implemented in both Hall voltage and resistivity measurements. The exact implementation is dependent on the sample structure (section 2.4.4.1). Geometry averaging is available via the hardware (Model 776 matrix) and software in the standard Model 8404. In some measurements, geometry averaging can be turned off to shorten measurement time, but it is only recommended when you are quickly screening samples.

2.4.4.11 Measurement Averaging

Measurement averaging is available via the software in the standard Model 8404. Measurement averaging averages individual measurements used in the derivation of Hall measurement results. It can reduce uncertainty and improve resolution by rejecting environmental noise, system noise, and sample noise. The improvement depends on the signal-to-noise ratio of the measurement configuration, and the number of samples averaged. Averaging more samples requires longer measurement time. AC techniques such as those used in the AC field Hall measurement method and the low resistance method are also effective when signal-to-noise ratios are low.

2.4.5 Van der Pauw Samples

The van der Pauw structure is probably the most popular Hall measurement structure, primarily because it requires fewer geometrical measurements of the sample. In 1958, van der Pauw¹ solved the general problem of the potential in a thin conducting layer of arbitrary shape. His solution allowed resistivity measurements to be made on any sample of uniform thickness, provided that the sample was homogeneous and there were no physical holes in it. All that is needed to calculate sheet resistivity or carrier concentration is four point contacts on the edge of the surface (or four line contacts on the periphery); an additional measurement of sample thickness allows calculation of volume resistivity. These relaxed requirements on sample shape simplify fabrication and measurement in comparison to Hall bar techniques.

1. Van der Pauw, L.J., "A method of measuring specific resistivity and Hall effect of discs of arbitrary shape"; *Philips Res. Reports*, 13, 1-9 (1958).

2.4.5.1 Structures of van der Pauw Samples and Their Errors

The structure of a practical van der Pauw sample is very similar to the ideal structure shown in FIGURE 2-20. Over the years, many variations of the structure have been developed to control and quantify the errors associated with finite contact sizes. We can summarize some of these effects here.

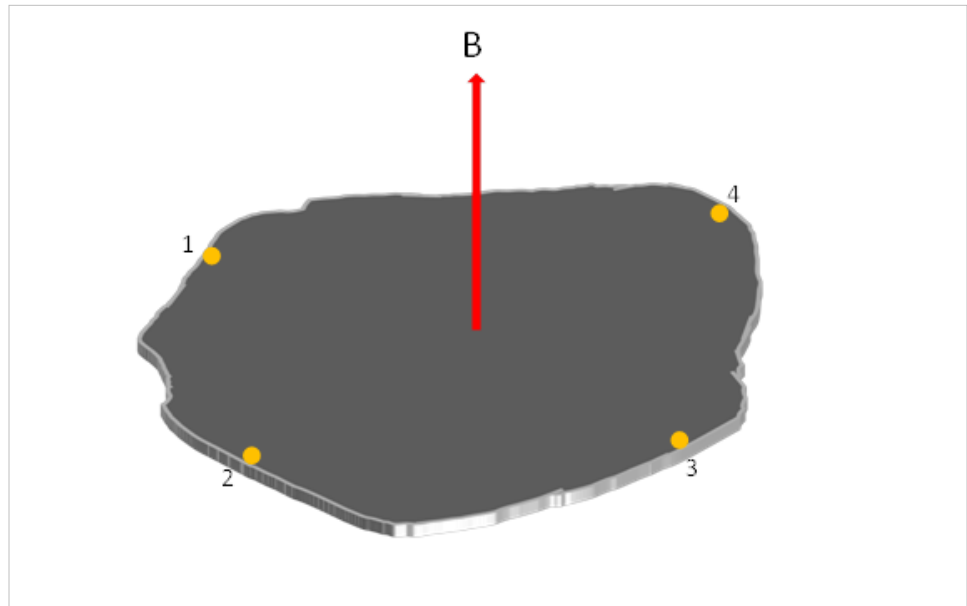


FIGURE 2-20 Four point contacts

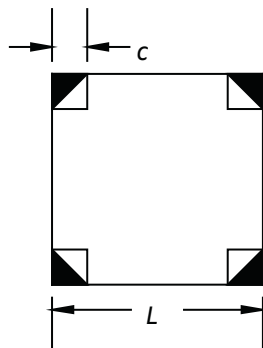


FIGURE 2-21 Square structure

2.4.5.1.1 Square Structures

The resistivity correction factor $\Delta\rho/\rho$ for a square van der Pauw structure (FIGURE 2-21) is roughly proportional to (c/l) for both square and triangular contacts. With $(c/l) = 1/6$, $\Delta\rho/\rho$ is 2% for identical square contacts, and $\Delta\rho/\rho$ is less than 1% for identical triangular contacts².

The correction factor $\Delta V_H/V_H$ is proportional to (c/l) , and is about 15% for triangular contacts when $(c/l) = 1/6$. The correction factor also increases by about 3% at this aspect ratio as the value of μB increases from $\mu B = 0.1$ to $\mu B = 0.5$.

2. Chwang, R., Smith, B.J., and Crowell, C.R., "Contact size effects in transition-metal doped semiconductors with application to Cr-doped GaAs", *J. Phys. C: Solid State Phys.*, 13, 2311-23 (1974).

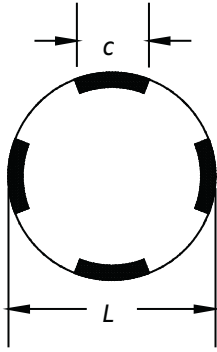


FIGURE 2-22 Circular structure

2.4.5.1.2 Circular Structures

Circular van der Pauw structures (FIGURE 2-22) fare slightly better. Van der Pauw¹ gives a correction factor for circular contacts of

$$\frac{\Delta\rho}{\rho} \cong -\frac{1}{16\ln 2} \left(\frac{c}{l}\right)$$

per contact, which results in a correction of $\Delta\rho/\rho = -1\%$ for $(c/l) = 1/6$ for four contacts. For the Hall voltage, van der Pauw¹ gives the correction

$$\frac{\Delta R_H}{R_H} \cong \frac{2c}{\pi^2 l}$$

per contact. At $(c/l) = 1/6$, this results in a correction of 13% for four contacts.

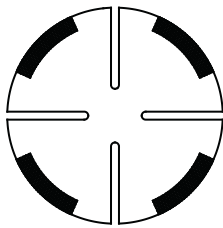


FIGURE 2-23 Cloverleaf structure

2.4.5.1.3 Cloverleaf Structures

Van Daal³ reduced these errors considerably (by a factor of 10 to 20 for resistivity, and 3 to 5 for Hall coefficient) by cutting slots to turn the sample into a cloverleaf (FIGURE 2-23). The cloverleaf structure is mechanically weaker than the square and round samples unless it is patterned as a thin film on a thicker substrate. Another disadvantage is that the active area of the cloverleaf is much smaller than the actual sample.

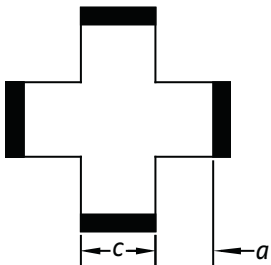


FIGURE 2-24 Greek cross

2.4.5.1.4 Greek Cross Structures

One of the best van der Pauw geometries to minimize finite contact errors is the Greek cross (FIGURE 2-24). Its advantage over simpler van der Pauw structures is similar to placing Hall bar contacts at the ends of arms. David and Beuhler⁴ analyzed this structure numerically. They found that the deviation of the actual resistivity ρ from the measured value ρ_m complied with this equation:

$$E = 1 - \frac{\rho}{\rho_m} = (0.59 \pm 0.006 \exp[-(6.23 \pm 0.02) \frac{a}{c}])$$

This is a very small error: for $c/(c+2a) = 1/6$, where $c+2a$ corresponds to the total dimension of the contact arm, the error is about 10^{-7} .

Hall coefficient results are substantially better. De Mey⁵ has shown that

$$\frac{\mu_H - \mu_{Hm}}{\mu_H} = \frac{\Delta\mu_H}{\mu_H} \cong 1.045e^{-\pi a/c}$$

where μ_H and μ_{Hm} are the actual and measured Hall mobilities, respectively, for $c/(c+2a) = 1/6$, this results in $\Delta\mu_H/\mu_H$ and the error is 0.04%.

3. van Daal, H.J., "Mobility of charge carriers in silicon carbide," Phillips research reports, Suppl. 3, 1-92 (1965).
4. David, J.M. and Buehler, M.G., "A numerical analysis of various cross sheet resistor test structures", Solid State Electron., 20, 539-43 (1977)
5. De Mey, G. "Influence of sample geometry on Hall mobility measurements," Arch. Electron. Uebertragungstechn., 27, 309-13 (1973).

2.4.5.2 Ideal Measurements of Samples with van der Pauw Structure

This section presents the theory of Hall measurements and resistivity measurements on ideal van der Pauw samples. Ideal measurements means perfect 2D uniform samples with four point contacts on the edges, as shown in FIGURE 2-20. The contacts are numbered in the counterclockwise direction. The voltmeter and current source used are assumed to be perfect. In section 2.4.5.3 these restrictions will be relaxed and the measurement in real materials with real instruments will be described.

2.4.5.2.1 Hall Voltage Measurements on van der Pauw Samples

In the ideal van der Pauw structure, to measure Hall voltage, connect the current source across one diagonal and measure the voltage between the other diagonal contacts. $V_H = V_{31,42} = V_{42,13}$

2.4.5.2.2 Resistivity Measurements on van der Pauw Samples

The main result of the van der Pauw method is that the resistivity of the sample can be calculated from two resistance measurements using this equation:

$$\rho = \frac{\pi t F (R_{12,43} + R_{23,14})}{\ln 2}$$

The quantity F is a transcendental function of the two measured resistances ($R_{12,43}$ and $R_{23,14}$). Let R_r be the greater of the ratios $R_{12,43}/R_{23,14}$ and $R_{23,14}/R_{12,43}$. The quantity F can be found by

$$\frac{R_r - 1}{R_r + 1} = \frac{F}{\ln(2)} \cosh^{-1} \left\{ \frac{\exp[\ln(2)/F]}{2} \right\}$$

In this equation, $F=1$ when $R_r=1$, which occurs with symmetrical samples like circles or squares when the contacts are equally spaced and symmetrical. The best measurement accuracy is also obtained when $R_r=1$. The 8400 Series software automatically calculates F and reports the value as the F factor.

2.4.5.3 Calculations for van der Pauw Samples

Section 2.4.5.3.1 and section 2.4.5.3.2 describe the Hall voltage and resistivity calculations for van der Pauw Samples.

2.4.5.3.1 Hall Voltage Calculations for van der Pauw Samples

The Hall voltage is calculated from the current reversed (section 2.4.4.6), field reversed (section 2.4.4.9), geometry averaged (section 2.4.4.10) voltage. The two geometries used in the average are the current reversed, field reversed voltage between contact 4 and 2 with the current applied between contacts 1 and 3 and the field reversed voltage between contacts 1 and 3 with the current applied between contact 4 and 2:

$$V_H = \frac{V_{31,42}^{FR} + V_{42,13}^{FR}}{2}$$

This measurement requires six individual measurements of applying a current and measuring the voltage.

2.4.5.3.2 Resistivity Calculations for van der Pauw Samples

In section 2.4.5.2.2 the resistivity of an ideal van der Pauw structure was defined as

$$\rho = \frac{\pi t F (R_{12,43} + R_{23,14})}{\ln 2}$$

This section will develop the practical protocols for measurement of the resistivity of real samples at zero magnetic field.

As explained in section 2.4.4.6, using current reversal will minimize errors associated with instrumentation offsets and thermoelectric voltages. When the current reversal method is applied to the resistivity measurement, the resistivity is calculated by

$$\rho = \frac{\pi t F (R_{12,43}^{CR} + R_{23,14}^{CR})}{\ln 2}$$

As explained in section 2.4.4.10, geometry averaging is used to reduce material inhomogeneous effects in the measurement. The Model 8404 measures the resistivity in both configurations and averages the result. The first measurement is

$$\rho_A = \frac{\pi t F (R_{12,43}^{CR} + R_{23,14}^{CR})}{\ln 2}$$

The second measurement is

$$\rho_B = \frac{\pi t F (R_{34,21}^{CR} + R_{41,23}^{CR})}{\ln 2}$$

The best estimate of the resistivity then, is

$$\rho = \frac{\rho_A + \rho_B}{2}$$

This resistivity is called the geometry averaged resistivity, or simply the resistivity.

2.4.5.4 Advantages and Disadvantages of van der Pauw Structures

The advantages of van der Pauw samples include:

- Only four contacts are required
- There is no need to measure sample widths or distances between contacts
- Simple geometries can be used

The disadvantages of van der Pauw samples include:

- Measurements take about twice as long as Hall bar
- Errors due to contact size and placement can be significant when using simple geometry

2.4.6 Hall Bar Samples

This section describes Hall bar structure. This structure is designed to approximate one dimensional current flow in a three dimensional sample. The calculation of the resistivity and Hall coefficient depend on the assumption of one dimensional flow. Unlike the van der Pauw structure, additional physical parameters are required for the calculations. Hall bar samples require fewer measurements than the van der Pauw to calculate the resistivity and Hall coefficient.

2.4.6.1 Structures of Hall Bar Samples

The Model 8404 system supports two different Hall bar structures. These will be referred to as 1-2-2-1 (FIGURE 2-25) and 1-3-3-1 (FIGURE 2-26).

An ideal six-contact 1-2-2-1 Hall bar structure (FIGURE 2-25) is symmetrical. Contact separations *a* and *b* on either side of the sample are equal, with contacts located opposite one another. Contact pairs are placed symmetrically about the midpoint of the sample's long axis. This structure allows two equivalent measurement sets to check for sample homogeneity in both resistivity and Hall coefficient. However, the

close location of the Hall voltage contacts to the sample ends may cause the end contacts to short out the Hall voltage, leading to an underestimate of the actual Hall coefficient. While the 1-2-2-1 Hall bar structure is included in the American Society of Testing and Materials (ASTM) Standard F76, the contact numbering given here differs from the standard.

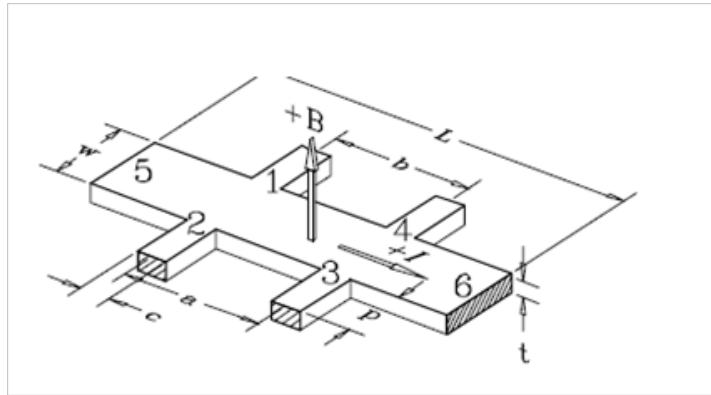


FIGURE 2-25 1-2-2-1 Hall bar structure

The eight contact 1-3-3-1 Hall bar geometry is ideally the most symmetrical of the Hall bars. Two sets of three equally-spaced contacts lie directly opposite one another on either side of the sample with center contacts (numbers 2 and 4) located at the exact center of the sample's length. Voltage measurement connections are made to contacts 1 through 4, while current flows from contact 5 to contact 6. Only six of the eight contacts are used in this measuring procedure. The remaining two (unnumbered) contacts are included to keep the sample completely symmetrical.

The eight-contact Hall bar attempts to combine the homogeneity checks possible with the 1-2-2-1 six-contact geometry and the benefit of measuring the Hall voltage in the center of the sample. It allows two resistivity measurements compare for homogeneity, but only one Hall voltage measurement. The 1-2-2-1 six-contact measurements can be made using an eight-contact Hall bar, simply by moving the electrical connections to the appropriate points. The eight-contact Hall bar geometry is included in ASTM Standard F76, but the contact numbering given here differs from the standard..

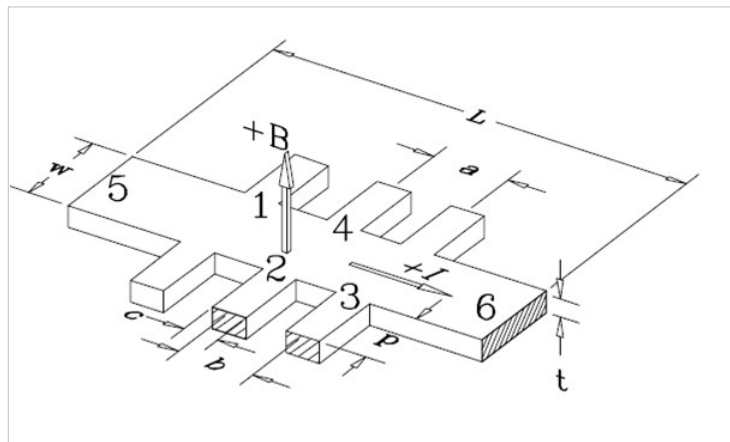


FIGURE 2-26 1-3-3-1 Hall bar structure

Geometrical error sources in the Hall bar arrangement are caused by deviations of the actual measurement geometry from the ideal of a rectangular solid with constant current density and point-like voltage contacts.

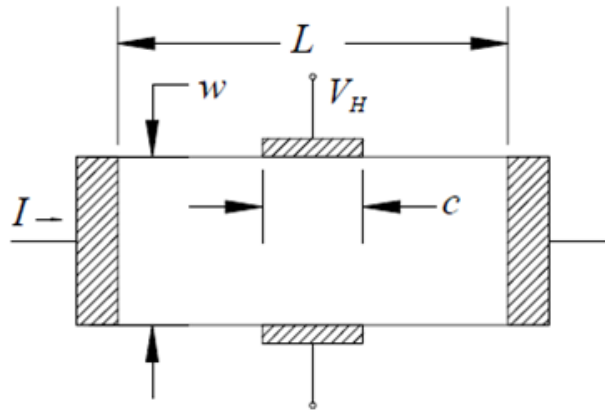


FIGURE 2-27 Hall bar with finite voltage contacts

The first geometrical consideration with the Hall bar is the tendency of the end contacts to short out the Hall voltage. If the aspect ratio of sample length to width $L/w = 3$, then this error is less than 1%⁶. Therefore, it is important $L/w \geq 3$.

The finite size of the contacts affects both the current density and electric potential in their vicinity, and may lead to fairly large errors. The errors are larger for a simple rectangular Hall bar than for one in which the contacts are placed at the end of arms.

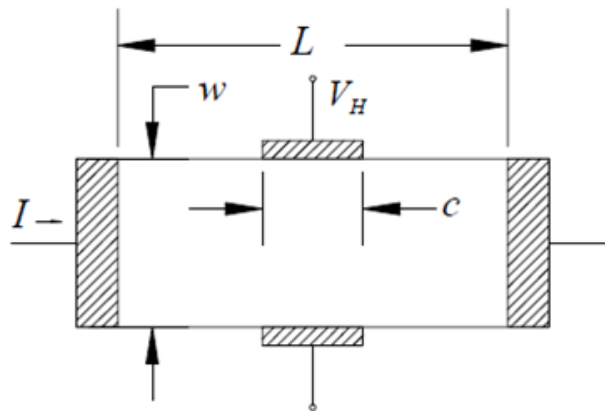


FIGURE 2-28

For a simple rectangle, FIGURE 2-28, the error in the Hall mobility can be approximated (when $\mu B \ll 1$) by⁷

$$\frac{\Delta\mu_H}{\mu_H} = e^{-\frac{\pi I}{2w}} \left(1 - \frac{2c}{\pi w}\right)$$

6. Chwang, R., Smith, B.J. and Crowell, C.R., "Contact size effects on the van der Pauw method for resistivity and Hall coefficient measurement", *Solid-State Electron.* 17 (Dec. 1974) 1217-1227.

7. Perloff, D.S., "Four-point probe sheet resistance correction factors for thin rectangular samples". *Solid-State Electron.* 20 (Aug 1977) 681-687.

$$\frac{\Delta\mu_H}{\mu_H}$$

Here, $\frac{\Delta\mu_H}{\mu_H}$ is the amount μ_H must increase to obtain a true value. If $l/w = 3$, and

$$\frac{\Delta\mu_H}{\mu_H} = 0.13$$

$c/w = 0.2$, then $\frac{\Delta\mu_H}{\mu_H}$, which is certainly a significant error.

Reduce the contact-size error to acceptable levels by placing contacts at the ends of contact arms (FIGURE 2-29)⁸. The following aspect ratios yield small deviations from the ideal: $p \approx c$, $c \leq w/3$, $l \geq 4w$.

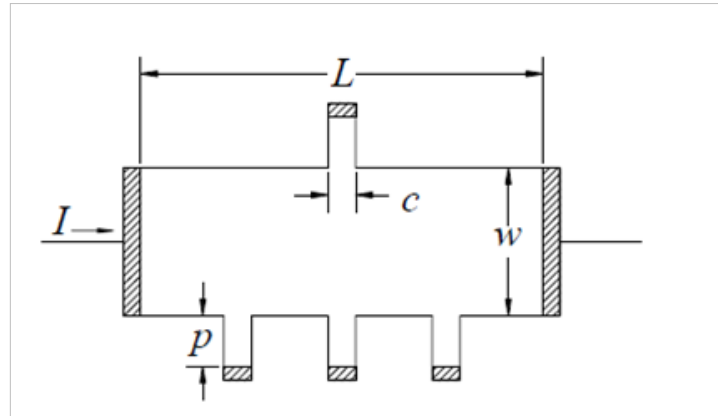


FIGURE 2-29 Contacts at the end of the contact arms

2.4.6.2 Ideal Measurements of Samples with Hall Bar Structure

A typical Hall bar is shown in FIGURE 2-25. In a Hall bar, the current source is always connected to contacts 5 and 6. The voltage can be measured between any of the four contacts on the sides of the Hall bar.

2.4.6.2.1 Hall Voltage Measurements on Hall Bar Samples

In the ideal Hall bar structure, the Hall voltage is the voltage between contacts 3 and 4 or contacts 2 and 1.

$$V_H = V_{56,34} = V_{56,21}$$

2.4.6.2.2 Resistivity Measurements on Hall Bar Samples

The resistivity can be calculated from

$$\rho = V_{56,23} \frac{wt}{a}$$

8. David, J.M. and Buehler, M.G., "A numerical analysis of various cross sheet resistor test structures", *Solid-State Electron.* 20 (Aug 1977) 539-543.

Where w is the width of the Hall bar, t is the thickness of the Hall bar and a is the center-to-center distance between contacts 2 and 3.

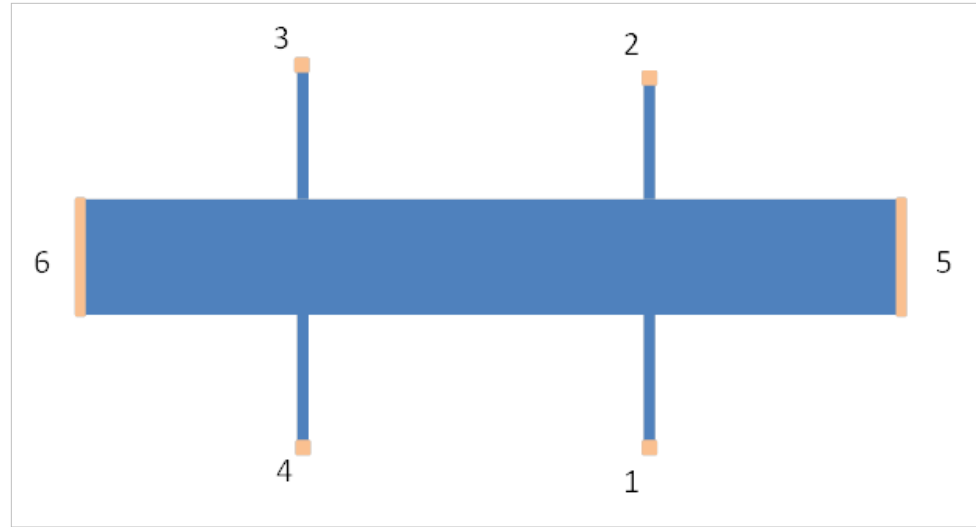


FIGURE 2-30

Notice that this method requires knowledge of two additional dimensions of the sample: the width of the sample and the distance between the two contacts.

2.4.6.3 Calculations for Hall Bar Samples

In this section we will provide the details of the Hall bar measurements sequence and calculations. With the Hall bar geometry, current reversal and geometry averaging are implemented in a different manner than in the van der Pauw method. Field reversal is implemented in the same manner in both Hall bar and van der Pauw samples.

2.4.6.3.1 Hall Voltage Calculations for Hall Bar Samples

In the Hall bar structure, the method to measure the Hall voltage is to connect the current source across contacts 5 and 6 and measure the voltage between two voltage arms directly across from each other.

- **Current reversal:** as explained in section 2.9 using current reversal will minimize the errors associated with instrumentation offsets and thermoelectric voltages. For Hall bar geometries, the current is only applied to contacts 5 and 6 so current reversal means interchanging contact 5 and 6.
- **Field reversal:** as explained in section 2.4.4, measuring the Hall voltage, and plus and minus fields, and subtracting the results removes many errors due to material properties and contact placement.
- **Geometry averaging:** in section 2.4.4., geometry averaging was defined as the average of two measurements by interchanging the current source and voltmeter. Since in the Hall bar measurement, the current source is always on contacts 5 and 6, this definition of geometry averaging does not apply.
 - For the Hall bar 1-2-2-1 geometry, averaging for the Hall voltage is defined as the average of the voltage measured across contacts 1 and 2, and the voltage measured across contacts 3 and 4. This average removes some of the effects of any non-homogeneity in the sample.
 - For the Hall bar 1-3-3-1 geometry, averaging is not defined and this step is skipped.
 - For Hall bar sample 1-2-2-1, the Hall voltage is

$$V_H = \frac{V_{56,21}^{FR} + V_{56,34}^{FR}}{2}$$

- For Hall bar sample 1-3-3-1, the Hall voltage is

$$V_H = V_{56,21}^{FR}$$

2.4.6.3.2 Resistivity Calculations for Hall Bar Samples

In the Hall bar structure, the method to measure resistivity is to measure specific voltages on the sample. The measurement points are a known distance apart. From the voltage, current and distance, the resistivity can be calculated.

- *Current reversal*: as explained in section 2.4.3.3.1.1 using current reversal will minimize errors associated with instrumentation offsets and thermoelectric voltages. For the Hall bar structure, the current is only applied to contacts 5 and 6 so current reversal means interchanging contact 5 and 6.
- *Geometry averaging*: in section 2.4.4.2.1.3, geometry averaging was defined as the average of two measurements by interchanging the current source and voltmeter. Since in the Hall bar measurement, the current source is always on contacts 5 and 6, this definition of geometry averaging does not apply.

- For the Hall bar 1-2-2-1 geometry averaging for the resistivity is defined as the average of the voltage measured across contacts 2 and 3 and the voltage measured across contacts 1 and 4. This average removes some of the effects of any non-homogeneity in the sample.

- For Hall bar sample 1-2-2-1

$$\rho = \frac{\frac{w}{a} R_{56,23}^{CR} + \frac{w}{b} R_{56,14}^{CR}}{2}$$

- For Hall bar sample 1-3-3-1

$$\rho = \frac{w}{b} R_{56,12}^{CR}$$

2.4.6.4 Advantages and Disadvantages of Hall Bar Structure

One of the advantages of the Hall bar structure is that fewer measurements are required. The ideal model is simple to understand. Also, offset voltages for the Hall voltage can be smaller in the Hall bar structure than it is for the van der Pauw structure.

Disadvantages of Hall bar structures include a minimum of six contacts to make mobility measurements. Also, the accuracy of resistivity measurements is sensitive to the structure of the sample. Hall bar width and the distance between the side contacts can be especially difficult to measure accurately. Creating such patterns can be difficult and can result in fragile samples.

2.5 AC Field Hall Effect Measurement

The AC field Hall effect measurement option complements the standard Model 8404 by extending the low end of the mobility range. The AC field Hall measurement method is effective on low mobility materials that are extremely difficult or practically impossible to measure with DC methods.

Materials with low mobility are particularly challenging to measure with traditional DC field Hall effect measurements primarily because of the diminishingly small Hall voltage (V_H). As V_H gets smaller it becomes more and more difficult to distinguish it from background noise, especially in the presence of relatively large misalignment voltages (V_M). When mobility is lower than approximately $1 \text{ cm}^2/\text{Vs}$, the optimization techniques described in section 2.4.4 cease to be effective. The problem can become so bad that the sign of V_H , and therefore, the sign of the carrier, can be reversed.

The AC field method is used for measuring Hall voltage only and not resistivity. It is compatible with van der Pauw and Hall bar sample structures and all temperature options. It is compatible with the standard and high resistance methods, but not the low resistance method.

2.5.1 AC Field Hall Measurement Overview

In the ideal case, AC and DC field Hall voltage measurements are very similar. Therefore, the nomenclature and system of units described in section 2.4.1 and 2.4.2 are applicable to both. In practice, the system configuration is different. The primary difference is the presence of a lock-in amplifier in the AC field option. Modern, digital lock-in amplifiers are the perfect tool for extracting the small Hall voltage from its background. A model of this extraction is shown in FIGURE 2-31.

The DC current source provides the measurement current through the current leads of the sample. The lock-in amplifier's oscillator output drives the power supply for the magnet that generates a sinusoidal, AC magnetic field at the desired frequency. The changing field generates an AC voltage across the samples voltage leads which is filtered by the Model 776 and directed back to the lock-in amplifier. The lock-in amplifier then measures the amplitude and phase of the filtered AC voltage. Synchronous detection in the lock-in amplifier allows it to discriminate the desired Hall voltage, which is at the same frequency as the lock-in amplifier's oscillator output frequency and has a known phase.

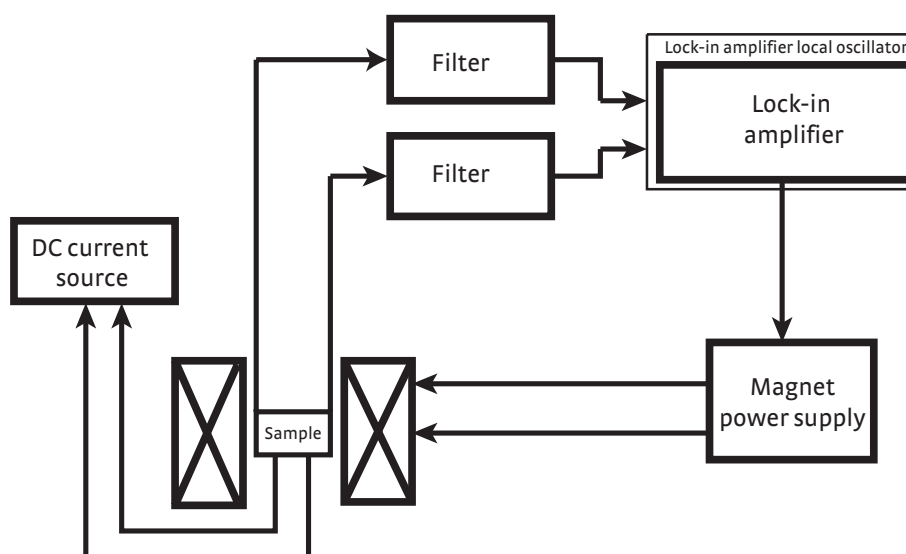


FIGURE 2-31 Hall voltage extraction process for the lock-in amplifier

2.5.2 AC Field Hall Measurement Optimization

Any AC measurement can seem difficult to anyone unfamiliar with the basic principles, and AC Hall voltage measurements are no different. A simple understanding of some of the fundamental trade offs will quickly lead to better optimization of the system. This section identifies several factors that must be considered when optimizing AC field Hall voltage measurements.

2.5.2.1 Similarity Between AC and DC Field Hall Voltage Measurements

Much of the information included in section 2.4.4 on optimizing DC field Hall voltage measurements is valid for AC Field. The resistivity portion of the Hall measurement and contact pre-testing, such as the ohmic check, are exactly the same because they do not include field. These sub-sections of section 2.4.4 are applicable to both: sample type and structure (2.4.4.1), contact type (2.4.4.2), resistance method (2.4.4.3), excitation current (2.4.4.4), current accuracy (2.4.4.5), and geometry averaging (2.4.4.10). The following sections contain discussions about characteristics of AC field measurements that are new or different.

2.5.2.2 Current Reversal

Current reversal is a valid technique for reducing measurement uncertainty in both AC and DC measurement, but for different reasons. Current reversal reduces the uncertainty caused by DC offset voltages in the DC method, but it is not necessary with the AC technique, because these offset voltages are naturally eliminated.

However, current reversal is necessary with the AC technique because it helps eliminate uncertainty from phase calibration that is only present in the AC method. Even in a properly calibrated system, there is some error in the lock-in amplifier phase. This can create a meaningful measurement error when the Hall voltage is small compared to the induced voltage in the leads. Therefore, current reversal is always enabled for AC field measurement.

2.5.2.3 Field Magnitude

When using the AC technique as compared to the DC technique, field magnitude has similar considerations for linear samples, but the AC technique is not effective for differentiating the non-linear response of materials. Therefore, the system is set at Lake Shore to always provide the maximum field amplitude available.

2.5.2.4 Field Accuracy

When using the AC technique as compared to the DC technique, field accuracy has similar considerations, but the calibration technique is different. Calibration of the AC field has no impact on the DC field behavior and vice versa. Both should be recalibrated periodically or any time the magnet pole cap or air gap is changed.

2.5.2.5 Field Reversal

Field reversal is an integral part of the AC technique which naturally rejects misalignment voltage V_M (section 2.4.4.9). The ability to distinguish the correct magnitude of the Hall voltage in the presence of a much larger misalignment voltage is one of the key advantages of the AC technique.

2.5.2.6 Field Frequency

Amplitude of the Hall voltage is not dependent on frequency for most materials, so frequency limitations usually come from other sources. The dominant one for many electromagnet systems is the response time of the electromagnet and power supply combination. The eddy currents generated in the magnet's core resists fast changes in field, creating a non-linear response at higher frequencies. The large inductance of the magnet also makes it difficult for the power supply to change current quickly. These factors significantly limit the frequency of all but very small or specially designed electromagnets to approximately 100 mHz to 1 Hz. The AC voltage filtering in the Model 776 is designed to be compatible with these low frequencies, and by necessity it has a long settling time.

The Model 8404 offers frequency choices based on the magnet and power supply configured with the system. The default frequency is 100 mHz (10 s per cycle) which is appropriate for most measurements. Lower frequency settings should be used if the sample material has a long settling time in response to changes in field. Faster settings can be used, if available, to improve signal-to-noise because more cycles will be completed in a given measurement interval.

2.5.2.7 Lock-In Amplifier Settings

The lock-in amplifier requires more setup than the DC voltmeter. The following settings are needed to get optimal readings.

Response: the response setting configures the lock-in amplifier's filters.

- *Medium*: the medium setting is appropriate for most applications.
- *Slow*: the slow setting provides improved noise rejection, but it requires a longer settling time. It is recommended for particularly difficult samples that appear noisy at the medium setting.
- *Fast*: the fast setting provides a faster settling time but reduced noise rejection. It is recommended for higher mobility samples or for quick screening of samples.
- *Measurement averaging*: in addition to the response setting, measurement averaging can be used to improve noise rejection (section 2.5.2.8).

Voltage range is a two-part setting that corresponds to the internal sensitivity and gain settings of the lock-in amplifier. These settings work together, and both must be adjusted properly for best performance. The 8400 Series software will not permit lock-in ranges that are not compatible with AC Hall voltage measurements.

Sensitivity is set as a voltage with an available range of 2 μ V to 1 V. The setting should be slightly greater than the voltage expected at the input of the lock-in amplifier. For small signals, it is not unusual for the optimal setting to be an order of magnitude (or more) greater than the voltage reading. This difference reflects noise and other unwanted signals present at the input of the lock-in amplifier that are subsequently rejected. The difference is smaller for larger signals. If sensitivity is set too low, an INPUT overload indicator will appear in the monitor pane, and measurement values should not be trusted. If it is too high, some measurement resolution may be lost.

Gain is set in dB with an available range of 0 dB to 72 dB. TABLE 2-3 illustrates the possible sensitivity and gain combinations of the lock-in amplifier. The combinations in black are not permitted by the software. Suggested gain settings are illustrated in TABLE 2-3 with check marks. It may be necessary to reduce the gain below the nominal setting when working with noisy samples or in a noisy environment. If the gain setting is too high, an OUTPUT overload indicator will appear in the monitor pane and measurement values should not be trusted. If it is too low, some measurement resolution may be lost.

Sensitivity	Gain (dB)															
	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90
1 V	✓															
500 mV		✓														
200 mV			✓													
100 mV				✓												
50 mV					✓											
20 mV						✓										
10 mV							✓									
5 mV								✓								
2 mV									✓							
1 mV									✓							
500 µV									✓							
200 µV									✓							
100 µV									✓							
50 µV									✓							
20 µV									✓							
10 µV									✓							
5 µV									✓							
2 µV									✓							
1 µV																
500 nV																
200 nV																
100 nV																
50 nV																
20 nV																
10 nV																
5 nV																
2 nV																

Checkmarks: suggested gain settings

White cells: possible sensitivity and gain settings

Black cells: these combinations are not permitted by the software

TABLE 2-3 Sensitivity and gain settings

2.5.2.8 Measurement Averaging

Measurement averaging can reduce uncertainty and improve resolution by rejecting noise. The purpose is the same as with DC field, but the implementation is different with AC field. In AC measurements, meaningful averaging intervals are closely related to the excitation period and the measurement setup format is intended to reflect that. Averaging over more than a few periods can create very long measurement sequences.

2.5.2.9 AC Fields and Induced Voltage

One of the trade-offs in using the AC technique is that changing field must be managed in the entire system. Changing field can cause problems by physically moving magnetic components, creating eddy currents in conductive metals and inducing voltage in signal leads. Many of these problems are minimized in the Model 8404 design and should not be a problem if the system is used properly. Induced voltage is the exception and requires more consideration during operation.

Induced voltage V_I is created anywhere signal leads are exposed to changing field where B is the field amplitude, and L is the inductance of the lead wire including the sample.

$$V_I = B L \omega \sin(\omega t)$$

The induced voltage is 90° out of phase with the Hall voltage, so the LIA can reject it from the result. Small errors in phase calibration can be eliminated with current reversal (section 2.5.3).

Lead lengths near the sample (magnet gap) are most susceptible because the field change is greatest but leads further from the magnet gap cannot be ignored because they tend to be longer and have larger inductance. Many problems can be avoided by following these guidelines when making AC field measurements.

- Keep highly conductive and magnetic materials away from the sample holder.
- Use the Model 8404 sample cards designed to minimize inductance.
- Attach short, direct lead wires from the bonding pads on the sample card to the sample.
- Dress the cable bundle with signal leads away from the ends of the magnet poles.
- Leave appropriate space between the electromagnet and instrument console as recommended in the system layout.

2.5.3 Calculations

The AC field Hall method uses similar but slightly different calculations for the Hall voltage. This section will provide the details of the Hall voltage calculation for the AC field Hall method.

2.5.3.1 Hall Voltage Calculations for van der Pauw Samples

Many of the limitations of the DC field Hall method become very visible when measuring low mobility materials. These limitations can be overcome by replacing the DC magnetic field with a low frequency AC magnetic field. In this case, magnetic field can be written as $B \cos(\omega t)$. If we assume a quasistatic approximation then the Hall voltage becomes

$$V_H = \frac{R_H I B}{t} \cos(\omega t)$$

However, we need to include one term beyond the quasistatic approximation. The sample and wiring to the sample has a finite inductance. The inductance will generate a voltage in a time varying field that is proportional to the time derivative of the field. Since the misalignment (V_{ma}) and thermal electric voltages (V_{TE}) are independent of the field, they remain DC voltages. Combining these terms the measured voltage for AC field Hall effect is

$$V_m = \frac{R_H I B}{t} \cos(\omega t) - B L \omega \sin(\omega t) + V_{ma} + V_{TE}$$

Since the misalignment and thermal electric voltages are now DC, they are separated in frequency space from the Hall voltage and the inductive voltage. Using a lock-in amplifier for synchronous phase sensitive detection at the frequency of the field, the measured AC voltage is then

$$V_m = \frac{R_H I B}{t} \cos(\omega t) - B L \omega \sin(\omega t)$$

Notice that the effect of the misalignment voltage and thermal electric voltage are removed by the AC technique. No current reversal was required.

If the lock-in amplifier is properly phased, that is the x channel response, V_x , is the voltage in phase with the field and the y channel response, V_y , is the voltage 90 degrees out of phase with the field, the response of the lock-in will be

$$V_x = \frac{R_H I B_{rms}}{t}$$

$$V_y = -L \omega B_{rms}$$

Often there is a phase error between the magnetic field and the lock-in. In this case the x and y channels will read

$$V_x = \frac{R_H I B_{rms}}{t} \cos(\varphi) - L \omega B_{rms} \sin(\varphi)$$

$$V_y = -\frac{R_H I B_{rms}}{t} \sin(\varphi) - L \omega B_{rms} \cos(\varphi)$$

To remove this phase error, note that the Hall voltage depends on the current (I) but the inductive voltage does not depend on the current. Hence using current reversal on the lock-in voltage allows the calculation of the Hall voltage from

$$V_x^{CR} = \frac{R_H I B_{rms}}{t} \cos(\varphi)$$

$$V_{xy}^{CR} = -\frac{R_H I B_{rms}}{t} \sin(\varphi)$$

Hence current reversal is used in the AC field method to remove phase errors in the system. This is somewhat different from the DC case where current reversal is used to remove the thermoelectric voltage.

Using these voltages as measured by the lock-in, the current reversed Hall voltage is calculated from

$$V_H^{CR} = \sqrt{(V_x^{CR})^2 + (V_y^{CR})^2}$$

The calculations described here are repeated for each of the two geometries of the van der Pauw sample. The first geometry used is the current-reversed voltage between contact 4 and 2 with the current applied between contacts 1 and 3,

$$V_{42,13} = V_H^{CR}$$

The second geometry is the current-reversed voltage between contacts 1 and 3 with the current applied between contacts 4 and 2,

$$V_{13,42} = V_H^{CR}$$

$$V_H = \frac{V_{42,13} + V_{13,42}}{2}$$

2.5.3.2 Determining the Sign of the Voltage

Determining the sign of the Hall voltage is a very important part of the Hall measurement. The sign of the Hall voltage is normally the same as the sign of the carrier type (holes or electrons) in the material. In the DC field method, the Hall voltage is determined by subtracting the positive field voltage from the negative field voltage. If the misalignment voltage is large, the subtraction of two large numbers can return either a positive or negative result depending on the noise and drifts in the system. So a measurement of the Hall effect can yield either p type, or n type material with repeated measurements. In the AC field case, the large misalignment voltage is separated in frequency space from the AC Hall voltage. However, if the Hall voltage is small compared to the noise of the system or the inductive voltage, repeated measurements of the Hall voltage will not always yield the same sign for the Hall voltage. Assume the noise is a normal random variable. The signal to noise ratio is defined as the true Hall voltage divided by the standard deviation of the noise.

A histogram of repeated measurements of the Hall voltage will look like FIGURE 2-32. Here we assume the material is p type. The signal-to-noise ratio is 1.6. The measurements in the red area give the wrong sign of the carrier type. Those in the blue give the correct sign of the Hall voltage. In this case, the probability that a measurement gives the wrong sign of the carrier type is 5%.

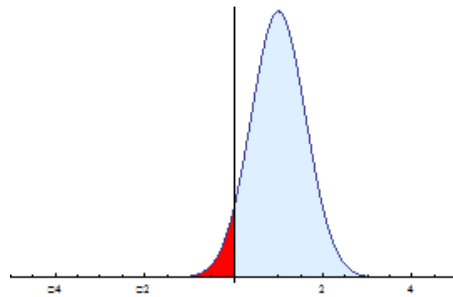


FIGURE 2-32 Histogram of repeated measurements of the Hall voltage

TABLE 2-4 shows the probability of the wrong sign of the Hall voltage versus the signal-to-noise ratios.

Probability of wrong sign	Signal to noise ratio
5%	1.64
1%	2.33
0.5%	2.56
0.1%	3.09
0.01%	3.72

TABLE 2-4 Probability of the wrong sign of the Hall voltage versus the signal-to-noise ratios

2.5.3.3 Resistivity Calculations for van der Pauw Samples

When using AC field Hall method, the resistivity is measured using only DC methods and the calculations are the same as described in section 2.5.3.

2.5.3.4 Hall Voltage Calculations for Hall Bar Samples

In the Hall bar structure, the method to measure the Hall voltage is to connect the current source across contacts 5 and 6 and measure the voltage between two voltage arms directly across from each other.

As explained in section 2.5.2.2 using current reversal in the AC field method will minimize the phase errors.

For the Hall bar 1-2-2-1 geometry, averaging for the Hall voltage is defined as the average of the current reversed voltage measured across contacts 1 and 2, and the current reversed voltage measured across contacts 3 and 4. This average removes some of the effects of any non-homogeneity in the sample.

For Hall bar sample 1-2-2-1, the Hall voltage is calculated as

$$V_H = \frac{V_{56,12} + V_{56,34}}{2}$$

For the Hall bar 1-3-3-1 geometry, averaging is not defined and the Hall voltage is

$$V_H = V_{56,12}$$

2.5.3.5 Resistivity Calculations for Hall Bar Samples

When using AC field Hall method, the resistivity is measured using only DC methods and the calculations are the same as described in section 2.5.3.3.

2.5.4 Advantages and Disadvantages of AC Field Hall Measurements

Advantages of the AC field method are that:

- It can measure low mobility materials that are extremely difficult or practically impossible to measure with DC methods.
- It may be able to measure Hall mobility on bulk or thin film without patterning a device.
- Higher sensitivity can be used to measure samples at lower current or lower field.
- With the DC method, increasing the current increases both the misalignment voltage and the Hall voltage by the same factor. Increasing the current in a DC measurement does not necessarily mean a smaller Hall voltage can be resolved. In the AC method, since the misalignment voltage is separated from the Hall voltage by the lock-in technique, increasing the current increases the Hall voltage and smaller Hall voltages can be resolved.
- The capacitance of the cables affect the AC field Hall voltage in a different manner than the DC field Hall voltage. One of the basic assumptions of the DC field Hall voltage calculations was that no current flows through the voltmeter leads of the measurements. This restriction can be realized by making the input impedance of the voltmeter much larger (1000 times larger) than the resistance of the sample. In the AC field case the Hall voltage is an AC voltage. Current can now flow from the sample through the capacitance (C) of the cables. This current can flow even if the input impedance of the lock-in amplifier is very large. I

The effect of the capacitance is to create a scaling error in the measurement of the Hall voltage. The methods to remove this scaling error included measuring at different frequencies or measuring the capacitance by some other method.

Without some method to correct for this, as the resistance of the sample increases the error will increase. If we assume 20 pF for the value of the capacitance, then a table can be shown with maximum sample resistance versus acceptable error and frequency.

f	0.1% error	1% error
0.2	40	400
0.1	80	800
0.05	400	4000

TABLE 2-5 *Maximum resistance in MΩ vs. frequency*

The disadvantages of the AC field method are that:

- The frequency of the measurement is limited, typically 0.1 Hz or less resulting in a relatively slow measurement.
- AC field methods cannot be used to determine if a sample has parallel conduction.
- The method is not as common, and consequently, it may be difficult to compare results from other systems.
- There is less foundation for interpreting results of very low mobility Hall measurements.

2.6 Expanded Hall Measurements

This section provides information for gated Hall measurements, optical excitation, variable temperature measurements, and variable field measurements.

2.6.1 Gated Hall Measurements

Gates can be used to control the carrier density, and hence the Hall coefficient, in a material. The Model 8404 offers an option to use a voltage source as a gate voltage. This gate voltage is set as an independent variable. The resistivity and Hall measurement can be performed to determine resistivity, mobility and carrier density at the applied gate voltage. Either DC field Hall or AC field Hall can be used with the gate option.

2.6.2 Optical Excitation

The Model 8404 offers an option to apply light to the sample. The optical path to the sample is through the pole pieces of the magnet and the sample module. Hence the light is applied parallel to the magnetic field and perpendicular to the sample. Using optical excitation is useful to study the Hall effect in materials that are photosensitive.

2.6.3 Variable Temperature

Temperature dependent Hall measurements of a material measure the resistivity, carrier density and mobility as a function of temperature. The details of the temperature dependency of these material characteristics are used to understand the electronic transport properties of the material. There are many material properties that can be determined from variable temperature Hall measurements. In this section a few of these properties will be briefly described.

Probably the most powerful extension of simple Hall effect measurements is to use the Hall effect to measure the density of carriers and the mobility of carriers versus temperature. The density of carriers versus temperature can be directly determined by measuring the Hall coefficient versus temperature. This information, coupled with simple models of band structure, can provide information about band gap of the semiconductor, activation energy of donors or acceptors, and doping density values.

The mobility of a carrier is determined by the scattering of the carrier in the material. If the carrier scatters off the lattice of atoms in the material this is called electron phonon scattering, or acoustic phonon scattering. There are many different ways an electron can scatter in a semiconductor. If a carrier scatters ionized impurity in the material, this called ionized impurity scattering. Each of the possible scattering mechanism will have a different temperature dependency. For instance, phonon scattering varies as $T^{-3/2}$. The following table shows some of the scattering mechanisms and the temperature dependency of mobility. Careful analysis of the temperature dependent mobility will determine the major scattering mechanism in the material.

Scattering mechanism	Scattering variance
Acoustic phonon scattering	$\sim T^{-3/2}$
Piezoelectric scattering	$\sim T^{-1/2}$
Alloy scattering	$\sim T^{-1/2}$
Ionized impurity scattering	$\sim T^{3/2}$

TABLE 2-6 *Scattering mechanisms and their temperature dependencies*

Variable temperature carrier density data can be used to determine the activation level and activity of donors in semiconductors. The carrier density measured by the Hall effect is the free carrier density. As the temperature changes, the number of donors, or acceptors, that are active will change. This change will be reflected in the carrier density as measured by the Hall effect.

Both AC and DC field methods may be used with variable temperature Hall measurements.

2.7 Resistance (Trans-impedance) Measurements

Resistance, or more accurately trans-impedance, measurements are one of the fundamental building blocks that define the capabilities and performance specification of the Model 8404. Even if finding the resistance of your sample is not the experimental goal, it is important to understand this section, because the concepts presented here impact Hall voltage, resistivity and many other values.

This section and much of the Model 8404 documentation uses the common term of “resistance measurement” to include the operations discussed below. The term trans-impedance is more correct, because these same operations are used to perform Hall voltage (section 2.4.1) and I/V measurements, which do not reflect the sample’s resistance. We use the term resistance measurement because it is a convenient analogy to describe the behavior and trade-offs of many trans-impedance measurements because the operation is so similar.

2.7.1 Resistance Nomenclature

This section provides an explanation of the naming conventions and nomenclature used in this manual and the system software. These definitions assume that the measurement is a DC measurement.

Electric potential, also called voltage (V), is the energy per charge required to move the electrons through a closed circuit.

Current (I) is the total charge per second passing through a closed circuit. In all materials except superconductors, current cannot flow through a closed circuit without expending energy. Ohm’s law states the energy required per charge (V) is proportional to the current (I). The constant of proportionality is the resistance (R); therefore: Ohm’s law: $V = IR$

Since V is the energy per charge, and the current (I) is the total charge per second, the power (P) (energy/second) is simply $P = IV$. Other ways to write this, using Ohm’s law, are: $P = I^2R = V^2/R$.

2.7.2 System of Units

In resistance measurements, unlike Hall measurements, the system of units is universally SI units.

- Current units are amperes (A); $1\text{ A} = 1\text{ C/s}$
- Electric potential units are volts (V)
- Power units are watts (W); $1\text{ W} = 1\text{ J/s}$
- Resistance units are ohms (Ω); $1\Omega = \text{V/A}$

2.7.3 Resistance Measurement Overview

The most common technique for measuring resistance is to pass a current through the sample with a constant current source and measure the resulting voltage with a digital voltmeter (DVM).

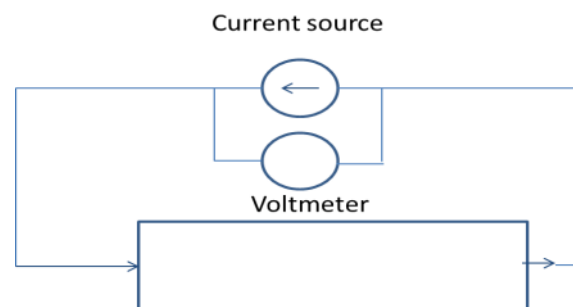


FIGURE 2-33 Typical resistance measurement

The quality of the measurement depends on several factors, but it is typically dominated by the performance of the current source, DVM, and lead configuration. A single set of hardware and measurement techniques can adequately cover many orders of magnitude in resistance. However, when the resistance is too high or too low, measurement uncertainty increases. The Model 8404 offers several different methods that are optimized for different applications with the goal of providing a robust measurement over a very broad range of experimental interest. These methods are described in section 2.7.3.1 through section 2.7.4.

2.7.3.1 Standard Resistance Method

The standard resistance method, included with every Model 8404, is an outstanding general purpose tool that provides relatively fast, accurate, low noise measurements. It relies on the Keithley 6220 Current Source and 2182 nanovoltmeter, which contribute essentially all of the system specifications over a range of 1 Ω to 10 M Ω . The typical voltage at the input of the DVM is in the range of 100 mV to 10 V and provides an excellent signal to noise ratio because of the low noise of the DVM. Measurement optimization (section 2.7.4) should always be considered, but the default settings usually provide a good starting point. Ensuring that the excitation current is appropriate for the sample is usually the biggest concern. A good starting point for the current is to adjust the current until the voltage across the material is about 10 to 20 mV.

2.7.3.2 High Resistance Method

The high resistance option increases the top of the resistance range to approximately 200 G Ω , depending on the sample. Measurement difficulty increases as resistance increases above 10 M Ω . The biggest problem that occurs is that the input impedance of the DVM begins to load the sample and weaken the voltage. To offset this, when the high resistance method is selected, electrometer grade buffers with very high input impedance are switched in series with the voltage leads, minimizing loading.

The second biggest problem is that the current leakage that is present in all resistance measurements becomes a more significant source of uncertainty. Even if the leakage does not increase, it becomes a higher percentage of the very low current required to measure high resistance. To offset this, the Model 8404 drives the guard in the signal leads to minimize the effect of current leakage. The high resistance option also adds a precision current meter to measure the true current passing through the sample for accurate resistance calculations. Another benefit of the option is that the electrometer grade buffers are capable of working to 100 V, allowing more excitation current and higher measured voltage when the sample will tolerate those conditions.

The high resistance method does have trade-offs. The high impedance buffers are noisier than the nanovoltmeter by itself, changing the resolution specification. The signal leads are also more susceptible to environmental noise when measuring high resistance samples. As a result, more averaging may be required to get the desired resolution, lengthening measurement time. Operating at higher voltages can improve signal to noise when applicable. Longer settling time may also be required to allow the current in the leads to settle. Even guarded leads need time to settle to the level necessary for the highest resistances.

2.7.3.3 Low Resistance Method

The low resistance option extends the bottom of the resistance range down to approximately 10 $\mu\Omega$ depending on the sample. Measurement difficulty increases as resistance decreases below 1 Ω .

The biggest problem when using the low resistance method is that the practical voltage across the sample gets smaller. Increasing current to increase sample voltage is not an option for many samples due to sample heating or potential damage. Input noise of the nanovoltmeter and voltage offsets dominate resolution and uncertainty as they become a larger percentage of the measured signal. Current reversal and measurement averaging can combat the effects, but it can take a very long time to get the desired resolution using the standard resistance method.

Alternating current excitation techniques have an advantage in situations like this where the signal to noise ratio is low. When the low resistance method is selected, current reversal, voltage capture, and averaging are synchronized and accelerated to minimize measurement time. Current reversal and some measurement averaging are inherent to the AC technique. Additional averaging can be selected if needed.

The low resistance method is less beneficial at higher resistances where signal to noise is typically higher. It will cause measurement uncertainty at high resistances where the sample resistance and lead capacitance act to resist fast changes in voltage.

2.7.3.4 AC Field Hall Voltage

AC field Hall voltage measurement is a special type of trans-impedance measurement that does not follow the resistance analogy and is not useful for measuring resistance. Refer to section 2.5 for more information.

2.7.4 Resistance Measurement Optimization

Choosing the best measurement method (section 2.7.3) is the first step to making a good resistance measurement, but there are other considerations. This section identifies several factors you will need to consider when optimizing resistance measurements to separate the desired result from unwanted signals.

2.7.4.1 Contact Type and Arrangement

Contact quality can have a profound impact on measurement uncertainty as described in section 2.10. The Model 8404 supports both fixed (soldered) and optional, movable (probe pin) sample contacts in the standard sample insert. Variable temperature options only offer one: fixed contacts on the CCR, and movable contacts on the oven. Features have been included in the 8404 software to evaluate and possibly improve contacts before measurement; these are explained in section 2.10.1, section 2.10.2, and in section 2.10.3.

Standardized measurements such as van der Pauw Hall mobility or MR frequently define the arrangement and location of contacts on the sample, and these guidelines should be followed with other measurements when possible. When making general resistance measurements, rectangular samples are usually preferred. One voltage and one current contact are typically placed at each end of the sample in a 4-lead arrangement. If the contact area is large compared to the sample width, the voltage contacts are typically placed inside the current contacts. See FIGURE 2-34 for a representation of a 4-lead measurement.

2.7.4.2 Four-Lead Measurement Technique

Nearly all default resistance measurements in the Model 8404 use the 4-lead technique. Sometimes the technique is required as part of the measurement protocol (for example, when performing Hall voltage measurements), but often it is chosen simply to cancel the effect of lead resistance from the result. The only exception to using 4-lead is when the quality of the contacts themselves is being evaluated.



For this discussion, lead resistance is assumed to include resistance in connectors and sample contacts.

When making 2-lead measurements, lead resistance is measured along with the sample resistance. The excitation current is passed through the leads and the sample in series, and the nanovoltmeter reads the sum of the voltages. See FIGURE 2-34 left, where $R_{\text{measured}} = V_{\text{measured}}/I$ and $V_{\text{measured}} = I R_{\text{sample}} + 2 I R_{\text{lead}}$. Lead resistance typically dominates measurement uncertainty in 2-lead measurements unless it is several orders of magnitude lower than the sample's resistance. Even then it can cause unnecessary measurement drift, because resistance in the leads and connectors is typically temperature dependent and their temperature is not as well controlled as the sample's temperature.

Four-lead measurement uses separate voltage and current leads from the current source and DVM to the sample. Current passes through the current leads but not the voltage leads. See FIGURE 2-34 right, where $V_{\text{measured}} = I R_{\text{sample}} + 0.2 R_{\text{vlead}}$. The high input impedance of the nanovoltmeter minimizes the amount of current flowing through the voltage leads which minimizes their lead voltage. The position of the voltage leads bypasses the current lead voltage. Contact placement is critical in continuing the four-lead arrangement all the way to the sample.

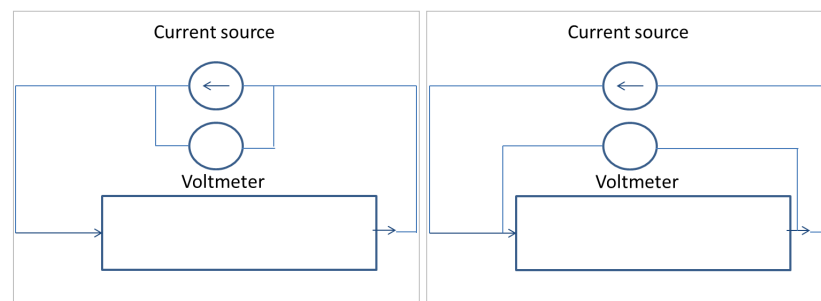


FIGURE 2-34 Typical 2-lead resistance measurement; Right: Typical 4-lead resistance measurement

2.7.4.3 Excitation Current and Power

Manual excitation current setting is available in the standard Model 8404. Setting an appropriate excitation current can be a little more complicated than it may first appear. The goal is clear: set a current high enough that the desired voltage is large compared to the unwanted signals. However, setting a current too high can have adverse effects on the measurement, and it can potentially damage the sample. High current can generate enough power to heat the sample. It can also create a voltage that is above the linear region of the sample contacts. Both of these problems can be observed in the results of the ohmic check feature (section 2.10.2).

2.7.4.4 Current Reversal

The desired voltage is proportional to the excitation current magnitude and polarity. Several unwanted signals are not proportional to current. Current reversal provides a straight forward method for separating the desired signals from the undesired signals. In some measurements, current reversal can be turned off to shorten measurement time, but it is only recommended for quick screening of samples.

In addition to the desired voltage, the voltmeter will measure additional voltages. These voltages can be removed by using current reversal. Here is a listing of the most common source of the undesirable voltages:

Thermoelectric voltage (V_{te}) is generated any time there is a thermal gradient across dissimilar metals. This is prevalent in sample leads and in other connections throughout the system wiring. The size of V_{te} is proportional to the temperature gradient and the difference in work functions of the metals in contact. V_{te} can be a significant source of uncertainty when the measured voltage is under 1 V.

Offset voltage in the volt meter (V_{os}) is the voltage read on the meter when the inputs are shorted (0V). V_{os} is typically smaller than V_{th} and is only a significant source of measurement uncertainty when measuring at voltages less than 100 mV such as when measuring very low resistance. Current reversal is an integral part of the low resistance measurement method.

Offset current in the current source (I_{os}) is the current produced when the source is set to zero output. I_{os} creates an unwanted voltage when it passes through the sample's resistance, $V_{Ios} = I_{os} R_{sample}$. I_{os} can cause significant uncertainty when the excitation current is less than 10 nA; for instance, when measuring very high resistances. When using the high resistance method, current meter offset, which is smaller than I_{os} , replaces I_{os} uncertainty. However, it, too, can be eliminated by current reversal.

Implementation of current reversal is relatively simple.

A positive current is applied to the sample to produce a positive measured voltage:

$$V_+ = I R_{sample} + V_{ts} + V_{os} + V_{Ios}$$

Then a negative current is applied to the sample to produce a negative measured voltage:

$$V_- = -I R_{sample} + V_{ts} + V_{os} + V_{Ios}$$

The desired voltage changes sign, but the unwanted voltages do not. The current reversed voltage (V_{cr}) is calculated by subtracting the negative voltage from the positive voltage and dividing by two: $V_{cr} = (V_+ - V_-)/2$.

2.8 Comparison to ASTM Measurement

To begin, the ASTM contact numbering schemes for the van der Pauw and Hall bar geometries are incompatible with one another. To allow either sample type to be mounted using the same set of contacts, Lake Shore's numbering scheme for Hall bar samples differs from the ASTM scheme.

The ASTM standard F76 is inconsistent with the “handedness” of the van der Pauw contact numbering order with respect to the applied magnetic field. Lake Shore numbered the contacts counterclockwise in ascending order when the sample is viewed from above, with the magnetic field perpendicular to the sample and pointing toward the observer.

Finally, ASTM assumes that the direction of the excitation current is to be changed by physically reversing the current connections. This technique is not well suited to high-resistance samples using a programmable current source like the Keithley Model 6220. This current source (and others like it) has a guarded “high” current output, and an unguarded “low” current return. For proper current source operation, the “high” output lead should be farther from common ground than the “low” return lead, a condition violated half of the time when physically reversing the high and low current leads to the sample. When this condition is violated, leakage current can flow through the voltmeter, leading to possibly serious measurement errors. To avoid this difficulty, Lake Shore reversed the sign of the programmed current source, while leaving the contacts alone.

The ASTM Standard implicitly assumes DC fields are used for the measurement. The standard requires the measurement of the field. The field monitor or field control option must be included in the Model 8404 HMS to comply with this requirement of the ASTM. For the 8400 Series HMS, the system assigns the field value from a calibration table. Similarly to measure the temperature as stated in the standard, the temperature monitor or control option must be included in the system.

2.9 Sources of Measurement Error

David C. Look gives a good treatment of systematic error sources in Hall effect measurements in the first chapter of his book.⁹ There are two kinds of error sources: intrinsic and geometrical.

2.9.1 Intrinsic Error Sources

The apparent Hall voltage, V_m , measured with a single reading can include several spurious voltages. These spurious error sources include the following:

1. Voltmeter offset (V_o): an improperly zeroed voltmeter adds a voltage V_o to every measurement. The offset does not change with sample current or magnetic field direction.
2. Current meter offset (I_o): an improperly zeroed current meter adds a current I_o to every measurement. The offset does not change with sample current or magnetic field direction.
3. Thermoelectric voltages (V_{TE}): a temperature gradient across the sample allows two contacts to function as a pair of thermocouple junctions. The resulting thermoelectric voltage due to the Seebeck effect is designated V_{TE} . Portions of wiring to the sensor can also produce thermoelectric voltages in response to temperature gradients. These thermoelectric voltages are not affected by current or magnetic field, to first order.
4. Ettingshausen effect voltage (V_E): even if no external transverse temperature gradient exists, the sample can set up its own. The $\mathbf{ev} \times \mathbf{B}$ force shunts slow (cool) and fast (hot) electrons to the sides in different numbers and causes an internally

9. Look, David C., *Electrical Characterization of GaAs Materials and Devices*. John Wiley & Sons, Chichester (1989).

generated Seebeck effect. This phenomenon is known as the Ettingshausen effect. Unlike the Seebeck effect, V_E is proportional to both current and magnetic field.

5. Nernst effect voltage (V_N): if a longitudinal temperature gradient exists across the sample, then electrons tend to diffuse from the hot end of the sample to the cold end and this diffusion current is affected by a magnetic field, producing a Hall voltage. The phenomenon is known as the Nernst or Nernst-Ettingshausen effect. The resulting voltage is designated V_N and is proportional to magnetic field, but not to external current. This is the one intrinsic error source which can not be eliminated from a Hall voltage measurement by field or current reversal.
6. Righi-Leduc voltage (V_R): the Nernst (diffusion) electrons also experience an Ettingshausen-type effect since their spread of velocities result in hot and cold sides and thus again set up a transverse Seebeck voltage, known as the Righi-Leduc voltage, V_R . The Righi-Leduc voltage is also proportional to magnetic field, but not to external current.
7. Misalignment voltage (V_M): the excitation current flowing through the sample produces a voltage gradient parallel to the current flow. Even in zero magnetic field, a voltage appears between the two contacts used to measure the Hall voltage if they are not electrically opposite each other. Voltage contacts are difficult to align exactly. The misalignment voltage is frequently the largest spurious contribution to the apparent Hall voltage.

The apparent Hall voltage, V_m , measured with a single reading contains all of the above spurious voltages: $V_m = V_H + V_o + V_S + V_E + V_N + V_R + V_M$.

All but the Hall and Ettingshausen voltages can be eliminated by combining measurements, as shown in TABLE 2-7.

Measurements taken at a single magnetic field polarity still have the misalignment voltage, frequently the most significant unwanted contribution to the measurement signal. Comparing values of $R_h(+B)$ and $R_h(-B)$ reveals the significance of the misalignment voltage relative to the signal voltage.

A Hall measurement is fundamentally a voltage divided by a current, so excitation current errors are equally as important. Current offsets, I_o , are canceled by combining the current measurements, then dividing the combined Hall voltage by the combined excitation current.

	I	B	V_H	V_M	V_S	V_E	V_N	V_R	V_o
V_1	+	+	+	+	+	+	+	+	+
V_2	-	+	-	-	+	-	+	+	+
$(V_1 - V_2)$			$2V_H$	$-2V_M$	0	$2V_E$	0	0	0
V_3	+	-	-	+	+	-	-	-	+
V_4	-	-	+	-	+	+	-	-	+
$(-V_3 + V_4)$			$2V_H$	$-2V_M$	0	$2V_E$	0	0	0
$(V_1 - V_2 - V_3 + V_4)$			$4V_H$	0	0	$4V_E$	0	0	0

TABLE 2-7 Hall effect measurement voltages showing the elimination of all but the Hall and Ettingshausen voltages by combining readings with different current and magnetic field polarities

2.9.2 Geometrical Errors in Hall Bar Samples	Refer to section 2.4.6.1 for information on geometrical errors in Hall bar samples.
2.9.3 Geometrical Errors in van der Pauw Samples	Van der Pauw's analysis of resistivity and Hall effect in arbitrary structures assumes point-like electrical connections to the sample. In practice, this ideal can be difficult or impossible to achieve, especially for small samples. The finite-contact size corrections depend on the particular sample geometry, and, for Hall voltages, the Hall angle θ (defined by $\tan\theta \cong \mu B$, where μ is the mobility). Look ⁹ presents the results of both theoretical and experimental determinations of the correction factors for some of the most common geometries. We summarize these results, and compare the correction factors for a 1:6 aspect ratio of contact size to sample size. Refer to section 2.4.5 for more information.
2.10 Contact Quality	All direct measurements of the electronic transport properties of a material require adequate electrical contacts between the sample and the measuring instrument. Adequacy depends on the particular measurement performed. Generally, low resistance ohmic contacts are desired.
2.10.1 Ohmic Contacts	The word ohmic ideally means “obeying Ohm’s Law,” a condition that is technically impossible to achieve in a metal-semiconductor interface. Ohmic usually means a contact with a small resistance compared to the resistance of the sample being studied, and therefore having insignificant non-linear current-voltage characteristics. Several parameters describe electrical contacts to semiconductors. The quantity of greatest interest is the contact resistivity or specific contact resistance, denoted by ρ_c and usually measured in $\Omega \text{ cm}^2$. Contact resistivity is the product of the contact resistance ρ_c and the area A of the contact. Other common contact parameters include the barrier height B, measured in eV, and the semiconductor doping concentration, measured in cm^{-3}.
2.10.2 Ohmic Check	The most important method to characterize the contact is the ohmic check procedure. The plot of voltage versus current should be a straight line. Ideally, the correlation coefficient of the best fit line should be 0.9999 or higher. Using contacts that are not ohmic for a Hall measurement is not recommended. Such measurements can produce results that depend on the nature of the contact rather than the properties of the material. For instance, a measurement of the Hall effect on a Schottky contact can measure minority carriers in the semiconductor. The best rule is: if the contacts are not ohmic, stop and fix them before proceeding.
2.10.3 Contact Deposition	There are several methods of contact deposition: applying metal-bearing paints and pastes, melting metals directly on the semiconductor surface, evaporation, sputtering, molecular beam epitaxy, ion-implantation, and others. Once deposited on the semiconductor, the contact may be thermally annealed by a conventional oven, laser or electron beam, or rapid thermal annealing/processing (RTA or RTP), in which halogen lamps rapidly heat the semiconductor to the annealing temperature, and hold it there for a short time (typically 10 to 30 s). Of these methods, the first two are the simplest and are often used to make contacts for Hall measurements, especially on low resistance samples. Metal-bearing paints are most commonly silver based. The most common metal to melt directly on the surface is Indium. Depending on the semiconductor material, a solder flux may be used with the Indium. Higher resistance material may require a method like evaporation or sputtering to get low resistance ohmic contacts.

Chapter 3: Installation and Setup

3.1 General

This chapter describes the process of preparing a site, unpacking the Hall effect measurement system components and assembling them into the standard 8400 Series Hall effect measurement system (HMS) configuration, as well as how to assemble and configure the options. Finally, it explains system checkout procedures.

3.1.1 Lake Shore Assisted Installation

Lake Shore personnel or trained representatives are available to assist with the installation process. When installation and training services are purchased with the Model 8404, the customer will be contacted and provided with the site prep form and applications engineer contact information.



To avoid delays and ensure a successful installation process, customers are responsible for completing section 3.2 through the end of section 3.4 of this manual before an installation trip can be scheduled.

3.2 Site Requirements

Plan the site layout before the system arrives. Use this chapter to guide you in making your decisions concerning physical location, environment, cryogenic storage and access, power, ventilation, safety, and local building, electrical, and safety codes. The floor plan in FIGURE 3-1 and FIGURE 3-2 show physical dimensions of the Model 8404, which will guide you in choosing the installation site. After initial screening, evaluate proposed sites according to space, location, power, and structural integrity.



Much of the equipment described in section 3.2.1 to section 3.2.7 is not included with a standard Model 8404 or as part of the installation and training service. Some of that equipment can be purchased from Lake Shore as options or accessories; those model numbers are listed in the relevant sections.

3.2.1 Space Requirements and Suggested Layout

The physical space should be adequate for system installation, operation, potential expansion, service, and storage of supplies. When considering the designated location, you will need to concern yourself with space requirements and the configuration of your system as well as height requirements.

3.2.1.1 Configuration Considerations for System Layout

When preparing a location for the system, there are system configuration considerations as well. Where you place the instrument console in relation to the measurement platform will likely depend on available laboratory space and traffic flow. The instrument console can be located on either side of the measurement platform. The cable boom, sample space gas handler (if ordered) and the standard insert stand locations depend on the location of the instrument console as well. Their locations will be explained in their respective sections.

3.2.1.2 Space Requirements

The site must have enough space to provide access to all controls without posing a risk to the operator. The standard Model 8404 measurement platform and instrument console are relatively compact. However, the optional vacuum pumping station, and CCR compressor can take considerable space during operation. A suggested floor plan is illustrated in FIGURE 3-1. The suggested layout can be mirrored or rearranged to fit in the available space.

3.2.1.3 Height Considerations

In addition to the necessary floor space, ceiling height is also a site consideration as illustrated in FIGURE 3-2. When using an optional CCR, you will need 2.03 m (80 in) of ceiling height to remove the CCR insert from the CCR. The same ceiling height is required to remove the oven insert from the oven.

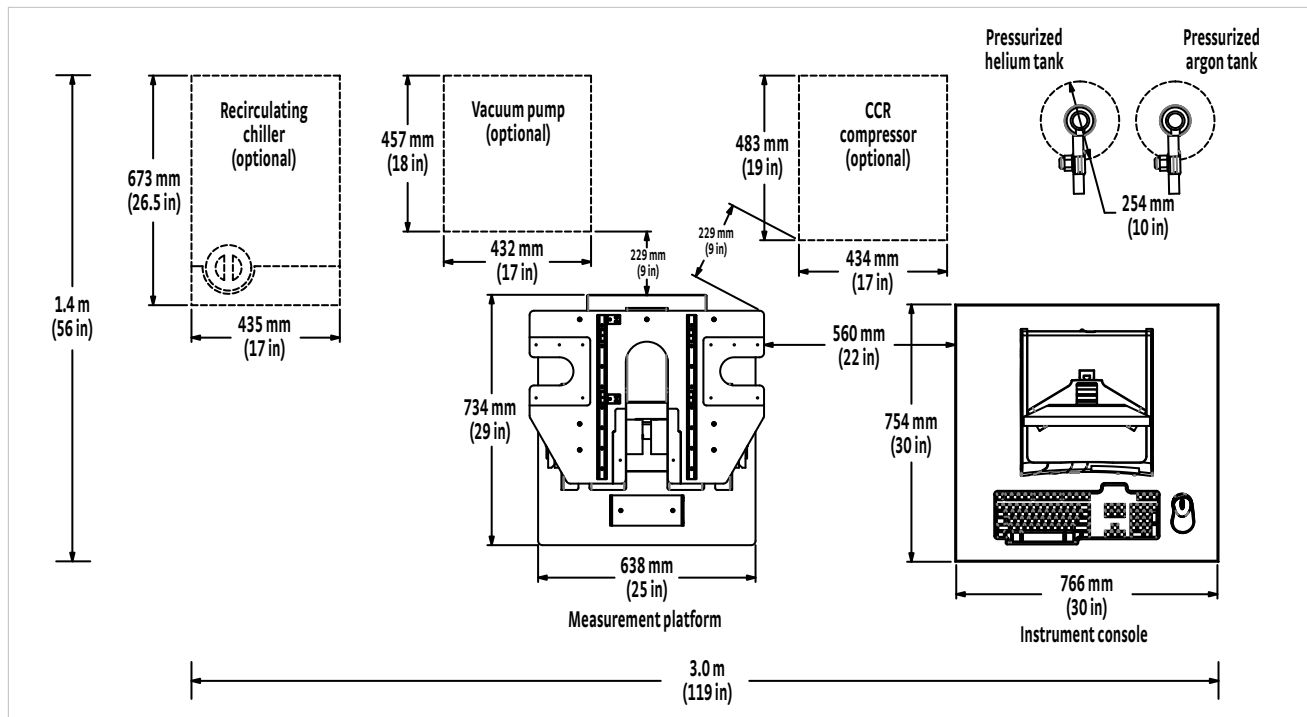


FIGURE 3-1 Model 8404 space requirements and suggested floor plan (console can be positioned to the right or left of the magnet)

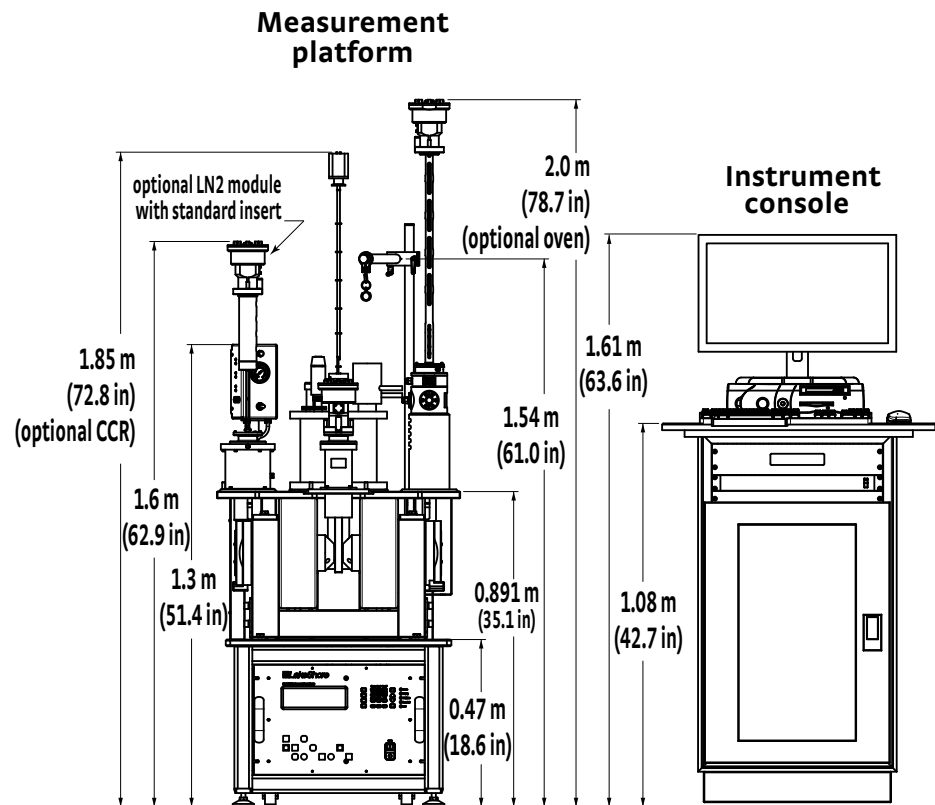


FIGURE 3-2 Model 8404 ceiling height requirements
(console can be positioned to the right or left of the magnet)

3.2.2 Environmental Requirements and Concerns

There are several environmental considerations that may affect Model 8404 operation, measurement performance or user safety. The following sections discuss vibration considerations, electrical noise, ventilation, and safety considerations.

3.2.2.1 Vibration

Place the Model 8404 away from major sources of vibration to avoid problems when running measurements and to avoid electrical noise. Place it on a concrete floor, on the lowest floor of the building, and away from elevators, large motors or moving equipment.

3.2.2.2 Electrical Noise

Place the Model 8404 away from major sources of electrical noise to avoid interference with measurements. Common electrical noise sources in buildings are power distribution panels, high capacity power lines, communications distribution centers, welding equipment, and RF (radio) transmitters.

Line power quality can also impact electrical measurements done in the Model 8404. When possible, avoid long or indirect power routing, circuits that are shared with motors or other noisy loads, unbalanced, overloaded, and poorly grounded circuits. When poor quality power circuits are unavoidable, an isolation transformer for measurement instruments may be required to achieve optimum performance.

3.2.2.3 Ventilation

Place the Model 8404 in a well ventilated area to avoid the risk of asphyxiation from liquid cryogens. Oxygen content monitors and alarms should be installed near the work site to warn against low oxygen levels if liquid cryogens are used. The air-conditioning system should filter dust and other particulates to reasonable levels. Consult an air-conditioning expert about special filtering if salt air, corrosive gases, or other air pollutants exist.



Failure to remove large quantities of vaporized cryogen from the working area can result in a loss of consciousness or death. Vaporizing cryogen displaces oxygen in its vicinity, presenting an asphyxiation hazard. There is a risk of oxygen deficiency if the oxygen level falls below 19.5%.

3.2.2.4 Magnetic Fields

The electromagnet is capable of generating a strong magnetic field in the air gap between the pole caps. Stray fields are also created in the region surrounding the electromagnet. These fields can be dangerous to people with some types of medical implants. The system should be located away from hallways or other frequently traveled areas. Appropriate barriers and signs should be placed near the Model 8404 to warn of high magnetic fields. For the EM4-CSA, the 5 gauss line is a 635 mm (25 in) sphere around the center of the electromagnet.



Ensure that no one with a pacemaker, magnetic implant, or neurostimulator comes near the Model 8404. The electromagnet is unshielded and produces a 1.67 T (16.7 kG) 0.91 T (9.1 kG) magnetic field within the magnet gap that can disrupt medical implants. Failure to comply could result in injury or death.



The electromagnet is unshielded and produces a high magnetic field that can erase magnetic media, damage watches and affect other instruments.

3.2.2.5 Safety Compliance

The system is designed to be used in a laboratory environment; therefore, safety testing is done to laboratory standards. For the CE mark, normal use is defined as: indoor use, altitude to 2000 m, temperature between 5 °C and 40 °C (41 °F and 104 °F), maximum relative humidity of 80% at 31 °C (88 °F), and air quality pollution degree 2 (nonconductive pollution of the sort where occasionally a temporary conductivity caused by condensation must be expected).

3.2.3 Power Requirements

Electrical power is required for the operation of the instrument console, and magnet power supply. It is also required for the optional vacuum pumping system, closed cycle refrigerator compressor and water chiller. The Model 8404 requires 1-phase and 3-phase power. Most equipment is designed to operate over a range of line voltages. Some equipment must be configured to operate at a specific voltage within the range listed. This equipment is configured at Lake Shore to the voltage specified when the equipment is ordered. Refer to section 3.4 for making utility connections.



The customer must provide wiring that follows local safety codes, to the back of the power supply. The optional chiller comes with a U.S. style plug that will need to be changed in some countries.

The electrical equipment can be grouped as shown in TABLE 3-1 and TABLE 3-2 to distribute the system power requirements over multiple facility circuits. TABLE 3-1 details the operational 1-phase power requirements for each circuit, and TABLE 3-2 details the operational 3-phase power requirements for the Model 643 electromagnet power supply and larger chillers. The Model 643 in the measurement platform will draw high inrush currents from the 3-phase line when it is powered on. Circuit protection capable of handling these short duration inrush currents is required to prevent nuisance tripping of the safety devices. Thermal circuit breakers perform best when available.

The turbo or rotary pumping station, closed cycle refrigerator compressor and water chiller should be powered from a circuit separate from the instrument console. This is to isolate electrical noise from the sensitive electronic instruments. It is also recommended that the circuit protection used for the turbo pumping system is capable of handling high inrush currents.

		8400 Series Hall measurement system	Operational current required (AAC)			
			100 VAC	120 VAC	220 VAC	240 VAC
Standard system	Circuit 1	Instrument console (1-phase equipment)	13	11	6	5.5
Optional components	Circuit 2 Option 1	PS-E2M-110120-220240 two stage rotary vacuum pump	—	—	4.5	6.8
	Circuit 2 Option 2	TPS-FRG-100120-220240CE turbo pumping station	6.2	6	3.1	3
		8400 Series Hall measurement system	200 V		208/230 V	
	Circuit 4	Closed cycle refrigerator	13*		15.5*	
	Circuit 5	Consult www.lakeshore.com to select the appropriate water chiller and current requirements.				

* Power should be provided through a separately fused safety switch with 20 A fuses.

TABLE 3-1 Single-phase power requirements

		8400 Series Hall measurement system	Operational current required (AAC)			
			200/208 VAC	220/230 VAC	380 VAC	400/415 VAC
Standard system	Circuit 6	Model 643 electromagnet power supply	13 A/phase	12 A /phase	7 A/phase	6.5 A/phase
Optional components	Circuit 7 Option 1	Consult www.lakeshore.com to select the appropriate water chiller and current requirements.	20 A/phase	20 A/phase	16 A/phase	16 A/phase
	Circuit 7 Option 2		—	—	20 A/phase	20 A/phase

TABLE 3-2 3-phase power requirements

The AC power source connected to the Model 8404 must be frequency and voltage regulated and isolated from sources that may generate electromagnetic interference (EMI). Ground fault interrupter (GFI) and transient surge protection circuitry at the AC source are also strongly recommended. If ground fault interrupters are used, on 3-phase circuits, a 3-phase GFI must be used. Use of three separate single-phase GFIs is not acceptable. In areas where AC voltage is variable, consider a constant voltage transformer suitable for laboratory equipment. If power outages are a problem, consider an uninterruptable power supply (UPS).

3.2.4 Water Requirements

The electromagnet, power supply and optional closed cycle refrigerator compressor require cooling water to operate even for short periods of time. Cooling water is typically supplied in one of three ways; municipal (tap) water, large recirculating cooling system sized for the building or lab, or a small dedicated recirculating chiller sized for the Model 8404.

When cooling with municipal (tap) water, an accessible shut-off valve is also recommended as it will make it more convenient to conserve water by shutting it off when its not in use. Pressure may be difficult to control if the Model 8404 is supplied from a shared building water line. Large seasonal variation in temperature can also cause problems. Low water temperature during humid months can cause excessive condensation that is incompatible with the power supply. High water temperature in summer months may exceed the specified temperature requirement. If large variations in the temperature or pressure of municipal (tap) water are expected, a dedicated chiller should be considered.

Use the pressure drop and flow rates from TABLE 3-3 to determine the type of water connection that is compatible with the cooling water capability at your site. Procedures for completing the connections are in section 3.2.4.3.

	Pressure drop		Flow rate	Maximum power dissipated to water (kW)	Water temperature
	Solenoid valve enabled	Solenoid valve bypassed			
Standard Model 8404	345 kPa (50 psi)	276 kPa (40 psi)	7.61 lpm (2 gpm)	4.25	15 °C to 25 °C
Model 8404 with CCR	345 kPa (50 psi)	276 kPa (40 psi)	10.31 lpm (2.7 gpm)	7.6	15 °C to 25 °C

TABLE 3-3 Pressure and flow rate guide for determining water connections

TABLE 3-3 allows for bypassing the internal solenoid valve in the measurement platform. Use of the internal solenoid valve is only recommended if you are using tap water. The valve may be bypassed to provide a lower system pressure drop. When bypassing the solenoid valve, the cooling water temperature must be maintained above the dew point (the temperature at which condensation will occur) to avoid damage to the electromagnet power supply. Refer to the Model 643 manual section 2.5.4 Avoiding Cooling Water Condensation for additional information.

3.2.4.1 Water Flow and Temperature

No matter what cooling water source is chosen, the water flow rate and temperature listed in TABLE 3-3 must be maintained to allow continuous operation of the electromagnet. Additional recommendations for water cooling are given in section 3.2.4.3. Poor or inconsistent water flow will cause nuisance shut down of the electromagnet power supply.

3.2.4.2 Water Quality

Water quality is important to the long term reliability of the electromagnet and power supply. Poor water quality may cause clogging of the internal cooling lines or even premature failure of the cooling lines themselves. Cooling water chemistry must be compatible with:

- Aluminum
- Copper
- Brass
- Polypropylene
- Ryton
- Viton
- Stainless steel

⚠ CAUTION

Pure distilled water is not compatible with the copper cooling lines used in the electromagnet and power supply.

When cooling with municipal (tap) water, chemistry is less of an issue because fresh water is constantly run through the system diluting any contamination. A well maintained water filter is highly recommended to remove any sediment that could cause a clog.

Recirculating water systems have many advantages in water conservation and regulation of temperature and pressure, but it is very important to address water quality issues early in the installation process. Closed loop systems need to be maintained so that the pH level, amount of dissolved minerals, and biological growth are kept within acceptable limits for all of the components of the cooling system. When setting up a new recirculating water system, begin by reading and understanding the recommendations of the chiller manufacturer. They typically provide good instructions in addition to water test and treatment kits. The regimen chosen must be compatible with the materials listed in section 3.2.4.2.

3.2.4.3 Water Routing and Connections

All cooling water distribution for the standard system (specifically, the electromagnet and magnet power supply) is handled by the internal water manifold located within the electromagnet's rear shroud. For the standard system, only two user connections to the internal water manifold are required. A 10 mm (3/8 in) hose barb fitting is provided for the cooling water inlet and another for the cooling water outlet. Additional user-supplied couplings and lengths of tubing may be required to connect the Model 8404 to your cooling water system. To ensure safe operation, users must supply the cooling water system with:

- Water filter
- Flow meter
- Safety shutoff
- Pressure gauge

For systems with the optional Model 84016 CCR, an additional external water manifold with proportioning valve is provided to distribute water to both the measurement platform and the CCR compressor. In this case, additional flexible hose is required to make connections. Fittings provided with the CCR compressor allow for 10 mm (3/8 in) ID hose connections as well.

For systems with the optional Model RC-EM7 or RC-EM10 chillers, fittings on the chiller allow for 10 mm (3/8 in) ID hose connections as well.

3.2.5 Cryogen Requirements

The optional single point LN₂ body uses liquid nitrogen cryogen to cool samples to near 77 K. Liquid nitrogen is consumed during low temperature operation. As the liquid level decreases, liquid nitrogen may be poured directly into the main sample space opening, once the insert is removed. A pour filled Dewar is required but not provided.

3.2.6 Vacuum Requirements

The single point LN₂ option, the oven option, and the closed cycle refrigerator option use a vacuum space to provide thermal insulation between the option's sample space and the ambient temperature of the surroundings. You will need to provide a high quality vacuum pumping system to evacuate their respective vacuum spaces as specified in TABLE 3-4. The Lake Shore TPS-FRG is compatible with each of these options, and the Model PS-E2M is also compatible with the oven option. Components and specifications for these vacuum pumps are in section 2.3.6.2. You should use these specifications as a guideline if you purchase a pumping system elsewhere.

Option	Blank-off pressure (Torr)	Operate	*Lake Shore compatible pumping system
Single point LN ₂ option	<10 ⁻⁵	For annual maintenance	TPS-FRG
Closed cycle refrigerator	<10 ⁻⁵	Continuously when the CCR is operating at or below room temperature	TPS-FRG
Oven option	<10 ⁻³	Continuously when the oven is in use	TPS-FRG or PS-E2M

*Components and specifications for this option is in section 2.3.5.2. You should use these specifications as a guideline if you purchase a pumping system elsewhere

TABLE 3-4 Vacuum requirements

For the single point LN₂ option: you will need to evacuate the vacuum space on an annual basis; it may also be necessary for service or troubleshooting (section 5.2.2). The single point LN₂ option body is equipped with an evacuation port, and an evacuation adapter compatible with a NW 25 vacuum flange. If you do not purchase the Lake Shore Model TPS-FRG for evacuating the single point LN₂ option, you will need to provide the appropriate gauges and vacuum lines.

For the optional closed cycle refrigerator: high quality vacuum equipment is necessary for good thermal performance and when the CCR is at or below room temperature. When cooling, condensation on the exterior of the CCR tail is indicative of poor vacuum, requiring the unit to be evacuated before continuing operation. The CCR is equipped with an NW 25 vacuum port and a vacuum isolation valve. Associated NW 25 vacuum lines and clamps terminating with an NW 25 vacuum flange are also provided with the CCR. If you do not purchase the Lake Shore Model TPS-FRG for evacuating the CCR, you will need to provide the appropriate gauges and vacuum lines.

For the optional oven: high quality vacuum equipment is necessary when the oven is in use and for good heating performance. The oven is equipped with an NW 16 vacuum port. Associated vacuum lines and clamps terminating with an NW 25 vacuum flange are also provided with the oven. If you do not purchase the Lake Shore Model PS-E2M or TPS-FRG for evacuating the oven, you will need to provide the appropriate gauges and vacuum lines.



The sample space vacuum requirements are explained in section 3.2.6.

3.2.7 Gas Requirements

The sample space gas handler included in the VTA option controls the delivery of He or Ar gas as well as creates a roughing vacuum to the sample space of the oven and closed cycle refrigerator. The roughing vacuum action is used momentarily to remove any air from the sample space prior to backfilling with He or Ar gas.

He gas is required for the closed cycle refrigerator. He acts as exchange gas and displaces any water vapor and other gases which could freeze in the sample space.

Ar gas is required for the oven. Ar acts as exchange gas and displaces any oxidizing gases from the sample space.

The following must be provided for each gas used:

- Gas cylinder or other source of dry, high purity gas
- An independent low pressure regulator capable of providing a steady pressure of 345 kPa (50 psi) (at a flow rate of 20 lpm (0.7 cfm) during evacuation),
- Fittings to attach the regulator output to the provided 3.2 mm (1/8 in) I.D. gas line attached to the sample space gas handler's gas inlet port

	Pressure	Flow rate
Regulator	345 kPa (50 psi)	20 lpm (0.7 cfm)

TABLE 3-5 Gas pressure and flow rate requirements

Lake Shore does not offer these components as accessories.



Gas cylinders must be anchored properly before use. Tipping cylinders can cause serious injury or death.

3.3 Unpacking the Hall Effect Measurement System

The following sections describe the unpacking of each component shipped with the Model 8404. A packing list is included with your shipment to assist in identifying and locating the items you ordered. Please report any shortages or potential shipping damage prior to arranging Lake Shore assisted installation and within five days of receiving the shipment. It is important that you read and understand this section thoroughly before starting the process. Clear enough space to complete all steps safely.

3.3.1 Shipping Containers

The standard components of the Model 8404 will be shipped in two crates; one crate contains the Model 8404 measurement platform, and the second crate contains the instrument console, options and accessories. Other crates and pallets are used for some options.

Each of the crates are numbered. The number is located on the top wall of the crate. It includes the total number of crates as well (for example, if you have three crates, the measurement platform will be marked 1/3 to indicate that it is crate 1 of 3).

TABLE 3-6 lists approximate size and weight of the standard shipping containers. The weight of the crates varies in the ranges listed below depending on Model 8404 configurations and options ordered.

	Size (l × w × h)	Weight
Measurement platform crate*	1.45 m (57 in) × 1.00 m (39 in) × 1.30 m (52 in)	500 kg (1100 lb) to 590 kg (1300 lb)
Instrument console, options, and accessories crate*	1.22 m (48 in) × 0.91 m (36 in) × 1.22 m (48 in)	272 kg (600 lb) to 363 kg (800 lb)
CCR insert and body crate (optional)	0.66 m (26 in) × 0.56 m (22 in) × 0.91 m (36 in)	61 kg (135 lb)
CCR compressor pallet (optional)	0.56 m (22 in) × 0.56 m (22 in) × 1.04 m (41 in)	48 kg (106 lb)
Turbo vacuum pump pallet (optional)	0.66 m (26 in) × 0.56 m (22 in) × 0.91 m (36 in)	61 kg (135 lb)
Rotary vacuum pump pallet (optional)	0.90 m (35.4 in) × 0.80 m (31.5 in) × 0.60 m (23.6 in)	35 kg (77 lb)
Chiller (for basic system)	1.22 m (48 in) × 0.66 m (26 in) × 1.2 m (47 in)	145 kg (320 lb)

*Weight may vary depending on configuration and options ordered

TABLE 3-6 Shipping container size and weight

3.3.2 Inspecting for Shipping Damage

Upon receipt of the system, check for signs of rough handling, such as damage to the shipping container or broken shock indicators attached to the outside and inside of the shipping container. If any physical damage is suspected, do not open containers before photographing the damage and informing the shipping agents and Lake Shore or your local representative. Contact information for Lake Shore service is given in section 5.5. Shipping containers and shipping materials should be kept in the event you would need to return your Model 8404.

3.3.3 Required Tools

The following tools are required to unpack the crated Model 8404 and are not included with the shipment.

- Lifting equipment
- Utility knife or scissors
- Phillips head screw driver (battery powered if available)
- 14 mm wrench (or socket and drive)
- 19 mm wrench (or socket and drive)
- 10 mm wrench
- 13 mm wrench
- 1/2 in wrench
- 10 mm hex driver
- Small diagonal wire cutters

3.3.4 Moving and Lifting the Crated Model 8404

This section explains lifting and moving the instrument console and measurement platform crates as well as lifting and moving them after they have been uncrated. Uncrating the measurement platform and instrument console is explained in section 3.3.5 and in section 3.3.6.

3.3.4.1 Lifting and Moving the Crates

If space and equipment is available, the loaded shipping crates should be moved to the installation site intact. They can be moved easily with a pallet jack while the contents remain protected.

3.3.5 Uncrating and Moving the Measurement Platform

These steps will assist you in safely removing the crate from the measurement platform, preparing the measurement platform to be moved, and moving the measurement platform.

3.3.5.1 Uncrating the Measurement Platform

The measurement platform is packed in crate 1.

1. Using a Phillips head screw driver, remove the screws from the top of the crate containing the measurement platform. Look inside for visible damage to the measurement platform.
2. Remove the screws around the perimeter of both short walls of the crate and remove both short walls. A second person should hold onto each of the walls as you remove the screws, to ensure the walls do not fall on you or the measurement platform.
3. Repeat step 2 to remove both long walls.
4. Using a utility knife or scissors, remove the plastic wrap covering the measurement platform. Avoid damaging the Hall system components when removing the plastic wrap.

3.3.5.2 Preparing the Measurement Platform For Moving

1. Using a 1/2 in wrench, loosen and remove the eight 5/16-18 hex head cap screws that attach the two long red horizontal lifting brackets to each side of the crate base (FIGURE 3-3).
2. Using a 13 mm wrench, loosen and remove the four M8 hex head cap screws that attach the two long red horizontal lifting brackets to each side of the measurement platform (FIGURE 3-3).

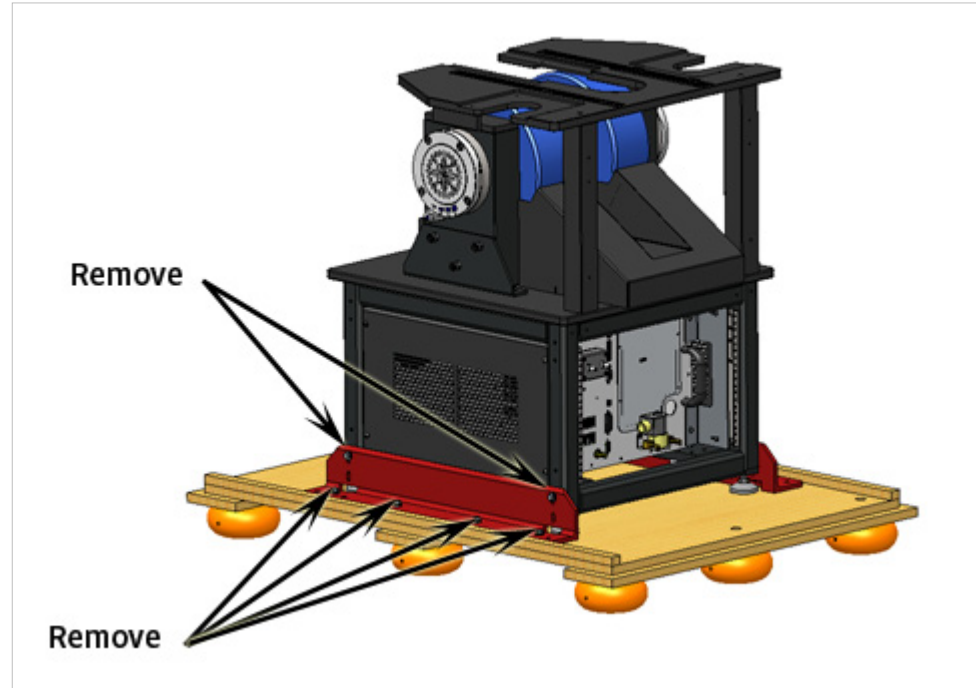


FIGURE 3-3 Remove the bolts from the lifting bracket

3. Turn the lifting brackets upside down so that the four bolt holes are facing up.
4. Using the same bolts, attach the lifting brackets to the middle of the measurement platform (FIGURE 3-5).
5. Attach the four lifting eyelets to the lifting brackets as shown in FIGURE 3-5.
6. Attach lifting equipment to the four lifting eyelets on the red upper lifting brackets attached to the measurement platform (FIGURE 3-5). When lifting the measurement platform, lifting straps or chains should not come into contact with the measurement platform except at the eyelets, as shown in FIGURE 3-5.

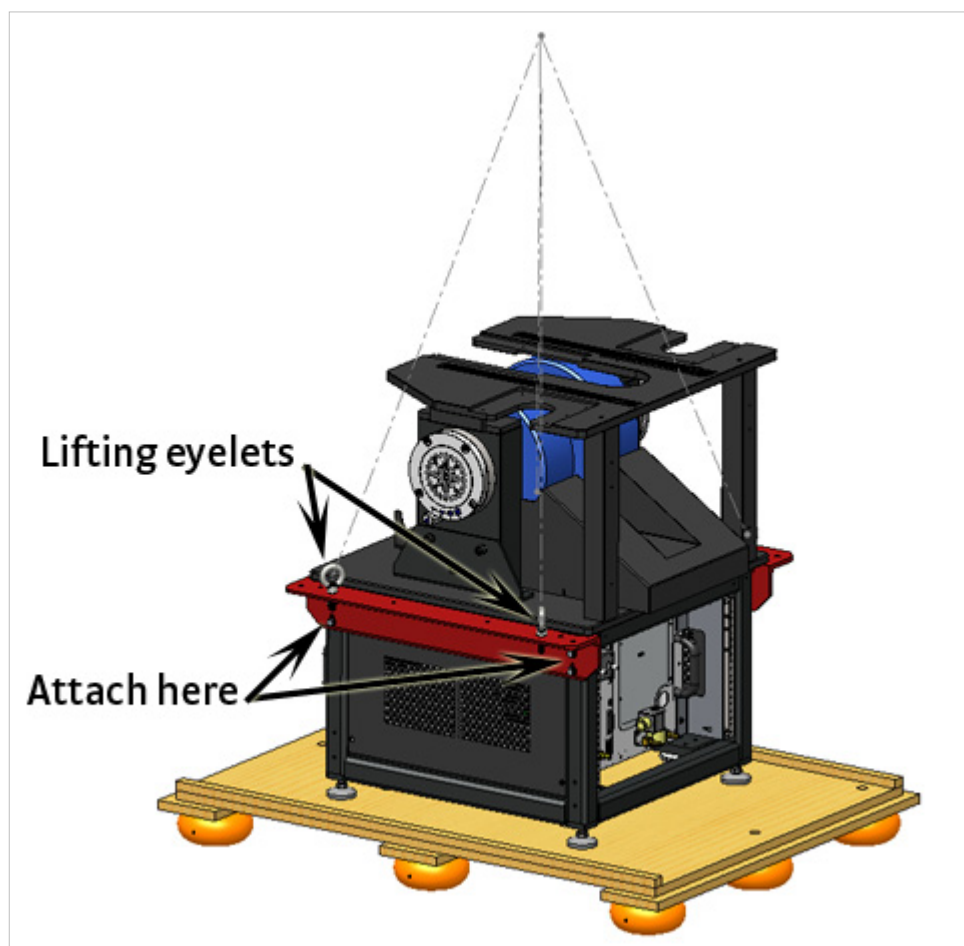


FIGURE 3-4 Location for reattaching the lifting brackets and eyelets, and proper lifting with lifting equipment

3.3.5.3 Moving the Measurement Platform

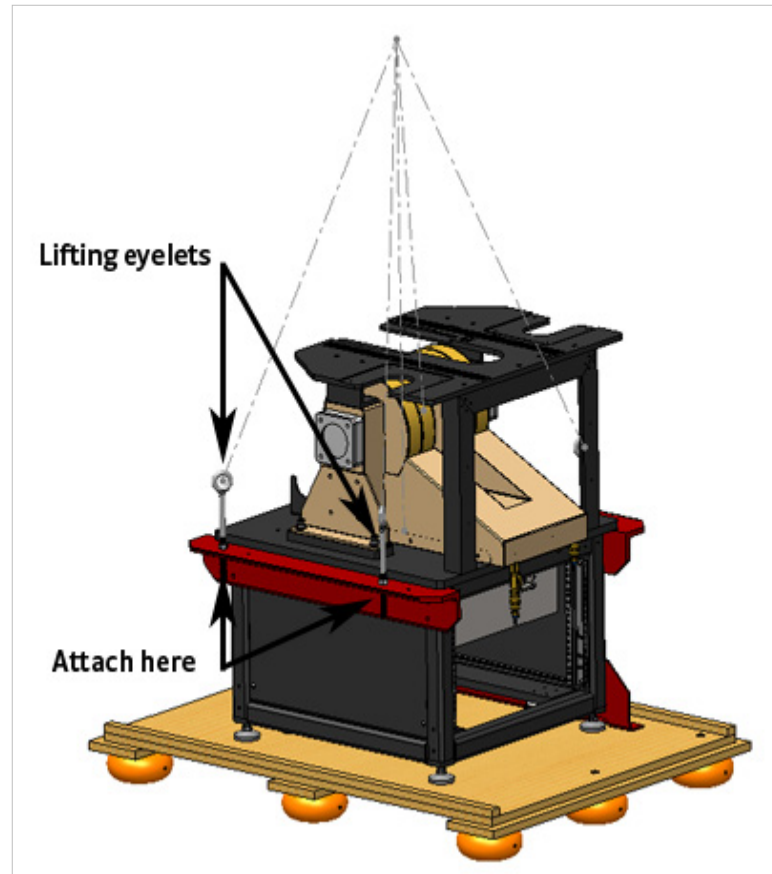


FIGURE 3-5 Location for reattaching the lifting brackets and eyelets, and proper lifting with lifting equipment

1. Using the lifting equipment, lift the measurement platform up and pull the crate base out from under the measurement platform.
2. Set the measurement platform on the floor.
3. Move the crate materials out of the work area. It is advisable to save these in the event you need to return the Model 8404.
4. Using a 13 mm wrench, remove the two lifting brackets from the measurement platform.
5. Carefully wheel the measurement platform to the final location.
6. Using a 19 mm wrench, lower the four leveling feet at the corners of the measurement platform so the wheels are not in contact with the floor.

NOTE

Retain the horizontal braces with the other Model 8404 packing supplies in the event you need to return it or move it to another location.

3.3.5.4 Leveling the Platform

The electromagnet and measurement platform were aligned at Lake Shore. In order to assure the system is level with your floor, follow this procedure.

1. If it is not already there, move the system to its final position.



If you purchased the floor mounting option, loosen the securing hardware prior to leveling.

2. Using a 19 mm wrench, turn the nut on the foot until the foot touches the floor, and then turn it two more rotations (FIGURE 3-6).
3. Place a level on the top surface of the measurement platform (FIGURE 3-6) and determine if it is level according to the standard of the level you use.
4. If it is not level, determine which leg on the system needs to be adjusted.
5. Using the 19 mm wrench, turn the nut on the foot that needs to be adjusted, until the level indicates the platform is level.



If you purchased the floor mounting option, tighten the securing hardware.

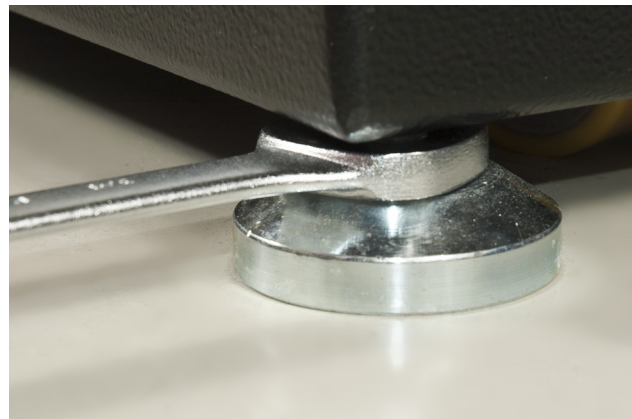
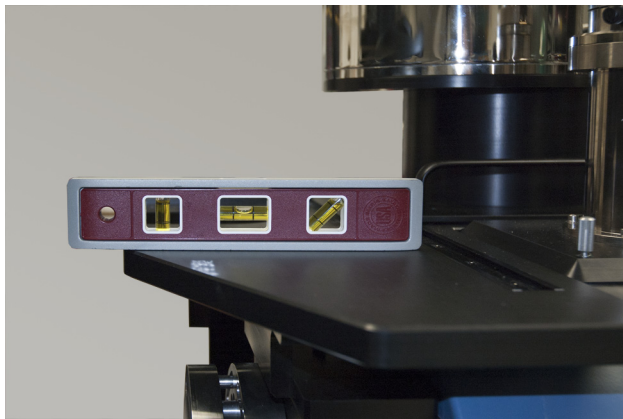


FIGURE 3-6 Leveling the measurement platform

3.3.6 Uncrating the Console and Accessories

The console is shipped in crate 2. Use section 3.3.5.1 as a guide to uncrate the console and accessories. Four lifting lugs are provided on top of the console to lift it up and off the crate base. Use the wheels to roll it into its final location. If necessary, use a 10 mm wrench to adjust the leveling feet on the console, after placing the console in its final location. Before moving the console, or moving on in this process, be sure to remove the crate and clean the area of any debris left over from the uncrating process. Remove the lifting eyelets from the top surface once the console has been moved to its position.

3.3.7 Uncrating the Closed Cycle Refrigerator (CCR) Option

The CCR option, compressor, and He gas lines are shipped on a wooden pallet. Cut the straps that secure the boxes and remove them from the pallet. They are now ready for unpacking. Be sure to remove any debris from the unpacking process. The CCR compressor and flexible helium lines are packed in separate boxes. The CCR tool kit and expander power cable are included in the flexible helium lines box. Unpack the tool set, expander power cable, and flexible helium lines and place them in a safe location for use in connecting the compressor to the CCR.



The CCR (cold head, compressor, and flexible helium lines) contain high pressure (1.86 MPa to 1.9 MPa (270 psig to 275 psig) helium gas. Hitting the equipment with a sharp edge or pointed object may cause explosion or rapid escape of gas.



Remove the shipping bolt retaining the compressor motor before running the compressor.

! CAUTION

The compressor should not be tilted by more than 5 degrees, as this may cause damage to the compressor capsule or oil contamination of the helium gas line.

To unpack the CCR compressor follow these procedures.

1. Using a utility knife, remove any plastic strapping that secures the box's cardboard lid to the wooden pallet base.
2. Lift the cardboard lid off of the wooden base.
3. Remove the compressor from its shipping container and inspect for signs of damage (section 3.3.7.1).
4. Raise the left rear corner of the compressor to locate the hex head shipping bolt. Support the compressor base with blocks only high enough to gain access to the bolt. Do not raise the corner more than 50mm (2 in).
5. Using a 17 mm wrench, remove the shipping bolt and keep it in a safe place in the event you need to return the CCR compressor.
6. Move the shipping materials out of the working areas. Keep these in a safe place in the event you need to return the CCR compressor.
7. Place the compressor in its final location relative to the Hall system.

The compressor may be oriented and positioned as allowed by the 3 m (10 ft) long flexible helium lines and the 3.35 m (11 ft) long power cable that connect to the Model 8404 (refer to section 3.6.4 for compressor setup). The layout shown in FIGURE 3-1 shows the closest position of the compressor to the Model 8404; however, the compressor may be placed further away. To minimize the audible noise of the compressor (~60 dB) during operation, the compressor may be located in an adjacent room with the flexible helium lines and power cable routed through an opening in the wall. Contact Lake Shore Systems Service to purchase longer He lines, if necessary.

! WARNING

Place the compressor in a well ventilated area to avoid asphyxiation in the event of a helium gas leak.

! CAUTION

Do not enclose the compressor in a confined space that limits the free convection of heat from the unit. Failure to do so may result in malfunction or damage.

3.3.7.1 Inspecting the CCR Components

Inspect the CCR compressor for any visible signs of damage caused during shipping, and for evidence of oil leakage. For the standard water-cooled CCR compressor, the static pressure reading should be 1.60 MPa to 1.65 MPa (232 psig to 239 psig) when the compressor is at room temperature. If any damage is suspected or the gauge reads less than the specified value, contact your Lake Shore representative prior to the scheduled installation.

! CAUTION

When checking the compressor for shipping damage, do not connect gas lines and cold head. The components may become contaminated with compressor oil.

! CAUTION

Do not tip the compressor more than 5 degrees from horizontal to avoid flowing oil into unwanted places.

1. Upon receipt, inspect the shipping container and the compressor for damage.
2. If there is evidence of external damage to the container, be sure the carrier's driver sees the damage. Note it on the shipping documents and have the driver acknowledge it by signing his/her initials on the delivery receipt.
3. If there is external damage to the compressor, remove the covers and check for internal damage. Notify the carrier immediately and take photographs of the damage to document the claim. In the event of damage to the compressor contact Lake Shore Systems Service.

4. Check the Tip-N-Tell sensor mounted on the compressor. If the Tip-N-Tell sensor shows no mishandling and there is no apparent physical damage, proceed with unpacking and positioning of the compressor described in section 3.3.7. If activated, the Tip-N-Tell sensor turns blue. Contact the Lake Shore Systems Service department in the event that the Tip-N-Tell sensor has been activated.

3.3.8 Unpacking the Instrument Console and Accessories

Once you have removed the crate from the instrument console, you will need to unpack the various items that were shipped in this crate. Depending on your options, these items may include sample card kits, calibration card kits, oven, the sample space gas handler, and other options. See your packing list for details.

3.3.8.1 Unpacking the Instrument Console

The instrument console is a cabinet that includes the following standard instruments: Model 776 Hall matrix switch, Keithley Model 6220 current source, and a Keithley Model 2182A nanovoltmeter. The following optional equipment may also be present: Model 336 temperature controller, Model 218 temperature monitor, Model 475 gaussmeter, Ametek Model 7230 lock-in amplifier, one or two Keithley Model 6487 voltage sources, and a Keithley Model 6514 electrometer. The installer will unpack the cables from the inside of the console when he arrives.

3.3.8.2 Unpacking the Instrument Console Top Surface

The instrument console top surface is a large black laminate surface that is packed in foam packaging material. Remove the top surface from the packaging. Set it on top of the instrument console, as shown in FIGURE 3-14 in preparation for completing the system setup and assembly.

3.3.8.3 Unpacking the Standard Module

The standard insert, light tight body, and exchange plate comprise the standard module. They are packed in their own box in the instrument console crate. Open the box, lift up the foam packaging and inspect the standard module for any damage that may have occurred during shipping. Repackage these components in their boxes for safe-keeping, in preparation for completing the system setup and assembly.

3.3.8.4 Unpacking the Computer and Monitor

The system computer and monitor are packed in the original manufacturer's packaging. Remove the packaging. Set these components aside in preparation for completing the system setup and assembly.

3.3.8.5 Unpacking the Cable Boom

The boom consists of two posts and various mounting components. The vertical post and horizontal post are shipped attached to the 8400 Series HMS measurement platform. The horizontal post is attached to the vertical post and wrapped in bubble wrap. Remove the bubble wrap from the horizontal post in preparation for completing the system setup and assembly.

3.3.8.6 Unpacking the Accessories Box

The manuals and additional accessories are located in the accessories box in the console crate. Remove the manuals, software discs and remaining documentation, and place them in the instrument console drawer for later reference. The accessories box also contains the sample card kit, calibration card kits, and maintenance toolkit. These items are packed in bubble wrap and foam packaging. Remove the packaging and set them in the instrument console drawer in preparation for completing the system setup and assembly.



Be certain to retain the 8400 Series software compact disc as it contains your system license file, which is required for system operation.

3.3.9 Unpacking the Options

This section describes unpacking the various options. For each of these items, unpackage them according to the instructions here, and check for any damage that may have occurred during shipping. Repackage them, or place them in the designated place as indicated in each section.

- *Optional sample card kits and prober card kits:* if optional sample mounting kits, premium sample mounting kits, 10mm prober card or 50 mm prober card kits were ordered, these items will be located in the optional accessories box in the instrument console crate. These items will be packed in bubble wrap and foam packaging. Remove the packaging and set these components in the instrument console drawer in preparation for completing the system setup and assembly.
- *Single point LN₂ option:* the single point LN₂ option body is packed in its own box in the instrument console crate. This item will be packed in foam packaging, along with the funnel. The stopper and evacuation adapter will be in the accessories box. Repackage these components in their boxes for safe-keeping in preparation for completing the system setup and assembly.
- *VTA option:* the sample space gas handler portion of the VTA option is packed in its own box in the instrument console crate. This item will be packed in a box. The VTA bracket and fittings will be wrapped in bubble wrap and placed in the console. Some gas lines and fittings will also be present in the packaging. The wireway panel for this option is attached to the right rear structural support of the measurement platform. Repackage these components in their boxes for safe-keeping in preparation for completing the system setup and assembly.
- *Oven option:* this option will be shipped in the instrument console crate. The oven and oven insert is packed in two foam halves and stored inside a cardboard box. Open the cardboard box and remove the foam to reveal the oven and insert together. A cable connection kit and vacuum handling kit will also be packaged with the oven. Repackage these components in their boxes for safe-keeping in preparation for completing the system setup and assembly.
- *Closed cycle refrigerator option:* the closed cycle refrigerator was uncrated in section 3.3.7. In the CCR crate you will also find a cable connection kit for various CCR, compressor and system connections as well as a vacuum handling kit. Repackage these components in their boxes for safe-keeping in preparation for completing the system setup and assembly.

The He gas lines are packaged in a cardboard box which was removed from the CCR compressor pallet. Remove the He gas lines from their packaging and cut the ties which secure them. The cardboard and any other packaging material for the CCR compressor should also be removed at this time. Repackage these components in their boxes for safe-keeping in preparation for completing the system setup and assembly.

- *845-FM DC field monitor:* the Model 475 will already be installed in the instrument console, the probe mounting rack will already be installed on the electromagnet c-frame, the probe will be in a white Lake Shore probe box, protected by a foam insert. When removing it from the box, take care not to apply any pressure to the aluminum stem. Hold it by the black handle.
- *360 degree rotation option for standard insert:* this option will be shipped in the crate with the console. It will be protected with two foam halves and packed in a box. Remove the packaging and set this component in the instrument console drawer in preparation for completing the system setup and assembly.
- *Model TPS-FRG turbo pumping station option:* open the box and remove all plastic wrap and ties. Remove the flexible stainless steel vacuum line from the plastic bag. The turbo vacuum system can be left on the floor near the Model 8404 or placed on a cart.

- *Model PS-E2M two stage rotary vacuum pump option:* open the box and remove all plastic wrap and ties. Remove the plastic flexible reinforced vacuum line from the plastic bag. The turbo vacuum pump can be placed on the floor near the 8400 Series HMS or placed on a cart.

3.4 Utility Connections

Use the following procedures to complete the utility connections required for the Model 8404. The items in this section must be completed prior to the arrival of a Lake Shore representative for installation and training. You may also need to refer to the Model 643 electromagnet power supply manual for further information.

3.4.1 Required Tools

The following tools are required to make the utility connections for your 8400 Series HMS. These tools are not included with your shipment.

- Hose cutters
- 10 mm (3/8 in) ID flexible tubing
 - Hose clamps
 - Couplings
- Screw driver

3.4.2 Cooling Water Connections

The internal water manifold on the measurement platform contains connections that distribute cooling water to the electromagnet power supply and the magnet coils. Therefore, there is only one inlet and one outlet which you will need to connect for the standard system. This section describes the water connections necessary for the standard system, as well as the optional CCR. Refer to TABLE 3-3 for cooling water specifications.

The common types of water connections for the system are described in section 3.4.2.2 and section 3.4.2.3. Before making the water connections, determine whether you need to remove the solenoid valve. If you are using tap water, leave the solenoid valve on the Model 643. If you are using a chiller, you will need to remove the solenoid valve. Follow the instructions in section 3.4.2.1 if you are using a chiller and need to remove the solenoid valve.

3.4.2.1 Removing the Solenoid Valve on the Model 643

The system is shipped with the solenoid valve installed, as shown in FIGURE 3-7. Follow this optional procedure to remove the solenoid valve. This procedure will lower the system's pressure drop.



FIGURE 3-7 Solenoid valve installed

⚠ CAUTION

The cooling water temperature must be above the dew point (the temperature at which condensation will occur) to avoid damage to the standard system. Refer to the Model 643 manual section 2.5.4 Avoiding Cooling Water Condensation for additional information.

1. Remove the clamp from the line attached to the Model 643 water inlet.
2. Remove the line from the Model 643 water inlet by pulling or cutting the line. You may need to remove the modular connector from the magnet power supply in order to access the line.
3. Remove the clamp from the line attached to the solenoid inlet.
4. Remove the line from the solenoid inlet.
5. Move this line and attach it to the Model 643 water inlet (FIGURE 3-8).
6. Attach the clamp to the line at the Model 643 water inlet.
7. Optional. The line that was connected to the water inlet is now hanging from the solenoid outlet. Connect the loose end to the solenoid inlet to store it.

NOTE

Step 7 is performed only to provide storage for the disconnected line. This is an optional step.

8. Attach the clamp to the line at the solenoid inlet.



FIGURE 3-8 Solenoid valve removed

9. Disconnect the solenoid power leads from the connector on the Model 643 rear panel. Tie off these leads neatly.
10. If you removed the modular connector, replace it.

3.4.2.2 Water Connections for the Standard System (No CCR Present)

You will need an appropriate length of 10 mm (3/8 in) ID flexible tubing and associated hose clamps, couplings, hose cutters and screw driver. Follow these procedures to make the water connections for the standard system.

1. To ensure safe operation, plumb these components to the cooling water system per local code.
 - Safety shutoff
 - Water filter
 - Flow meter
 - Pressure gauge

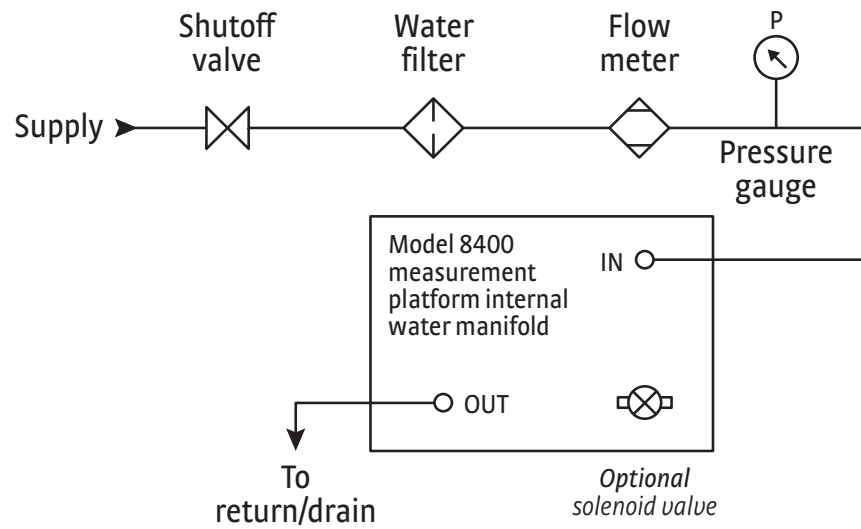


FIGURE 3-9 Water connections for the standard system

2. Locate the 10 mm (3/8 in) inlet barb connections on the internal water manifold (FIGURE 3-10) and connect them to your preferred water supply with the appropriate 10 mm (3/8 in) ID flexible water lines and associated hose clamps.
3. Locate the 10 mm (3/8 in) outlet barb connections on the internal water manifold (FIGURE 3-11) and connect them to your preferred water return with the appropriate 10 mm (3/8 in) ID flexible water lines and associated hose clamps.

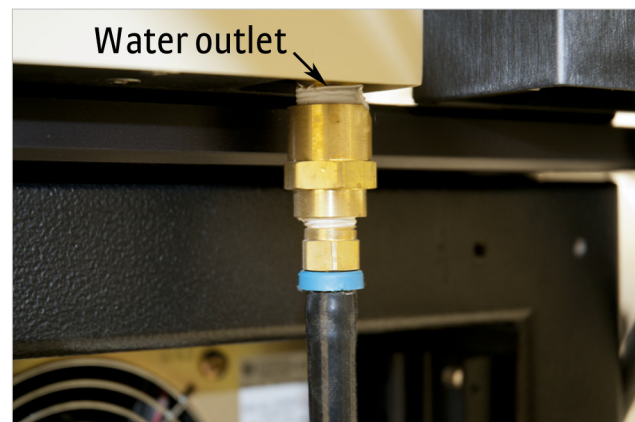
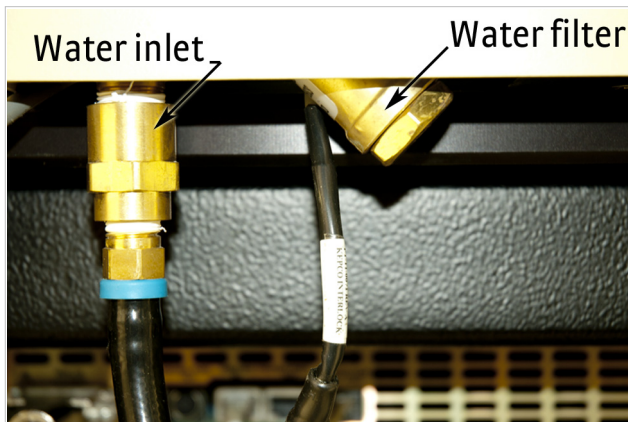


FIGURE 3-10 Left: Water inlet on the water manifold--notice it is to the left of the water filter; Right: Water outlet on the water manifold

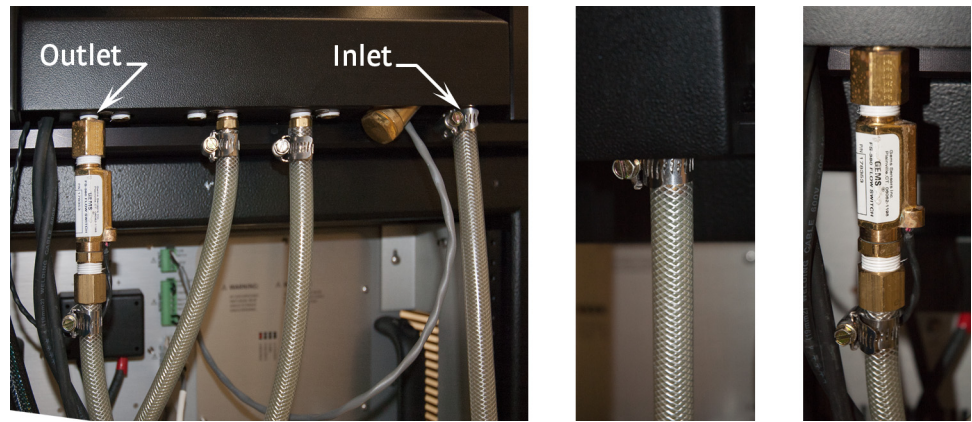


FIGURE 3-11 Left: Outlet and inlet connections on the internal water manifold;
Middle: Closeup of inlet; Right: Closeup of outlet

3.4.2.3 Water Connections for the Standard System with CCR Present

When connecting the cooling water in parallel, the standard system and the optional CCR each get independent inlet and outlet cooling lines. Two supply and two return connections are required for the parallel configuration. Alternatively, a single supply and return can be used with a splitter for each. A block diagram of this setup is shown in FIGURE 3-12.

You will need an appropriate length of 10 mm (3/8 in) ID flexible tubing and associated hose clamps, couplings, hose cutters and screw driver. Each of these devices require 10 mm (3/8 in) hose barb. Follow these procedures to make the water connections for the standard system with optional CCR. Refer to FIGURE 3-12 for a block diagram of this procedure.

1. To ensure safe operation, plumb these components to the cooling water system per local code.
 - Safety shutoff
 - Water filter
 - Flow meter
 - Pressure gauge

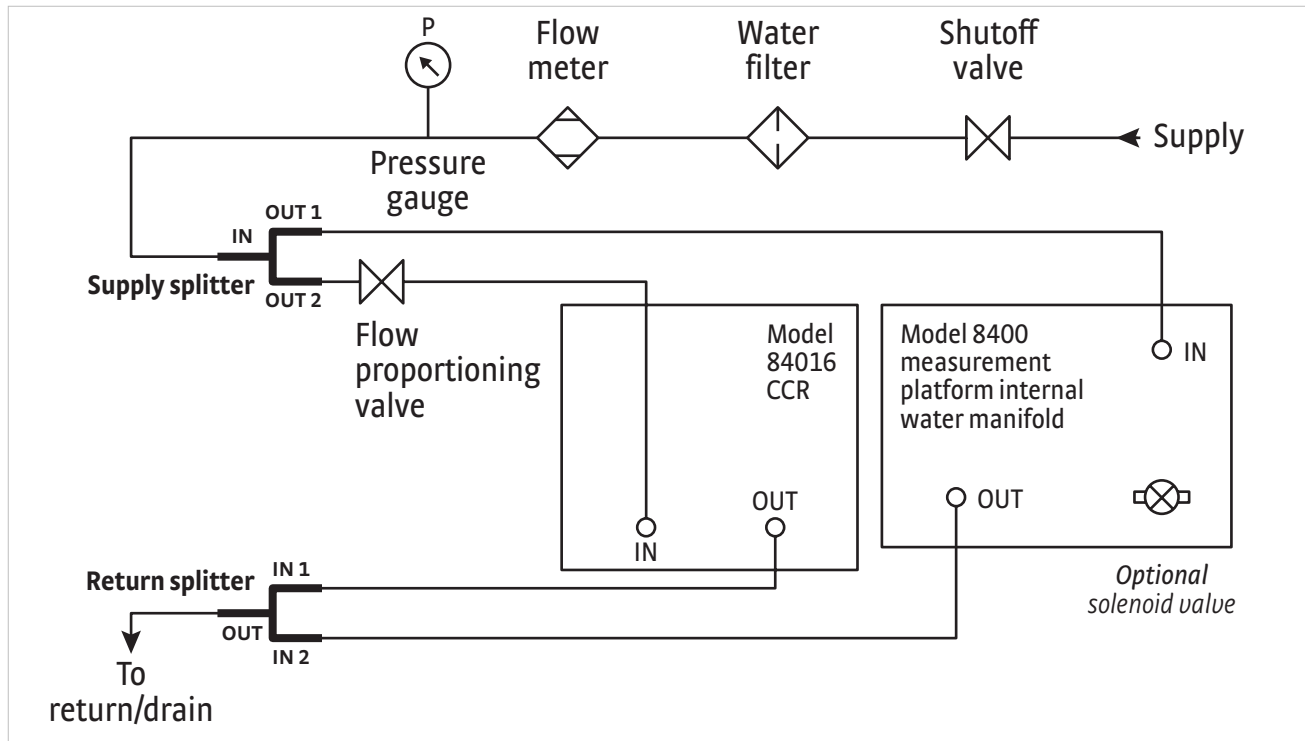


FIGURE 3-12 Water connections for the standard system with CCR

2. From the outlet of the pressure gauge, connect an appropriate length of flexible hose to the inlet of the supply splitter.
3. At outlet 1 of the supply splitter, connect an appropriate length of flexible hose to the inlet of the internal water manifold.
4. At outlet 2 of the supply splitter, attach the flow proportioning valve.
5. At the other end of the flow proportioning valve, connect an appropriate length of flexible hose to the water inlet of the CCR compressor.
6. At the outlet of the internal water manifold, connect an appropriate length of flexible hose to inlet 1 of the return splitter.
7. At the CCR water outlet, connect an appropriate length of flexible hose to inlet 2 of the return splitter.
8. At the outlet of the return splitter, connect an appropriate length of flexible hose to the cooling water system return line.

3.4.3 Voltage Selection

The console is shipped from Lake Shore with user specified line voltage selected. However, it is good practice to verify that the proper voltage is selected upon initial install. Also, if the system is being moved, or there is any reason to believe the voltage may not be appropriate for the installation site, verify line voltage settings. To check the voltage, see the instructions below.

3.4.3.1 Single Phase Voltage Selection

This section explains verification and selection of the equipment with single phase voltage.

1. Determine the single phase voltage at your site.
2. For these instruments, verify the AC line voltage indicator in the fuse drawer window shows the appropriate AC line voltage. If the correct voltage is not shown, refer to the appropriate instrument manual to change it.

- Model 776
- Keithley 2182A

- Keithley 6487 (option)
 - Keithley 6514 (option)
 - Model 336 (option)
3. These instruments auto-configure to input voltage and do not need to be changed.
 - Keithley 6220
 - Ametek 7230 (option)
 4. If you ordered the Model RC-7 single phase chiller, refer to its user's manual to verify and select single phase voltage.

3.4.3.2 3-Phase Voltage Selection

This section explains verification and selection of the equipment with 3-phase voltage.



WARNING

Lethal voltage and currents exist with 3-phase equipment. There is a risk of injury or death if an operator or technician comes in contact with these potentials.

Follow these procedures to verify and change the voltage selection for the Model 643.

1. A qualified electrician is necessary for this step: determine the 3-phase voltage at your site.
2. Locate the voltage indicator tab on the wiring cover at the rear of the Model 643 electromagnet power supply. Verify that the voltage indicator tab denotes the correct voltage.
3. If the site 3-phase voltage does not match that on the Model 643, refer to the Model 643 user's manual to change the voltage selection.

If you ordered the Model RC-7 or Model RC-10 3-phase chiller, refer to the appropriate user's manual to verify and select 3-phase voltage.

3.4.4 3-Phase Power Connections

All 3-phase electrical wiring should be completed by a qualified electrician adhering to all local codes and standards, prior to the arrival of a Lake Shore representative for installation and training.

The qualified electrician should refer to the Model 643 electromagnet power supply manual, Chapter 3, to complete the connection of 3-phase power to the Model 643. If you use a 3-phase water chiller, refer to the Water Chiller manual to complete the connection of 3-phase power to the water chiller.

3.4.5 Attach the Floor Mounting Option

This section briefly outlines the steps necessary to install the floor mounting option. You will need the Model 840950 floor mount kit.



WARNING

Consult with the facilities personnel to confirm that the floor may be modified to support the floor mounting option and to determine the location of water or gas lines that may be present.



WARNING

There are safety issues concerning the installation of the floor mounting option. These issues can vary depending upon the method and tools you use. These directions are intended only to give a brief summary of the installation process. Consult local codes and regulations before installation.

1. Place the instrument console and the measurement platform in their designated positions.
2. For the instrument console, obtain the four smaller anchoring brackets as shown in FIGURE 3-13, left.
3. Attach the brackets oriented at 45° angles from the instrument console. Attach one on each foot of the instrument console.

4. Use the hole in each of the bracket as a template, and trace their positions on the floor.

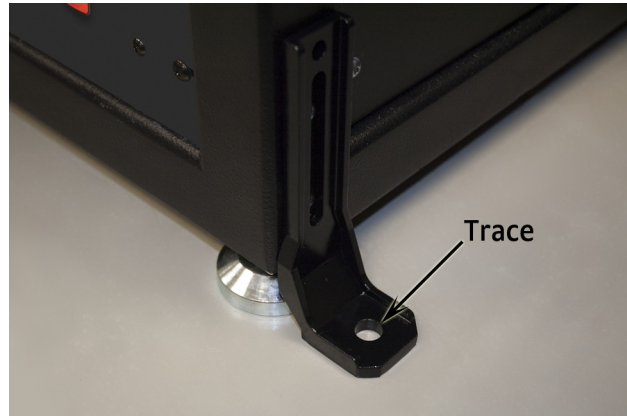
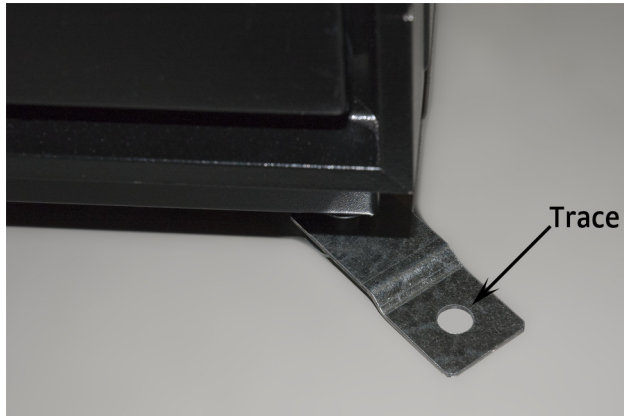


FIGURE 3-13 Floor mount

5. For the measurement platform, repeat steps 2 through 4, except use the larger anchoring brackets shown in FIGURE 3-13, right.
6. Move the instrument console and measurement platform away from their designated positions to reveal the traced circles.
7. Using the traced circles as a guide, drill mounting holes in the floor according to local codes and regulations.
8. Move the instrument console and measurement platform back to their designated positions.
9. Attach securing hardware to fasten the floor mounting straps to the floor.

3.5 Assembling a Standard Hall Measurement System Configuration

Use the following procedures to complete the assembly process. If you purchased Lake Shore training with the system, the trainer will begin at this point.

When the trainer arrives, he will take an inventory of parts to insure that they are all there. He will then confirm that the site prep has been finished. The trainer will train you on the contents of section 3.5 through the end of Chapter 3. Using these sections, you will be able to complete the operational training and verification checklist that the trainer provides you.

3.5.1 Required Tools

The following tools are required to assemble a basic Hall measurement system, and are not included with the system.

- Level
- 19 mm hex driver
- 3 mm hex driver
- 4 mm hex driver

3.5.2 Assembling the Instrument Console

This section describes preparing the instrument console and making the proper computer connections.

3.5.2.1 Setting Up the Instrument Console Surface

1. Place the top surface on the top of the instrument console. You can find the “back” of the surface by looking for the side with the wooden piece flush with the top surface (FIGURE 3-14). It should face the rear of the instrument console.
2. Place the computer, mouse and keyboard on the instrument console top surface.
3. Place the monitor on top of the computer (FIGURE 3-14).

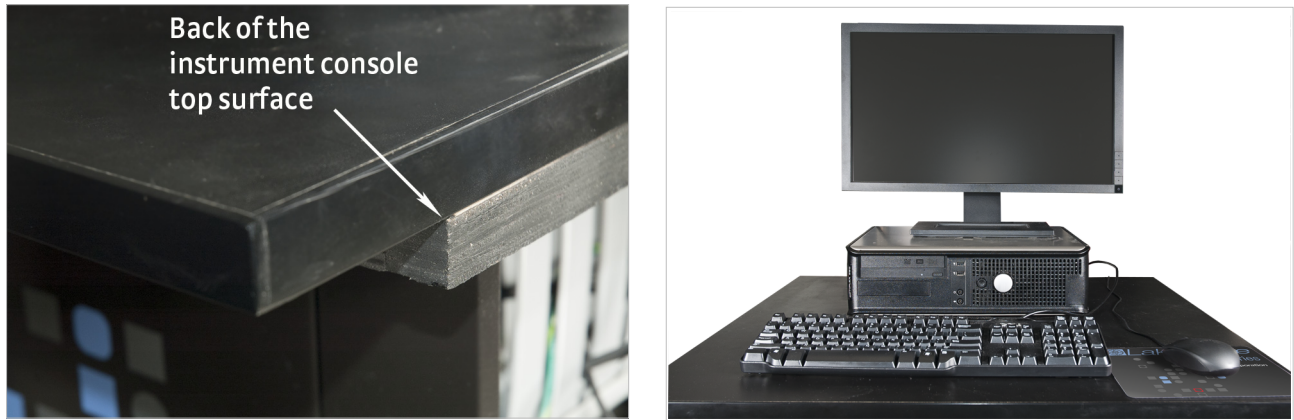


FIGURE 3-14 Left: The back of the top surface indicated by the wooden piece; Right: Instrument console with computer, mouse and keyboard

3.5.2.2 Computer Assembly

The computer connections are defined as follows (FIGURE 3-15). The monitor (not shown) also requires input and power connections.

CAUTION

Installing other software may cause conflicts with the operation of the Model 8404 and can have unintended consequences. Lake Shore assumes no responsibility for damage to the Model 8404 as the result of unauthorized software installation.

NOTE

Because of the volatility of the computer market, the computer shown here is a typical representative. Your actual computer may vary in form, but the functions will remain.

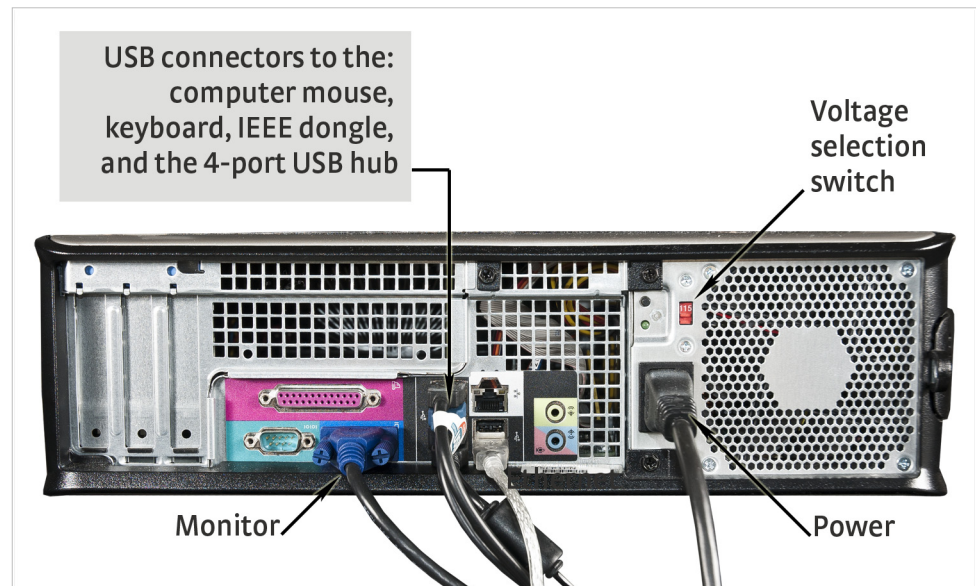


FIGURE 3-15 Computer rear panel connections

- **Monitor:** this connector goes to the computer monitor. It may have a VGA, HDMI, or DVI style cable.
- **USB connector:** this connector goes to the computer mouse.
- **USB connector:** this connector goes to the computer keyboard.
- **USB connector:** this is the USB to IEEE dongle. This connection allows communication to all IEEE compatible instruments.
- **USB connector:** this goes to the 4-port USB hub located on the interior side panel of the instrument console. This connection allows communication with USB instruments in the instrument console.
- **Ethernet:** this is the Ethernet connector for your network.

- **Power:** this power cord runs inside the instrument console and plugs into the front distribution strip. (Also run the monitor power connector to this same distribution strip.)
- **Voltage selection switch:** if your computer includes this switch, make sure it matches your local power requirements.



FIGURE 3-16 Voltage selection switch

NOTE

While Ethernet is provided with the computer, Lake Shore assumes no responsibility for making the computer communicate with your network.

3.5.2.3 Verifying Internal Cables are Attached Correctly

The internal cables have been connected at Lake Shore. However, if you have had to move the system or if you suspect an incorrect connection, refer to FIGURE 5-9 to verify that the internal cables are attached correctly.

3.5.2.4 Preparing the Cables

Remove any packaging material from the interior of the console and prepare the cables for routing. There are four main system cables in the interior of the system console:

- Main AC input cord
- Sample insert cable
- Field control cable bundle
- VT control cables (optional)

CAUTION

Do not plug in the console until the computer has been assembled. Refer to section 3.5.2.2 to assemble the computer.

Follow this procedure to prepare the cables. See FIGURE 3-17 for an illustration of the cable routing.

1. Locate the power cord in the rear of the console.
2. Route the cord to the exterior of the console through an opening in the lower plastic wiring duct located below the rear door of the electronics console.
3. Plug it into a 1-phase outlet. Refer to section 3.2.3 for power requirements.

WARNING

Do not use 2-wire (without ground) AC power. If the plug does not mate with available sockets, remove the plug and attach a plug of the correct type with equal or better rating, per local code. Use a grounded plug

NOTE

The instrument console is designed for single-phase 3-wire AC power. The power strip in the instrument console has a 3-conductor power input connector which grounds equipment in the instrument console when plugged into a 3-wire receptacle.

4. Locate and unpack the sample insert cable. The sample insert cable consists of a multifunction cable with a 22-pin connector, bundled with eight primary triaxial cables.
5. Route the sample insert cable to the exterior of the console through the upper plastic wiring duct located above the rear door of the electronics console.

6. Locate the field control cable bundle. The bundle consists of the 3 m (10 ft) IEEE-488 cable which is designated as the magnet power supply communication cable, the analog magnet program cable, and a ground cable. It will be in the console, bundled within a black vinyl jacket.
7. If you did not order the VTA, route the field control cable bundle to the exterior of the console through the lower plastic wiring duct.
8. If you ordered the VTA, follow this procedure to finish preparing these cables.
 - a. When the Model 8404 is purchased with the VTA option, the VT control cable and the VTA mount angle bracket will also be located within the console. Locate the VT control cable, unfold it, and route it to the exterior of the console through the lower plastic wiring duct.
 - b. Open the black vinyl jacket holding the field control cable bundle, and add the VT control cable to it. Remove the VTA bracket from the console, and set it aside in preparation for completing the system setup and assembly.

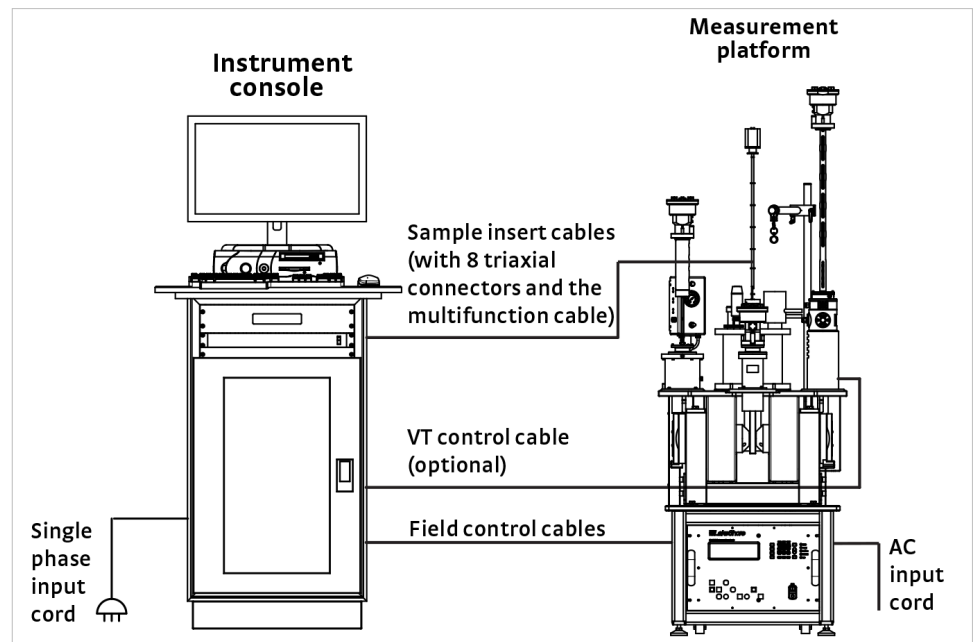


FIGURE 3-17 Cable routing

3.5.3 Assembling the Measurement Platform

This section describes assembling the measurement platform, which includes routing the cables from the console to the platform, and assembling and installing the cable boom and standard insert stand.

3.5.3.1 Attaching the Field Control Cables

There are two field control cables that exit from the rear of the console and that will need to be connected to the magnet power supply. One has an IEEE-488 connector and the other has a 15-pin D-sub connector.

- IEEE-488 magnet power supply communication cable: attach this cable to the IEEE connector on the rear of the magnet power supply (FIGURE 3-18).
- D-15 analog magnet program cable: attach this cable to the D-15 connector on the rear of the magnet power supply (FIGURE 3-18).

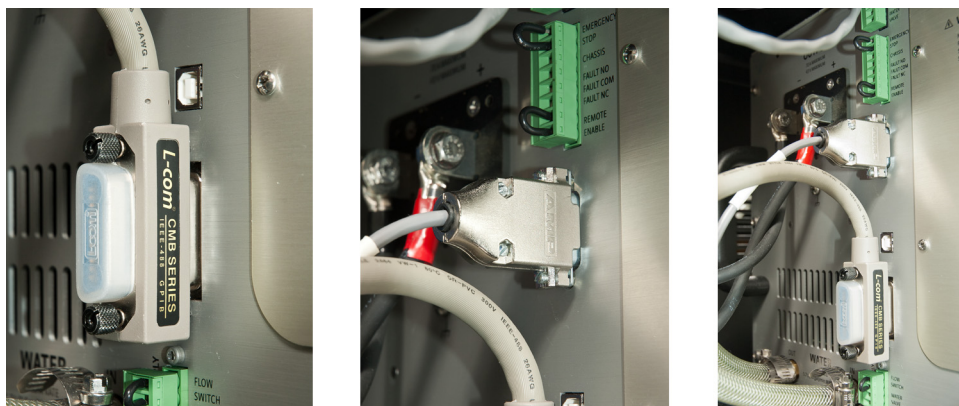


FIGURE 3-18 Left: Connection for the communication cable; Middle: Connection for the D-15 cable; Right: Context for the location of both cables

3.5.3.2 Assembling the Cable Boom

The location of the cable boom is determined by the location you chose for the instrument console. The cable boom should be mounted on the measurement platform's rear structural support, the side closest to the instrument console, (and if you purchased it, mount the sample space gas handler on the opposite side of the cable boom). The system is shipped with the cable boom mounted to the rear left structural post (FIGURE 3-19). If you mount the cable boom on the right, first remove the mounting block and re-mount it to the rear right structural post.



The purpose of the cable boom is to keep the sample insert cable back and away from the magnet pole, while still allowing for easy movement of the sample insert.

1. Using a 3 mm hex driver, loosen the M6 × 1.0 × 8 socket set screws on the mounting block (FIGURE 3-19, left)
2. Raise the vertical post so that the horizontal post is approximately eye level.
3. Tighten the socket set screws on the mounting block to secure the vertical post's position.
4. Attach the sample insert cable to the hook and loop fastener near the bottom of the vertical post (FIGURE 3-19, middle).
5. Near the other end of the cable is a hook and loop fastener with a ring. Attach the ring to the hook located on the long side of the horizontal post. Maintain enough slack in the cable so that there is a curve in it (FIGURE 3-19, right).

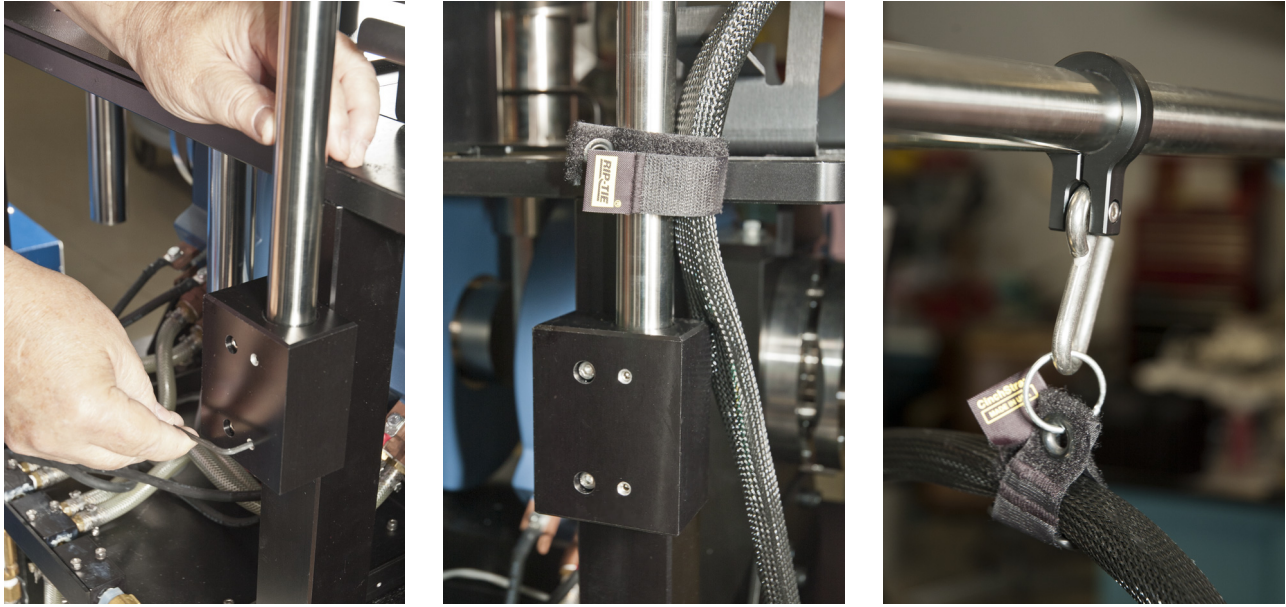


FIGURE 3-19 *Left: Loosen the screws holding the vertical post into the mounting block; Middle: Secure the cable to the cable boom vertical post; Right: Secure the cable to the cable boom horizontal post*

3.5.3.3 Mounting the Standard Insert Stand

The standard insert stand can be mounted in two different locations: either the position in front of the cable boom or the position at the front of the measurement platform. The place you choose to mount it will depend upon how many options you have (you may need to use the position in front of the cable boom for any additional options you may have purchased).

If you place it in front of the measurement platform, the square end of the stand should be placed closest to the cable boom's vertical post (as shown in FIGURE 3-20, right). If you place it in front of the cable boom, the square end should face rearward (as shown in FIGURE 3-20, left).

Use a 4 mm hex driver and the M5 × 10 mm socket cap screws to secure the stand to its position.

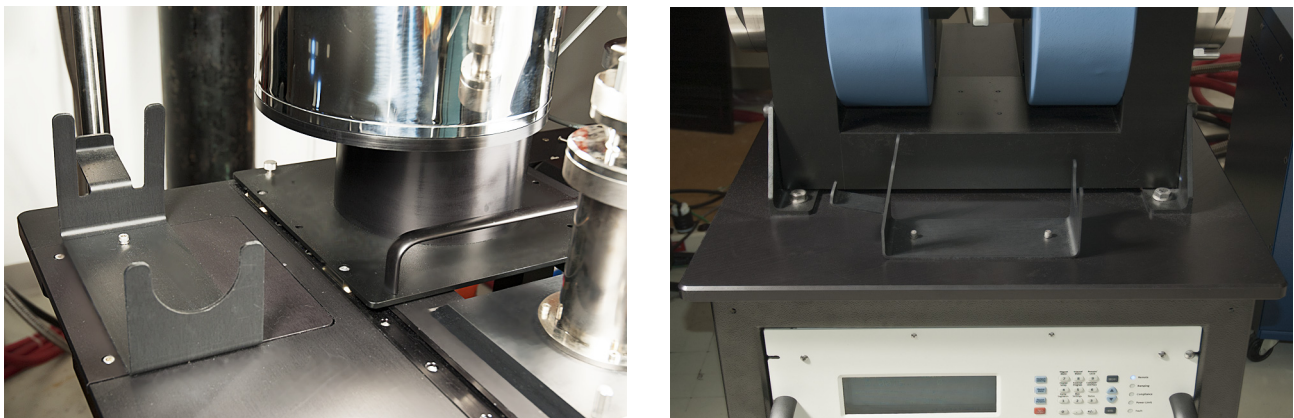


FIGURE 3-20 *Left: Orientation for the standard insert stand when it is mounted in front of the cable boom; Right: Orientation when it is mounted to the front of the measurement platform*

3.5.4 Assembling the Standard Module on the Measurement Platform

This section explains how to assemble the standard module onto the measurement platform. The standard module includes the light tight body, and standard insert, along with the exchange plate, and the captive thumb screws. The standard module is shipped with the standard spacer. If you ordered the rotation option, refer to section 3.7.2 to assemble it. Follow these instructions to mount the standard module onto the measurement platform.

1. Confirm that the magnet gap is set at 25 mm. If it is not already set at 25 mm, refer to section 4.4.1 to set it.
2. Move the standard module into the measurement position:
 - a. Position the standard module so that the captive screws are to the front of the measurement system.
 - b. Slide the standard module into the measurement position slot and push it all the way back, using the alignment guide, until the captive screws line up with their corresponding holes at the front of the alignment guide.
3. Push down on the captive thumbscrews to hand tighten them and secure the module to the measurement position.



FIGURE 3-21 *Left: Sliding the standard insert into the measurement position;
Right: Finger tighten the screws on the exchange plate to secure the module to the measurement position*

3.6 Assembling the Temperature Options

This section provides instructions for setting up the options into the storage positions. There are potentially three different places you can place a temperature option. In section 3.5.4, we placed the standard module onto the measurement position. If you did this, then you have the right and left storage positions available to you. The CCR option is always positioned on the sliding plate at the rear of the mounting support. You will need to determine the best place for the other options, depending on how many options you ordered and which options you expect to use the most.

3.6.1 Required Tools

The following tools are required to assemble the temperature options for the Hall measurement system, and are not included with the system.

- Lifting equipment (CCR)
- 2.5 mm hex driver (VTA)
- 2 mm hex driver (VTA)
- 4 mm hex driver (VTA)
- 5 mm hex driver (VTA)
- 3 mm wrench (CCR and sample rotation)

3.6.2 Assembling the Single Point LN₂ Option

To assemble the single point LN₂ option, you will need the LN₂ body, the funnel and the plug that came with the option. Follow this procedure to prepare the single point LN₂ option for future operation and place it into the storage position.

1. Choose a storage position for the single point LN₂ option.
2. Move the single point LN₂ option into the storage position:
 - a. Position the module so that the captive screws are to the outside of the measurement system.
 - b. Slide the single point LN₂ module into the storage position slot and push it all the way back, using the alignment guide, until the captive screws line up with their corresponding holes at the front of the alignment guide.
3. Push down on the captive thumbscrews to hand tighten them and secure the module to the storage position.
4. Place the funnel in the single point LN₂ body opening.
5. Place the plug, small side down, into the funnel to cover the opening.
6. Store the evacuation adapter in the console drawer.



FIGURE 3-22 Left: Proper orientation in the storage position slot; Right: Funnel and plug inserted into the single point LN₂ opening

3.6.3 Assembling the Oven Option

To assemble the Model 84017 oven option, you will need the oven and the insert that came with the option. Follow this procedure to prepare the oven option for future operation and place it into the storage position.

1. Choose a storage position for the oven module.
2. Move the oven module into the storage position.
 - a. Position the module so that the captive screws are to the outside of the measurement system.
 - b. Slide the oven module into the storage position slot and push it all the way back, using the alignment guide, until the captive screws line up with their corresponding holes at the front of the alignment guide (FIGURE 3-22).
3. Push down on the captive thumbscrews to hand tighten them and secure the module to the storage position.

To finish preparing the oven for operation, follow the procedures in section 3.6.5 to set up the VTA option, section 3.6.6 to prepare the vacuum pump and section 4.5.2 to operate the oven module.

3.6.4 Assembling the Closed Cycle Refrigerator Option

This section provides instructions on positioning the CCR module into its position at the rear of the measurement position.

! WARNING

The CCR (cold head, compressor, and flexible helium lines) contain high pressure (1.41 MPa (205 psig) helium gas. Hitting the equipment with a sharp edge or pointed object may cause explosion or rapid escape of gas.

! WARNING

The minimum bend radius of the flexible helium lines is 150 mm (5.9 in); the bend radius must be increased to 300 mm (11.8 in) at the connection point to the compressor and cold head. Bending the flexible helium lines at a smaller angle may cause explosion or rapid escape of gas.

! WARNING

The CCR module is approximately 50 lbs; this, combined with lifting it above the measurement platform makes it necessary to use lifting equipment. Failure to use proper lifting equipment may result in injury to personnel, or damage to the system.

! CAUTION

Inspect the flat rubber gasket of the flexible helium line connections at both the cold head and the compressor unit for dirt, dust, and proper fitting before connecting the flexible lines. Connection of the lines with abnormal fitting may cause escape of the helium gas.

! CAUTION

With the connection of both flexible helium lines to the compressor unit, always connect the return line first and then the supply line. The opposite order may cause misoperation.

3.6.4.1 Assembling the CCR onto the Measurement Platform

1. Ensure that the CCR insert is not installed.
2. Install the expandable plug into the port on the body to seal it. The expandable plug was shipped with the CCR.
3. Verify that the magnet air gap is at least 50 mm (2 in). If it is not, follow the procedures in section 4.4.1 to change the air gap.
4. Slide the forward set of carriers to the front of the track.
5. Measure 158.75 mm (6.25 in) from the front of the sliding track, and slide the rearmost set of carriers to that position.
6. Connect the lifting equipment eyelets to the lifting lugs on the CCR.

! CAUTION

Before lifting the CCR, ensure the lifting straps are not applying pressure at any point on the CCR. Failure to comply may cause damage to the CCR.

7. Lift the CCR module in line with the front of the measurement position (FIGURE 3-23).
8. Slide the CCR module all the way back to the rear of the measuring position.
9. Using a 3 mm hex driver, tighten the M5 × 8 mm screws on the CCR exchange plate to lock it into place.
10. Align the pin plunger on the exchange plate to the bushing on the track

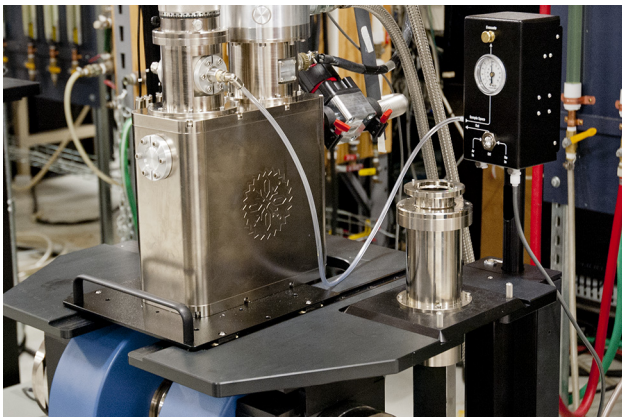


FIGURE 3-23 Left: Position the CCR module in front of the measuring position, so that the exchange plate lines up with the slot; Right: Tighten the screws on the CCR exchange plate once the module is in its position

3.6.4.2 Flexible Helium Line Connection

Follow these procedures to connect the flexible helium lines to the cold head and to the compressor unit.

1. Remove the protective caps from the supply and return ports of both the compressor and the cold head. Put them in the toolkit for later use.
2. Remove the protective caps from both ends of both helium lines.
3. Check that the flat rubber gaskets are clean and in place on each supply/return connection on the compressor and cold head (FIGURE 3-24).
4. When making each connection of the flexible helium lines in steps 4 through 7, follow the steps below to ensure that the gas seal is not compromised, allowing the helium gas to escape.
 - a. Using your fingers, start the threading of the self-sealing nut.
 - b. Using the two wrenches provided in the CCR tool set, tighten the self-sealing nut. Hold the nut with one wrench and turn with the other as shown in FIGURE 3-24. Do not over tighten; the maximum allowable torque is 50 Nm.

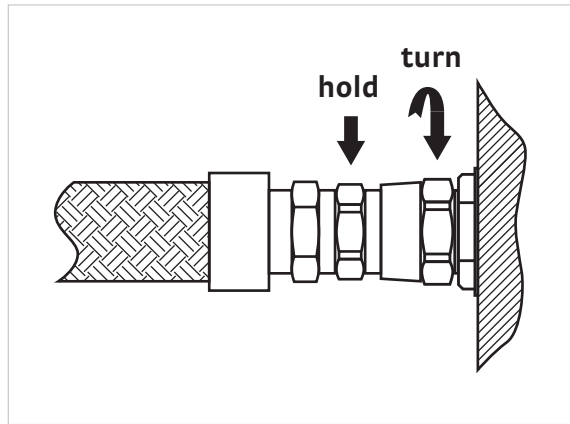


FIGURE 3-24 Placement of wrenches on the self-sealing nut

5. Connect the return line to the compressor unit.
6. Connect the supply line to the compressor unit.
7. Connect the return line to the cold head.
8. Connect the supply line to the cold head.

3.6.4.3 CCR Module Electrical Connections

1. Locate the expander cord (FIGURE 3-25) and make the following connections to prepare the compressor:
 - a. Connect the 28-pin connector into the expander power connection on the back of the compressor (FIGURE 3-25).

- b. Connect the 4-pin connector into the 4-pin connection on the top rear of the CCR module's cold head (FIGURE 3-25).



FIGURE 3-25 Left: Connect the 28-pin connector into the expander power connection; Right: Connect the 4-pin connector into the 4-pin connection on the CCR module's cold head

2. Locate the CCR cable (FIGURE 3-26) and make the following connections to prepare the CCR:
 - a. Connect the 18-pin connector to the feedthrough on the left side of the coldhead (FIGURE 3-26).
 - b. Connect the 4-pin connector to the connection at the rear of the CCR (FIGURE 3-26).



FIGURE 3-26 Left: Connect the 10-pin connector to the feedthrough; Right: Connect the 4-pin connector to the rear of the CCR

3. Install the CCR insert following the procedures in section 4.5.5.5.
4. Locate the CCR insert cable (FIGURE 3-27) and make the following connections to prepare the CCR insert:
 - a. Connect the 10-pin connector to the top connection on the CCR insert (FIGURE 3-27).
 - b. Connect the 8-pin connector to the lower connection on the CCR insert (FIGURE 3-27).
 - c. Connect the six triaxial cables to the top connections on the insert.

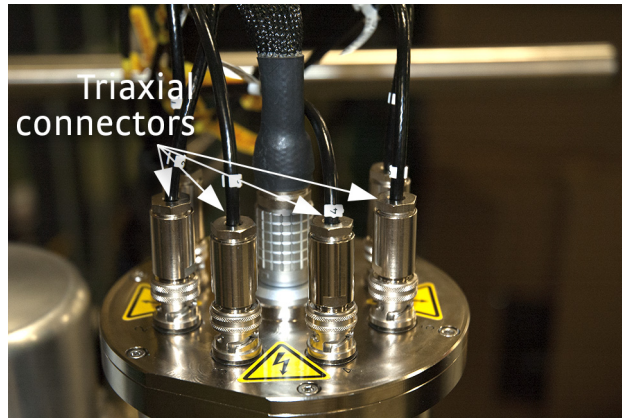


FIGURE 3-27 *Left: Connect the 10-pin connector to the top connection on the CCR insert and the 8-pin connector to the lower connection on the CCR insert; Right: Connect the triaxial connectors to the top of the insert*

3.6.4.4 CCR Module Vacuum Connections

1. Remove the blank-off from the closed isolation valve on the back of the CCR.
2. Using the clamp and centering ring, connect the stainless steel vacuum line to the closed vacuum supply valve.
3. Connect the other end of the flexible line to the top opening on the vacuum supply bracket at the rear of the measurement platform

3.6.5 Mounting the VTA Option

There are five main components to be concerned with when mounting the VTA option:

- VTA option plate (which includes a connector, VTA mount, and VT control connector and cable bundle)
- Sample space gas handler
- He and Ar gas line bundle
- Wireway cover (attached to the VTA mount)
- Electronics: the Model 336 is already mounted in the instrument console

Mount the sample space gas handler on the side opposite the place where you mounted the cable boom. The system was shipped with the VTA mount installed on the right side. When mounting the sample space gas handler on the left side, follow step 2 to remove the VTA mount as well.

Follow these instructions to mount the sample space gas handler onto the measurement platform:

1. Using a 2.5 mm hex driver, remove the four screws on the wireway cover; remove the cover and set it aside (FIGURE 3-28).



FIGURE 3-28 Remove the screws on the wireway cover and remove the cover

2. If you want to mount the sample space gas handler on the left side, follow this procedure to remove the VTA mount from the right side and remount it on the left side:
 - a. Detach the VTA option plate from the VTA mount by using a 2 mm hex driver to unscrew the four screws on the VTA mount.
 - b. Align the bolt-holes on the VTA mount with the corresponding bolt-holes on the left structural post. Using a 5 mm hex driver and the four bolts provided, attach the VTA mount to the rear left structural post on the measurement platform.
3. Insert the sample space gas handler post through the hole on the VTA option plate. Be sure the face of the sample space gas handler faces front.
4. Using a 4 mm hex driver, tighten the M5 × 0.8 × 25 socket head screw on the clamp under the VTA option plate to secure the sample space gas handler post to the rear structural post (FIGURE 3-29).



FIGURE 3-29 Left: Sample space gas handler inserted through the hole on the VTA option plate (view from the rear); Right: Location for the screw under the VTA option plate to secure the sample space gas handler post

5. Obtain the He and/or Ar gas line and the supplied clippard hose coupler. Push the hose coupler onto the gas line to connect them (FIGURE 3-30).

6. Insert the gas supply end of the He and/or Ar gas line into the oval-shaped hole on the sample space gas handler post and pull it through the bottom (FIGURE 3-30).

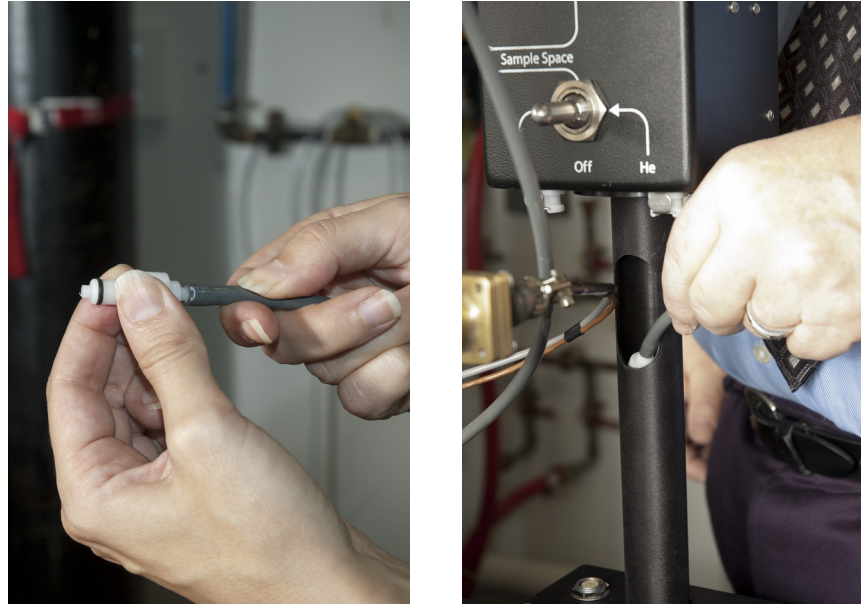


FIGURE 3-30 *Left: Attaching the coupler to the gas line;
Right: Routing the gas lines through the sample space gas handler*

7. Attach the other end of the coupler to the corresponding He and/or Ar gas inlets on the sample space gas handler (FIGURE 3-31).

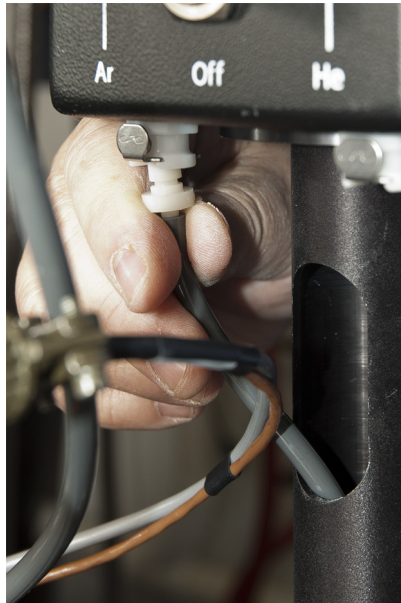


FIGURE 3-31 *Attaching the coupler to the corresponding gas inlet on the sample space gas handler*

! CAUTION

Avoid pinching or kinking the gas tubing when you insert it into position.

8. Replace the wireway cover using a 2.5 mm hex driver to screw in the four screws.
9. Ensure the helium gas cylinder is properly secured as per local code.
10. Attach the gas supply end of the He and/or Ar gas line to the appropriate customer-supplied regulator and gas supply tank, specified in section 3.2.7.

3.6.5.1 VTA Dial Gauge Zeroing/Burping

The VTA diaphragm requires a “burping” procedure for proper operation.



The gauge does not need to read zero for this process. It is a general indicator for positive and negative pressure.

1. Remove the four back cover screws.



FIGURE 3-32 Remove the back cover screws

2. Locate the gauge's diaphragm.
 - a. *Option 1:* Gently push on the side of the diaphragm to release the seal. Hold for a few seconds and allow the diaphragm to seal again. (This method is preferable if you move the system in the future.)
 - b. *Option 2:* Cut the nipple on the diaphragm.



Oil will leak from the cut at the nipple if the gauge is stored on its side. Avoid cutting or perforating the diaphragm.

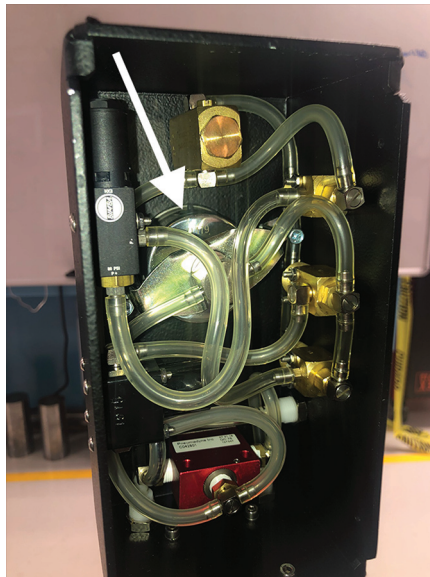


FIGURE 3-33 Diaphragm

3. Verify the dial gauge is in the zero area.
4. Reinstall the back cover screws.

3.6.6 Assembling the Turbo Pumping System

There are two types of vacuum pumps available with the Model 8404: the Model TPS-FRG turbo pumping system and the PS-E2M two stage rotary oil pump. Before assembling the turbo vacuum pump with the Model 8404, it is a good idea to test the turbo vacuum pump alone. FIGURE 3-34 and section FIGURE 3-35 shows the assembled turbo pumping system.

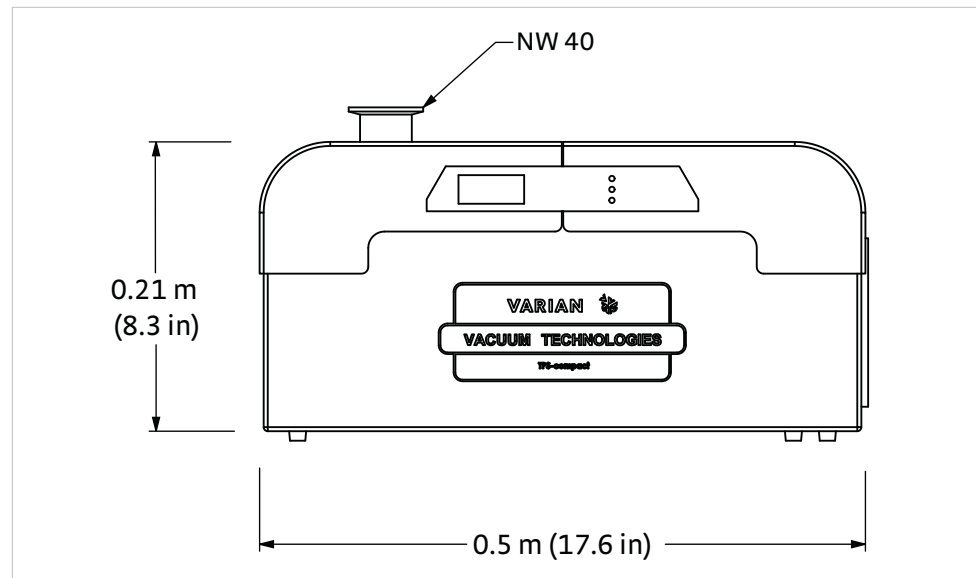


FIGURE 3-34 Assembled turbo pumping system and its connections



FIGURE 3-35 Rotary oil pump

3.6.6.1 Assembling the Turbo Pump

The Model TPS-FRG turbo pumping system is the pump necessary for the CCR module. Some steps in these procedures will require you to attach a flexible vacuum line to the turbo pump. You will need appropriately sized centering rings and clamps. Refer to these instructions to attach the vacuum lines when indicated.

1. Remove any protective caps from the fittings to which you are attaching the vacuum line.
2. Place the appropriately sized centering ring on the top of the fitting on the pump.
3. Holding the centering ring in place, set the vacuum line against it.
4. Close the clamp around the fitting.
5. Finger tighten the clamp with the accompanying screw.

If you purchased the turbo pump specified by Lake Shore, follow this procedure to prepare it. Locate the turbo pumping kit in the accessories box. It contains the necessary fittings to connect the turbo pump to the Model 8404.

1. If the vacuum gauge is not already installed on the turbo vacuum pump as shown in FIGURE 3-36, remove the protective cap from the pump.
2. Attach the NW 40-to-25 adapter to the pump.
3. Use the provided NW 25 tee, clamps and centering rings to attach the gauge as shown in FIGURE 3-36. Use steps a through e in this section as a guide.
4. Attach the supplied gauge cable to the connector (FIGURE 3-36). If not already done, attach the other end of the cable to the connector on the back of the turbo pumping system.
5. Attach the NW 25 vacuum line to the upper NW 25 connection.

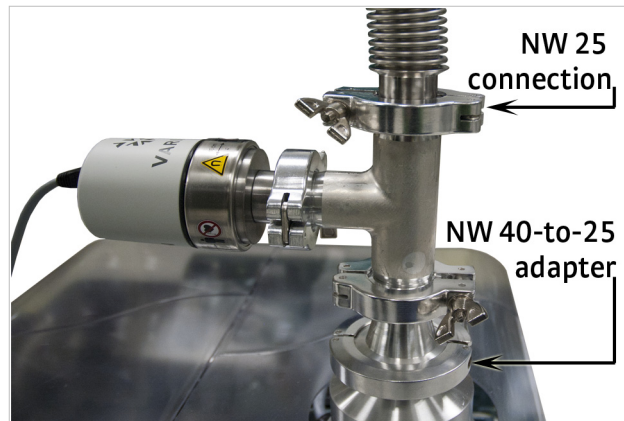


FIGURE 3-36 Install the vacuum line to the pump

6. Locate the vacuum supply bracket. Using the provided screws, attach the bracket to the rear structural support as shown in FIGURE 3-37.
7. Attach the free end of the vacuum line to the bottom opening of the NW 25 feedthrough on the vacuum supply bracket at the rear of the measurement platform (FIGURE 3-37).

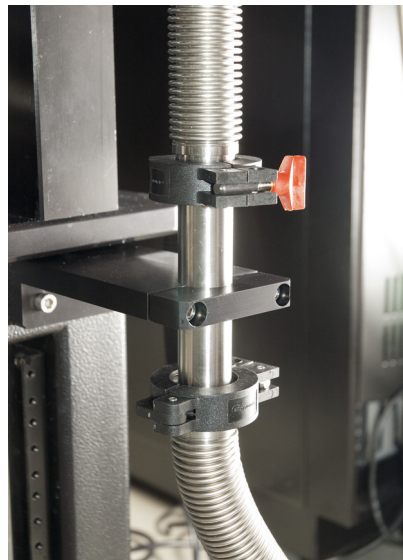


FIGURE 3-37 Vacuum supply bracket on the measurement platform (image shown with the CCR stainless steel vacuum line attached to the top opening; the oven uses a plastic flexible line)

8. Connect the power cord to the turbo pumping system (refer to TABLE 3-1 for power requirements).

3.6.6.2 Assembling the Rotary Oil Pump

1. Assemble the pump according to the instructions provided in the vacuum pump user's manual.
2. If you have a rotary pump, add the oil according to the instructions in the pump's user manual.
3. Attach the mist filter.
4. Connect the NW flanges and lines.

3.7 Assembling the Measurement Options

The measurement options include the electronic options (AC field Hall measurement option, the high resistance option and the gate bias option), the sample rotation option, and the optical access body. This section provides procedures and or references to assembling and configuring these options.

3.7.1 Assembling the Electronic Options

The electronic options consist of the AC field Hall measurement option, the high resistance option and the gate bias option. These require no assembly if you ordered them at the same time as you ordered the Model 8404. If you ordered them subsequent to the purchase of your Model 8404, the electronics will need to be configured.

3.7.2 Assembling the Sample Rotation Option

Rotation applies only to the 10 mm sample cards; the 50 mm sample cards do not fit in the sample rotation option. This procedure is written for installing the sample rotation option on the standard module. However, this option can be installed in the same way on the LN₂ module and the optical access light tight body. Refer to section 4.3.4.2 to operate the sample rotation option. Use this procedure to install the sample rotation option.

1. Remove the standard insert from the light tight body and place it on the sample insert stand. Using the 3 mm hex driver, unscrew the four screws from the standard spacer's lower flange (FIGURE 3-38).
2. Remove the spacer; be sure that the o-ring is seated properly on the o-ring groove of the light tight body.
3. On the sample rotation option, if the friction lock is tightened, loosen it.



FIGURE 3-38 Left: Unscrew the four screws from the spacer's lower flange; Right: Loosen the friction lock;

4. Pull out to release the locking pin from the indexed position. Keep it pulled out through the next step.

NOTE

If you release the pin while you are rotating the insert, and you do not turn the pin to lock it, the pin will automatically engage in the next indexed location.

5. Rotate the index dial so that 0° is at the indexing mark (FIGURE 3-39).
6. Release the locking pin.
7. Place the sample rotation option on the body so that the option's 0° index mark faces forward (in the same direction as the thumbscrews). Screw in the four screws in the counter-bored holes on the lower flange.
8. Using a hex driver, tighten the bolts on the lower flange of the rotation stage.

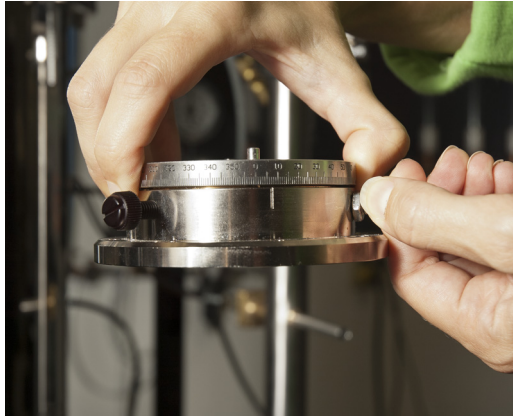


FIGURE 3-39 Left: Pulling out on the locking pin; Right: Setting the index dial to 0°

9. Install the standard insert into the light tight body.

3.7.3 Assembling the Optical Access Body Option

The assembly for the optical access body is nearly the same as it is for the standard module. Use the procedure in section 3.5.4, but take these items into consideration:

- The standard module will already be in the measurement position, so you will need to place the optical access body in one of the storage positions.
- The optical access body uses the standard insert; therefore, if the standard insert is in the light tight body, the optical access body can be placed in the storage position.

3.8 Model 8404 Verification and Testing

This section describes a sequence of short tests that can be used to verify that the Model 8404 has been assembled correctly and is in good working order. These tests should be done after installing the system and after making changes to the system configuration.

These procedures assume that the station has been fully assembled as described in section 3.5.

3.8.1 Verifying Instrument Console Power

The instrument console is a housing cabinet that includes the following standard instrumentation: the Model 776 Hall matrix, the 6220 Keithley current source, the 2182A Keithley nanovoltmeter. It may also include other instrumentation as a part of the options you purchase for your system.

3.8.1.1 Verifying Voltages

The console is shipped from Lake Shore with user specified line voltage selected. If the system is being moved, or there is any reason to believe the voltage may not be appropriate for the installation site, please verify line voltage settings. Refer to section 3.4.3 to verify the voltage.

3.8.1.2 Preliminary System Checks

Before verifying the power, it is important to physically check for any leaks in the flexible lines used in the cooling system.

1. Ensure the standard module is in position and all electrical connections have been made (section 3.5.4 and section 4.3.3).

2. Open the water valve that supplies water to your system.
3. As the water flows, look for any leaks, and also feel around the tubing for leaks.
4. On the front right hand side of the instrument console, near the top, you will find a rocker switch. This is the main power switch. Turn it on and verify the light comes on.
5. Turn on the computer and monitor.
6. Turn on the magnet power supply.
7. On the computer, click on the 8400 Series software icon to start the program. Verify that no fault messages appear upon opening the software. If a fault appears, refer to section 5.3.7.2.
8. On the 8400 Series HMS interface, look on the monitor pane for the phrase “Model 84000 standard insert” (the identification should reflect the module that is currently positioned in the measuring position).

3.8.2 Verifying the Standard System

This section verifies field performance, power supply, and the electrical limits. These tests have been run at Lake Shore as part of the quality check, but we run them again during the on-site installation to assure the system was not damaged during shipping.

3.8.2.1 Verifying Basic Operation: Run Indium Arsenide

Refer to section 1.3 of the Software Manual for the 8400 Series AC/DC Hall Effect Measurement System, to run the indium arsenide sample. This will take you through the three-step DC Hall measurement, consisting of the ohm check, resistivity, and Hall voltage measurements.

Verify the carrier type is N. This result verifies basic operation of the system. If you do not get this result, refer to section 5.3.1.2.1 for troubleshooting.

3.8.2.2 Verifying Basic System Limits

The following tests will verify the basic system limits and are tests that the installer will run for you. These tests include the following:

- 10 MΩ
- 0.5 mΩ

Chapter 4: Hardware Operation

4.1 General

This chapter describes the majority of daily hardware operation. The system software is described in detail in the Software Manual for the 8400 Series AC/DC Hall Effect Measurement System. This chapter assumes that the system has been installed and set up as described in Chapter 3.

4.2 Preparing the System for Operation

During periods of normal usage, the system should remain powered on for best performance. This eliminates the need to wait for instrumentation to reach thermal stability before use. If the system is powered down, it requires one hour to reach thermal stability.

4.2.1 System Startup

1. Turn the instrument console on using the power switch located above the front console door (FIGURE 4-1).
2. Turn the computer on using its power switch.
3. Turn on the system cooling water at the user-supplied shutoff valve.
4. Turn on the electromagnet power supply by using the power switch located on its front panel.
5. Start the system software by clicking the 8400 Series software icon on the desktop or startup menu.
6. Confirm that there are no error messages displayed by the system software.



If a magnet power supply interlock error is displayed, refer to section 5.3.4.1 to remove the error.

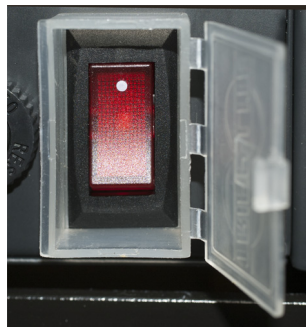


FIGURE 4-1 Instrument console power switch

4.2.2 System Shutdown

When the system is not being used, the following procedure should be used to power off the system.

1. Exit the system software.
2. Turn off the electromagnet power supply by using the power switch located on its front panel.
3. Turn off the system cooling water at the user-supplied shutoff valve.



Keep AC power to the electronics on unless you are shutting down for an extended period of time.

If the system will not be used for an extended period, perform these additional steps:

- a. Turn off the PC.
- b. Turn off the instrument console power.

4.2.3 Preparation Before Removing and Installing All Sample Modules

Before removing or installing any sample module, it is important to ensure that the system is in the neutral state. The system is in the neutral state when all environmental variables and sample excitation have been turned off. To establish the neutral state, simply press **Abort** on the HMS software ribbon.

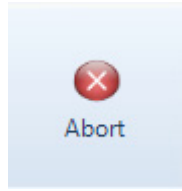


FIGURE 4-2 *Abort on the HMS software ribbon*

The following environmental variables and sample excitation are turned off:

- Field
- Temperature
- Gate Bias
- Current

When these have been turned off, it is safe to proceed with removing and installing the sample module.



If you are using the oven module, it could take over an hour for the oven insert to cool below 60 °C (140 °F). Removing a hot oven insert can result in serious injuries.



In the event that you do not turn off the environmental variables and the sample excitation, each insert is equipped with a safety interlock that will force the system into neutral. However, do not rely on this, as it is best practice to actively ensure that the system is neutral.

4.3 Operating the Standard System Hardware

This section explains how to set up the standard module on the measurement position, make the electrical connections, and remove the standard module from the measurement position. It then details procedures for mounting a sample, making a sample exchange and rotating the sample. The text in this section is written assuming that you are starting with a system that has no sample in it.

4.3.1 Operating the Standard Module

This section explains how to position the standard module for measurements, make the electrical connections, and remove the standard module from the measurement platform. The standard module includes the light tight body, the standard insert with the standard spacer or the sample rotation option, along with the exchange plate and captive thumb screws. Follow these instructions to mount the standard module onto the measurement platform.

4.3.1.1 Moving the Standard Module into the Measurement Position

Follow this procedure to set up the standard module on the measurement position.

1. Place the system in neutral by pressing **Abort** on the HMS software ribbon (section 4.2.3).
2. Use TABLE 4-2 to determine the air gap setting. Follow the procedures in section 4.4.1 to change the air gap setting if necessary.
3. If the magnet air gap or pole caps have changed, calibrate the system (section 5.2.12)



Changing the air gap requires recalibration of the system. Using a larger gap than recommended in TABLE 4-2 is acceptable, but will result in lower applied fields.

4. Move the standard module into the measurement position:
 - a. Position the standard module so that the captive screws are to the front of the measurement system.
 - b. Slide the standard module into the measurement position slot and push it all the way back, using the alignment guide, until the captive screws line up with their corresponding holes at the front of the alignment guide (FIGURE 4-3).
5. Push down on the captive thumbscrews to hand tighten them and secure the module to the measurement position (FIGURE 4-3).

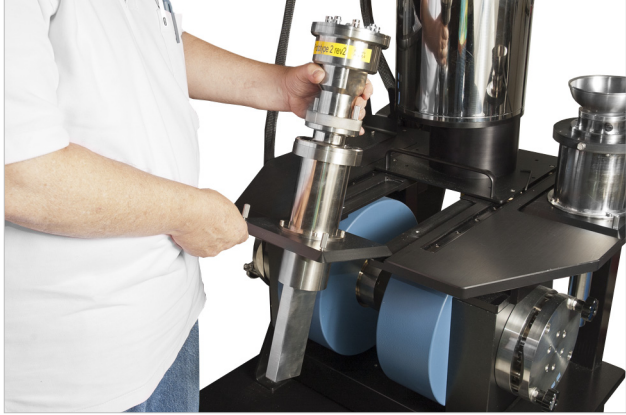


FIGURE 4-3 *Left: Sliding the standard insert into the measurement position;
Right: Finger tighten the screws on the exchange plate to secure the module to the measurement position*

6. If the magnet air gap or pole caps have changed, calibrate the system (section 5.2.12).

4.3.1.2 Electrical Connections

Follow these procedures to complete the electrical connections for the standard module. For this procedure, it is assumed the cable boom has already been mounted as described in section 3.5.3.2.

! WARNING

It is important to make the connections in the order listed here, as hazardous live voltage may exist on the triaxial connectors. Failure to comply may result in death or injury to personnel.

1. Attach the cable mounting ring on the sample insert cable to the hook located on the cable boom's horizontal post.

2. Locate the triaxial cables on the sample insert cable. Connect the triaxial cables to the standard insert, according to the numbers on each connector that corresponds to the numbers on the standard insert (FIGURE 4-4).

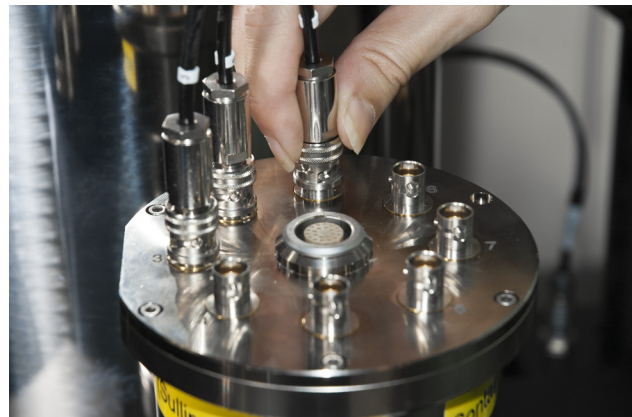
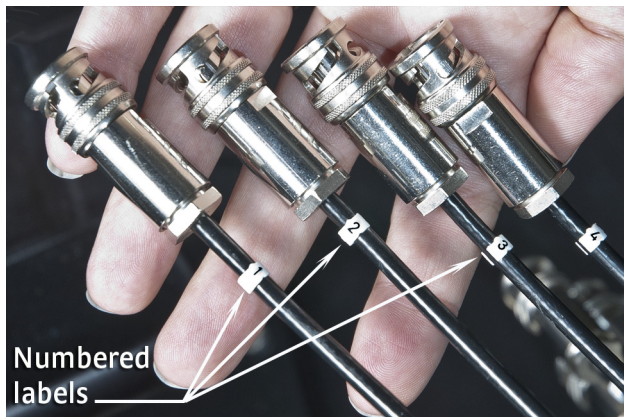


FIGURE 4-4 Left: Each triaxial cable is numbered to correspond to a number on the standard insert;
Right: Connect the triaxial cables to the standard insert

3. Connect the 22-pin multifunction cable connector to the standard insert's 22-pin receptacle, using the red index mark on the insert and cable connector to align them.



FIGURE 4-5 Connect the multifunction cable

! WARNING



Do not remove the triaxial connectors when the multifunction cable is attached to the installed insert. It is important to make/break the connections in the order listed here, as hazardous live voltage may exist on the triaxial connectors. Failure to comply may result in death or injury to personnel.

4.3.1.3 Removing the Standard Module from the Measurement Position

This text is written assuming you have finished running sample measurements and there is still a sample inside the standard insert. These steps will assist you in removing the standard module in order to place a different module on the measurement position.

1. Place the system in neutral by pressing **Abort** on the HMS software ribbon (section 4.2.3).
2. Ensure a storage position is available on the measurement platform.

! WARNING

It is important to break the connections in the order listed here, as hazardous live voltage may exist on the triaxial connectors. Failure to comply may result in death or injury to personnel.

3. Holding onto the silver locking sleeve of the multifunction cable, pull to disconnect it from the standard insert (FIGURE 4-6).
4. Disconnect the triaxial cables from the top of the standard insert.
5. If sample removal is desired, remove the standard insert from the light tight body, and the sample card from the standard insert (section 4.3.3.1).
6. Replace the standard insert in the light tight body (section 4.3.3.2).
7. Loosen both captive thumbscrews on the exchange plate.
8. Carefully slide the module out of the measurement position, ensuring that you do not hit the bottom of the light tight body on the measurement platform (FIGURE 4-6).



FIGURE 4-6 Left: Pull the multifunction cable as shown to disconnect it; Right: Slide the module out of the measurement position; do not hit the bottom of the light tight body on the measurement platform

9. Carefully place the module in the designated storage position.
10. Tighten the captive thumbscrews on the exchange plate to secure the standard module in the storage position.

4.3.2 Mounting a Sample

This section provides an overview of the sample card components and step-by-step instructions for mounting a sample on a sample card for measurement in the standard insert. Contact to the sample is made with either soldered wires or proper pins, depending on the sample card in use.

NOTE

Always use gloves to handle the sample and sample card. Oil from your skin can alter measurements on high resistance samples and can alter chemically reactive sample materials.

4.3.2.1 Sample Card Components

All sample cards are constructed so that they can be used multiple times if desired. Proper care and handling will prolong the use of the sample card, but they will need to be replaced periodically. Spare or backup sample cards should always be kept in reserve so that you can quickly replace the active cards if necessary.

FIGURE 4-7 and FIGURE 4-8 show images of the various sample cards and their components. The components are explained in section 4.3.2.1.1 through section 4.3.2.1.3.

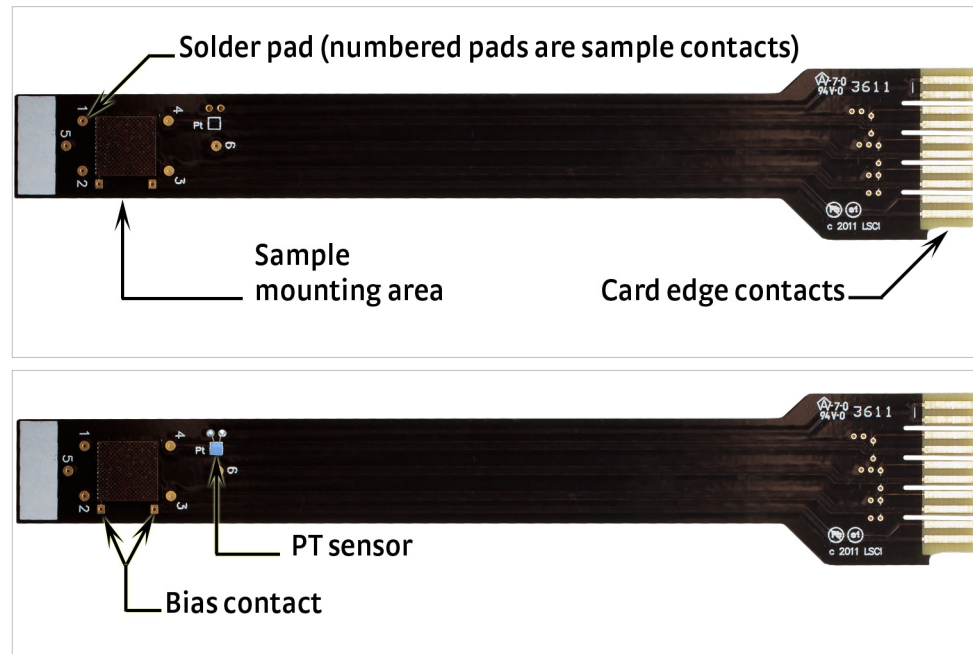


FIGURE 4-7 Top: 10 mm solder pad sample card; Bottom: 10 mm solder pad sample card with PT sensor

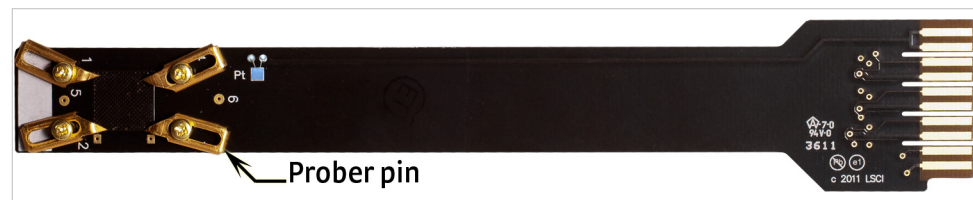


FIGURE 4-8 10 mm probe pin sample card with PT sensor

Model	Description	Limits
Model EMP-HP-SC-10-P	10 mm probe pin sample card with PT sensor	10 mm × 10 mm × 3 mm
Model 840911	50 mm probe pin sample card with PT sensor	50 mm × 50 mm × 3 mm
Model 840930	10 mm solder pad sample card	10 mm × 10 mm × 3 mm
Model EMP-HP-SC-10-S	Five 10 mm solder pad sample cards	10 mm × 10 mm × 3 mm
Model EMP-HP-SC-10-S	10 mm solder pad sample card with PT sensor	10 mm × 10 mm × 3 mm

TABLE 4-1 Sample card part numbers and size limits

4.3.2.1.1 Sample Card Edge Contacts

Each sample card has 20 gold-plated card edge contacts. These make electrical connection to the card edge connector in the insert. Finger oils and other contaminants on the contacts may alter measurement results.

4.3.2.1.2 Sample Card Contact Pads

Depending on the type of sample card, a variety of user accessible contact pads or probe pins are present near the sample mounting area of a sample card. Eight sample contacts are present on solder pad sample cards. Van der Pauw measurements use guarded contacts one through four. Contacts five and six are for future expansion of the 8400 Series HMS. Contacts seven and eight are for measurements that require gate bias voltage. Refer to section 2.3.3.4 for more information on gate bias.

Each of the numbered contact pads correspond to a guarded signal line. Routing the driven guards onto the card minimizes leakage currents, allowing more accurate measurements on very high resistance samples. Solder pad sample cards are also available with a PT temperature sensor already mounted on them. Prober pin sample cards differ in that they have four prober pins representing contacts one through four, along with two contact pads for gate bias. PT temperature sensor contacts are always populated on the prober pin card.

4.3.2.1.3 Sample Contacts

Standard solder pad sample cards have solder pads where wires from the sample are connected to the card. Soldered contacts are the most reliable, but take more time and effort to make. Samples can be pre-mounted and stored for rapid insertion and measurement in the standard module.

Prober pin sample cards have prober pins to contact the sample. They are available in sizes to accommodate up to 10 mm and up to 50 mm samples. The prober pins are present on contacts 1 through 4 only. Samples mounted on prober pin sample cards can be rapidly mounted and demounted. The contact size and metallurgy can have a significant impact on measurement accuracy.

Refer to section 2.4 for general Hall effect measurement theory and a discussion of Hall sample geometries.

4.3.2.2 Sample Mounting Materials and Tools

This list contains the tools and materials necessary for mounting a sample to the solder pad sample card.

- Gloves
- Pen (provided by Lake Shore)*
- Solder pad sample card (provided by Lake Shore)*
- Lead wire (provided by Lake Shore)*
- Indium (provided by Lake Shore)*
- Glass microscope slide
- Solder for the contact pad: any lead free electronic solder
- Solder for the sample: indium solder, silver paste, conducting epoxies, etc. depending on the material
- Flux: use the flux that goes with the solder, but only use it on the contact pad

** Initial stock included in the shipment of your 8400 Series HMS*

NOTE

Do not use flux on the sample material because the flux can damage the sample.

- Soldering iron with fine pointed tip
- Magnifying lens or microscope
- Tweezers
- Toothpick
- Cotton swabs
- Adhesive such as double sided Kapton® tape or Elmer's® rubber cement (also known as art gum, commonly available at stationary or art supply stores); grease such as silicone vacuum grease may also be used

This list contains the tools and materials necessary for mounting a sample to the prober pin sample card.

- Gloves
- Pen
- Prober pin sample card (provided by Lake Shore)
- Magnifying lens or microscope

- Glass slide
- Tweezers
- Toothpick
- Cotton swabs
- #1 Phillips screw driver (provided by Lake Shore)
- Adhesive such as double sided Kapton tape or Elmer's® rubber cement (also known as art gum, commonly available at stationary or art supply stores); grease such as silicone vacuum grease may also be used

NOTE

Always use tweezers, gloved hands, or a vacuum pen to handle the sample. Oil from your skin can alter measurements on high resistance samples and can alter chemically reactive sample materials.

4.3.2.3 Sample Preparation

Much of sample preparation depends on the sample material and type. Develop specific procedures applicable to your samples. These steps are some general guidelines.

It is noted in step 4 that it is necessary to identify the contact regions on the sample before mounting it to the sample card. Patterning by photolithography or grit blasting might be possible. Some materials require etching of the surface, while other materials require alloying with a suitable contact metal followed by annealing. This type of preparation is outside the scope of this document.

The procedures beginning in section 4.3.2.4 assume that the sample is directly contactable or that contact metallization is already present.

1. Select a sample card (use TABLE 4-1 as a guide).
2. Verify the sample fits in the sample mounting space. Samples can be cut to size by many methods (scratch and break, diamond sawing, etching), depending on the sample material and form (such as bulk crystal, wafer, thin film).
3. Clean the sample.
4. Identify contact regions. Refer to section 2.4 to determine where to attach the leads to the sample.

4.3.2.4 Mounting a Sample to a Solder Pad Sample Card

Solder pad sample cards have solder pads so that wires from the sample are connected to the card. Soldered contacts are the most reliable, but take more time and effort to make. Samples can be pre-mounted and stored for rapid insertion and measurement in the standard module. A pre-mounted InAs sample is included with the system. You can use it as an example.

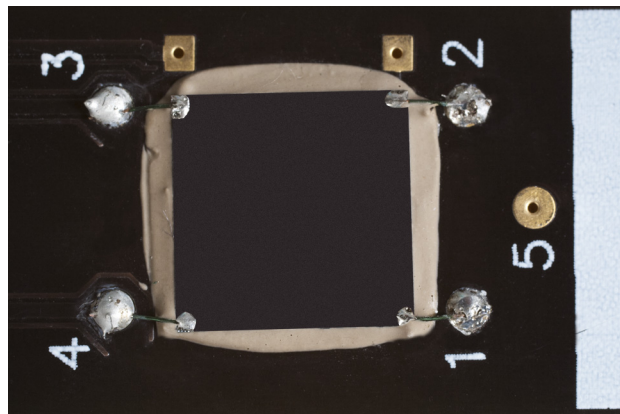


FIGURE 4-9 Pre-mounted InAs sample, leads attached to the sample and sample card

4.3.2.4.1 Attaching Leads to a Sample

Attach wire leads to your samples with solder, silver paste, conductive epoxy, wire bonding, spot welding, or other means. Only indium solder lead attachment is covered here. Lead wire (75 μm diameter silver-plated copper) is provided by Lake Shore. Recommended lead wire is 50 μm to 100 μm diameter copper, silver-plated copper, or gold wire. This procedure assumes the sample is directly contactable or that contact metalization is already present.

CAUTION

Applying high temperature during soldering can damage some samples.

NOTE

Limit the amount of solder on the sample. Place solder on the contact points in small amounts only.

1. Heat the soldering iron. Indium melts at 156.6 °C (313.9 °F), so it does not require a very hot iron.
2. Cut indium or other suitable solder metal and place it on the glass slide.
3. Using a soldering iron, melt solder metal onto the tip of the soldering iron and place a small amount of solder on each contact point on the sample. Refer to section 2.10 for contact point locations.
4. Cut the lead wire to the proper length. Length is determined by the distance between the sample, where the lead attachment is made, and the contact pad on the sample card.
5. If you are using multi-stranded lead wire, unravel the cut lead wire into single strands of wire.
6. Using tweezers, place one end of a single strand of lead wire at the proper sample contact point. Hold the wire in place with tweezers.
7. Solder the end of the wire to the sample contact point (FIGURE 4-10).
8. Repeat for all leads to sample contact points.

NOTE

It is helpful to cut the lead wire long enough so that it extends beyond the contact pad on the sample card as shown in FIGURE 4-10. This ensures that you will have enough wire, and it relieves the tedious process of measuring, cutting, and soldering an exact length of lead wire.

NOTE

Do not cut the excess lead wire until after it has been soldered to the contact pad as described in section 4.3.2.4.3.

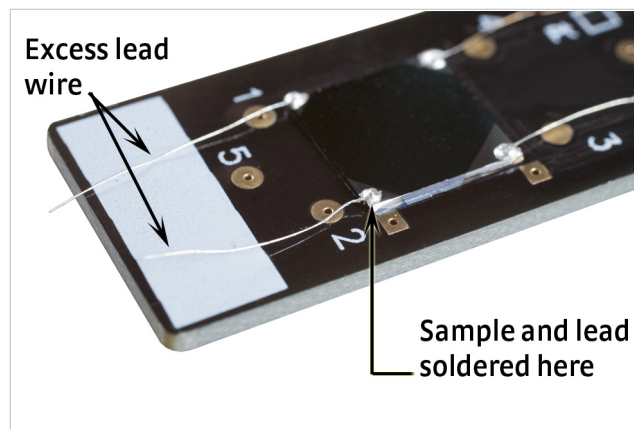


FIGURE 4-10 Lead wire soldered to the sample with excess wire not yet cut

4.3.2.4.2 Mounting a Sample on a Sample Card

Be careful not to damage the sample surface. Scratches can alter measurement readings, especially with thin film samples. Avoid overheating the contact pad. To avoid direct contact with the sample, lightweight samples often can be lifted by a contact wire.

NOTE

Sample cards are reusable. Do not use permanent adhesive if the sample is to be removed from the sample card. Refer to section 5.2.5 for sample card reuse.

1. Select a sample card. Do not touch the gold plated card edge contacts at the top of the card. Fingerprints might create electrically conductive paths that can change measurement readings on high resistance samples.
2. Using a toothpick, place a small amount of adhesive in the center of the sample mounting area on the front side of the card. The sample ID area on the card indicates the front side of the card.
3. Using tweezers, place the sample on the adhesive in the center of the sample mounting area.
4. Using a cotton swab, press down gently on the sample. Continue pressing down gently for a few seconds and then release. Allow the adhesive to dry if necessary.

4.3.2.4.3 Soldering Leads to Sample Card Contacts

To complete the mounting procedure, solder the other end of the lead (the end not soldered to the sample) to a contact on the sample card. See FIGURE 4-7 for an illustration of sample card contacts.

1. Using tweezers, bend the lead wire to allow some strain relief. Hold the lead wire in place on the sample card contact.

NOTE

Bends in the lead wire are good practice if you are conducting DC field measurements. If you are taking AC field measurements, the lead wire should have the shortest path to the contact as possible, with no bends. See FIGURE 4-9 for an image of contacts for AC measurements.

CAUTION

On the next step, do not overheat the sample card contact pad.

2. Solder the lead wire to the sample card contact (FIGURE 4-11).
3. Clip the excess lead wire (FIGURE 4-12).

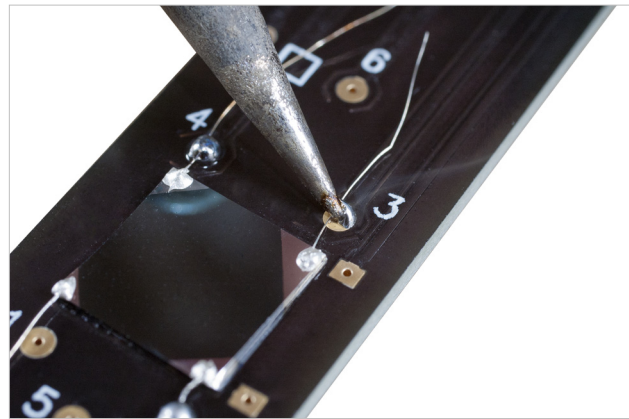
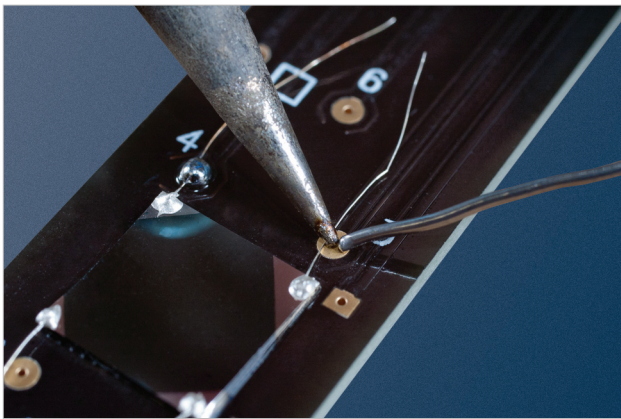


FIGURE 4-11 Soldering the lead wire to the sample card contact pad

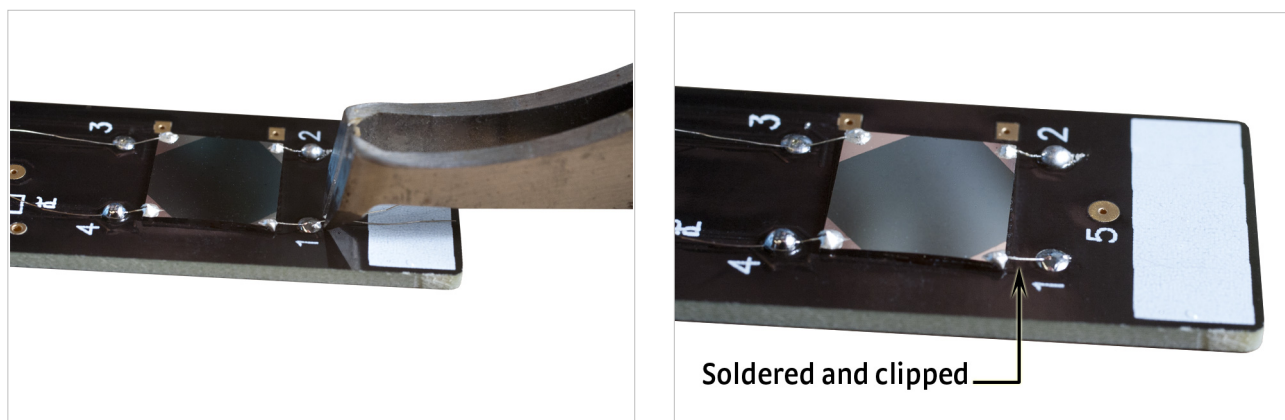


FIGURE 4-12 Left: Clip the excess lead wire; Right: Sample card contacts 1 and 2 are finished contacts

4. Repeat for all leads to sample card contacts.
5. Write the sample name in the sample ID space on the front side of the card (FIGURE 4-13).

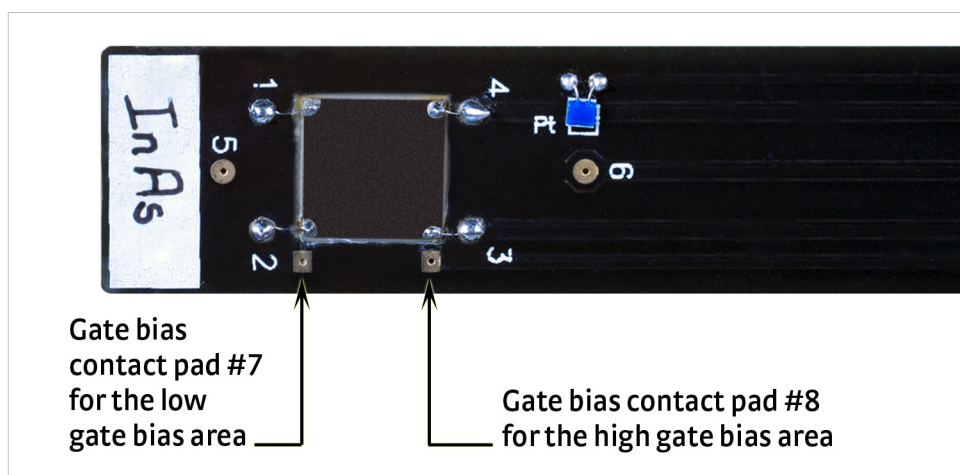


FIGURE 4-13 Solder pad sample card with mounted Van der Pauw sample and leads; also notice the sample name is hand-written in the ID space.

4.3.2.5 Making Bias Contacts

If you wish to take gate bias measurements, you also need to prepare the bias contacts and make the proper electrical connections. There are two ways to prepare the sample card and make the electrical connections. Use one of the following procedures to make the appropriate electrical connection, depending on the criteria noted for each one.

4.3.2.5.1 Electrical Connections for Gate Bias Measurements

If the gate bias voltage can be referenced back to the LO side of the current source (on the Model 6487), there are no connections for you to make. The system was shipped with the #8 triaxial connector attached to the appropriate outlet on the Model 6487.

If you want to float the gate bias voltage relative to the measurement common (i.e. the gate bias voltage cannot be referenced back to the LO side of the current source), then you need to connect the #7 triaxial connector to the rear of the Model 6487. To make the electrical connections for this scenario, follow this procedure:

- a. Pull out the banana connector that is attached to the LO end at the rear of the Model 6487.

- b. Adapt the connector on the rear of the Model 6487 for a triaxial connector. You can use the supplied kit to do this.
- c. Locate the #7 triaxial connector that is bundled in the sample insert cable.
- d. Attach the #7 triaxial connector to the newly-adapted triaxial connector on the Model 6487.

4.3.2.5.2 Making Contacts for Gate Bias Measurements

This section is written assuming the sample has already been mounted on your sample card and you have already determined the high and low gate bias areas on your sample.

1. Use the steps in section 4.3.2.4.3 to make a contact between the #8 bias contact pad on the sample card and the high gate bias area of your sample (FIGURE 4-14).
2. If you connected the #7 triaxial cable to the rear of the Model 6487, then use the steps in section 4.3.2.4.3 to make a contact between the #7 bias contact pad on the sample card and the low gate bias area of your sample (FIGURE 4-14).

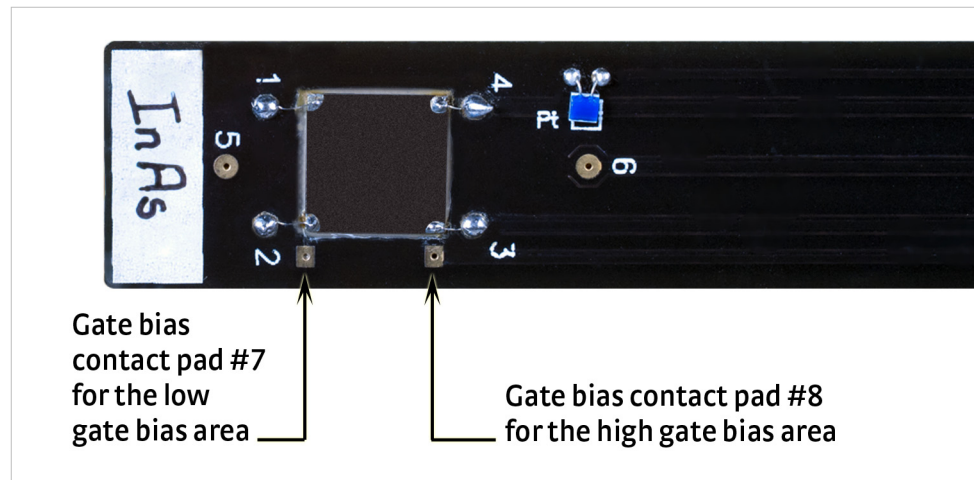


FIGURE 4-14 Gate bias contact pads on the sample card

4.3.2.6 Mounting a Sample to a Prober Pin Sample Card

The prober pin sample card has prober pins to contact the sample. Samples contactable with the prober pins can be rapidly mounted and demounted. A prober pin sample card with a 10 mm × 10 mm sample area is shown in FIGURE 4-15.

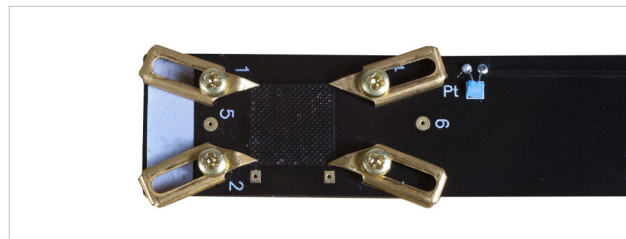


FIGURE 4-15 10 mm prober pin sample card

Use this procedure to mount samples.

1. Using a #1 Phillips screwdriver, loosen the screw and rotate or slide the prober pin away from the mounting region to provide clear access to it.



FIGURE 4-16 Left: Loosen the screw on the prober pin card;
Right: Rotate the prober pin away from the mounting region

2. Follow the procedure in section 4.3.2.4.2 to mount the sample onto the sample card.
3. Pick up one probe tip at a time, and place it on the desired contact location on the sample. You may need to loosen the prober pin more to ensure that it clears the sample. Some samples might have metallized contact pads. Be careful not to scratch the surface of the sample when moving the prober pins.
4. Secure the sample with the prober pins by tightening the screws. Do not over tighten.

CAUTION

Over tightening the prober pin screw may result in damage to the sample or prober pin.

NOTE

Nothing (sample or prober pins) should extend beyond the edges of the sample card or it could contact the inside of the sample module. This could result in damage to the sample or shorting of the signal.

Accurate van der Pauw measurements require the probes to be as near to a sample edge as possible. Some compromise might be necessary if the edge of the sample is not uniform. Symmetrically placed probes on a symmetrical sample generally improve measurement accuracy by minimizing misalignment voltages. For further discussion of this subject, refer to section 2.4.

4.3.3 Standard Insert Install and Removal

This section provides procedures to install and remove the standard insert and the sample card. These procedures assume that you have already set up the standard module according to section 4.3.1.1 and section 4.3.1.2.

4.3.3.1 Standard Insert and Sample Card Removal

Use gloves for any steps that require you to touch the internal components of the standard insert.

1. Stop any measurements and toolbox activities that are running in the HMS software.
2. Ensure the sample insert stand is attached to the measurement platform and available for use.
3. Detach the cable mounting ring from the hook located on the cable boom's horizontal post.
4. Unscrew the two captive thumbscrews on the standard insert (FIGURE 4-17).
5. Lift the standard insert carefully out of the light tight body. Raise it vertically until the sample card has cleared the opening of the light tight body.

6. Rest the standard insert on the sample insert stand so that the sample card is facing up (FIGURE 4-17).

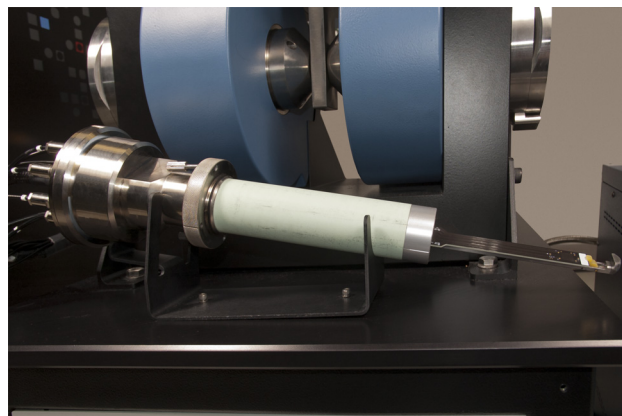


FIGURE 4-17 Left: Unscrew the two captive thumbscrews; Right: Standard insert parked on the sample insert stand

7. To remove the sample card, release the sample card retainer at the end of the sample holder by pushing it down with your thumb or forefinger (FIGURE 4-18).
8. Hold onto the edges of the sample card and the center of the standard insert. Pull on the card firmly to release it from the standard insert (FIGURE 4-18).

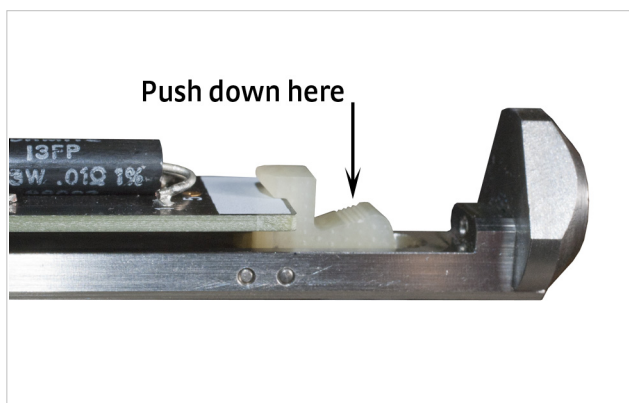


FIGURE 4-18 Left: Push down on the sample card retainer to release the sample card; Right: Proper handling to remove the sample card

9. Place the sample card in its protective case (FIGURE 4-19), or if you are ready to mount a sample onto the card, refer to section 4.3.2.6 to mount a sample.

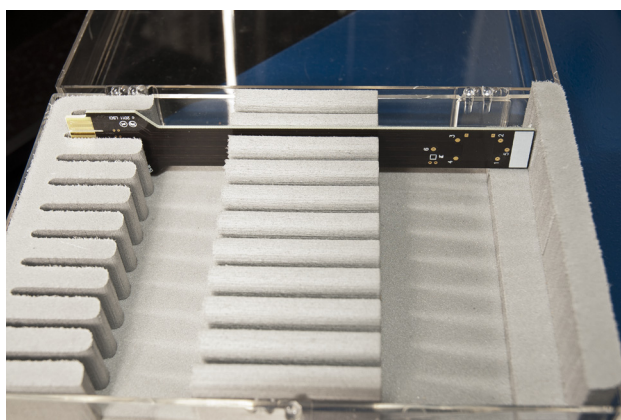


FIGURE 4-19 Sample card protective case: proper storage

4.3.3.2 Replacing the Sample Card and Standard Insert

Use the following procedures to install the sample card into the standard insert and to install the standard insert into the light tight body. If you need to mount a sample, refer to section 4.3.2.6 before using these procedures.

1. Position the sample card in line with the sample holder so that the sample is facing up. The sample holder is polarized so that the sample card will not fully engage if you have it facing in the wrong direction (FIGURE 4-20).
2. Grasp the bottom of the standard insert and the card, and push the card in until the two engage fully (FIGURE 4-18).
3. Engage the sample card retainer by rotating it up onto the sample card (FIGURE 4-20).

CAUTION

The sample card retainer must be engaged before inserting the insert into the body or damage may occur.

NOTE

You may need to move the sample card up or down to mate the retainer with the card.

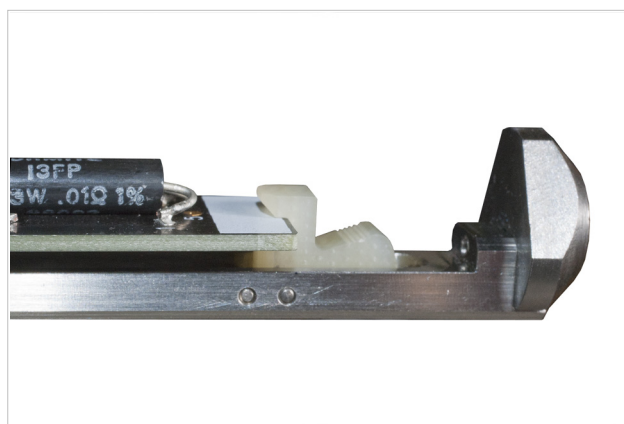
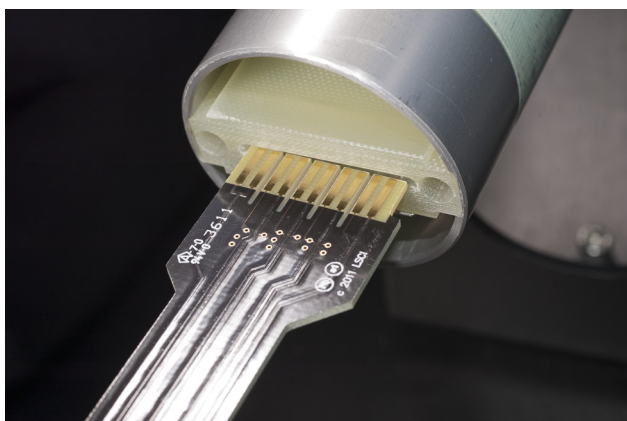


FIGURE 4-20 Left: Aligning the sample card with the sample insert; Right: Sample card fully engaged

4. Using both hands, pick up the standard insert and carefully place it into the light tight body, lowering it vertically so that you do not bump the sample card along the opening of the light tight body (FIGURE 4-21).
5. Align the standard insert with the light tight body, using the 0° alignment marks on both components to assist you.
6. Finger tighten both captive thumbscrews on the standard insert (FIGURE 4-21).

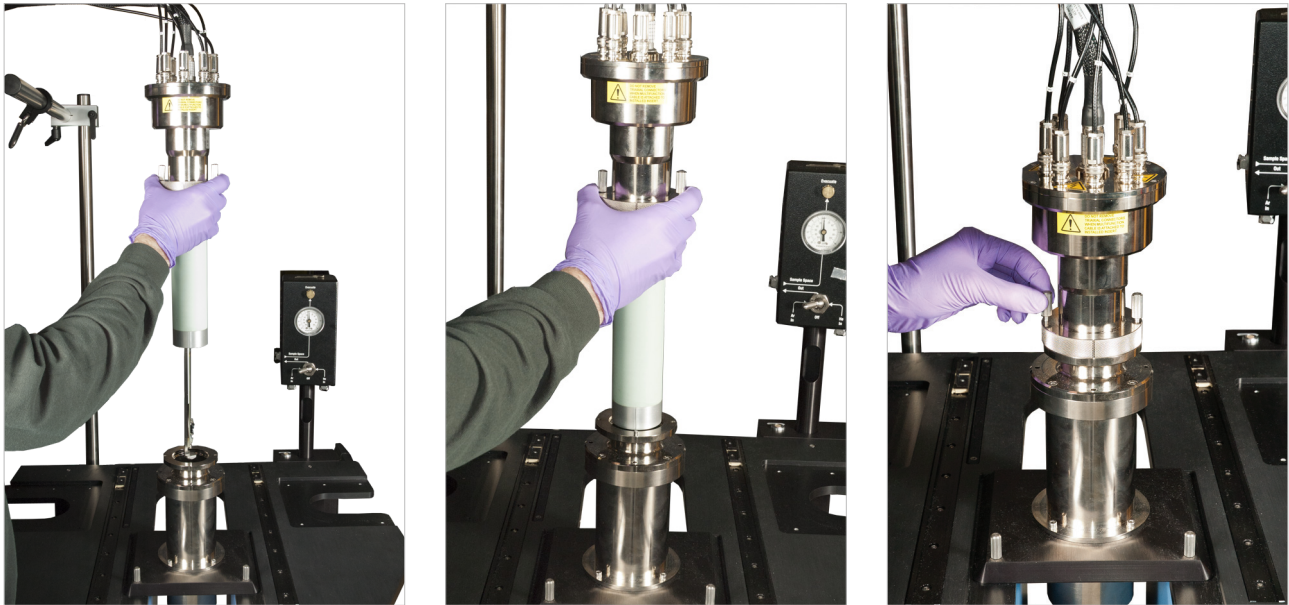


FIGURE 4-21 *Left and Middle: Lower the insert vertically to avoid bumping the sample card along the opening of the light tight body; Right: Finger tightening the thumbscrews to finish replacing the insert*

4.3.4 Rotating the Sample

The sample can be mounted in any 90 ° orientation with the standard spacer. It can be manually rotated from 0 ° to 360 ° with the Model 84010 sample rotation option. Sections 4.3.4.1 and 4.3.4.2 explain how to rotate the sample using the standard spacer and the Model 84010 sample rotation option, respectively.

4.3.4.1 Rotating the Sample with the Standard Spacer

The standard spacer is shipped with the 0 ° alignment mark to the front of the standard body (FIGURE 4-22). If your measurement requires a 90 ° sample orientation (sample in the plane of the field), you can manually rotate the standard spacer prior to installing the standard insert. Follow this procedure to rotate the sample with the standard spacer.



FIGURE 4-22 *0 degree alignment mark; the spacer is in the default position*

1. Remove the standard insert from the light tight body and place it on the sample insert stand. Using the 3 mm hex driver, unscrew the four M4 screws from the standard spacer's lower flange (FIGURE 4-23).
2. Remove the spacer; be sure that the light tight body o-ring is seated properly on the o-ring groove of the light tight body.

3. Turn the spacer to the 90 ° position; the raised pins will be on the left and right sides of the spacer.

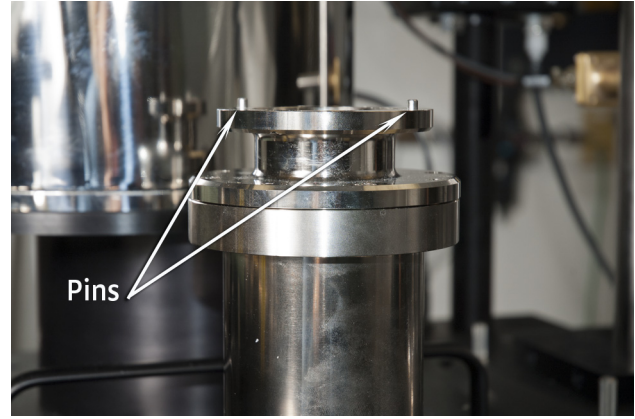


FIGURE 4-23 *Left: Unscrew the four screws from the spacer's lower flange; Right: When the spacer is at the 90 ° position, the pins will be on the left and right sides of the spacer, and the 0 ° alignment mark will be on the back side of the spacer*

4. Place the spacer back on the body, and screw in the four screws in the counter-bored holes on the standard spacer's lower flange.
5. Replace the insert.

4.3.4.2 Rotating the Sample with the Model 84010 Sample Rotation Option

If your measurement requires a 0 ° to 360 ° sample orientation, you can use the sample rotation to manually rotate the sample. Rotation applies only to the 10 mm sample cards; the 50 mm sample cards do not fit in the sample rotation option. Refer to section 3.7.2. to install the sample rotation option. Follow this procedure to rotate the sample with the sample rotation option.

1. If the friction lock is tightened, turn it counterclockwise to loosen it (FIGURE 4-24).
2. If the locking pin on the pin plunger is engaged at one of the 90 ° locations, then pull out to release the locking pin from the indexed position, and rotate it to lock it into the out position.
3. Rotate the option to the desired position before releasing the pin (FIGURE 4-24).

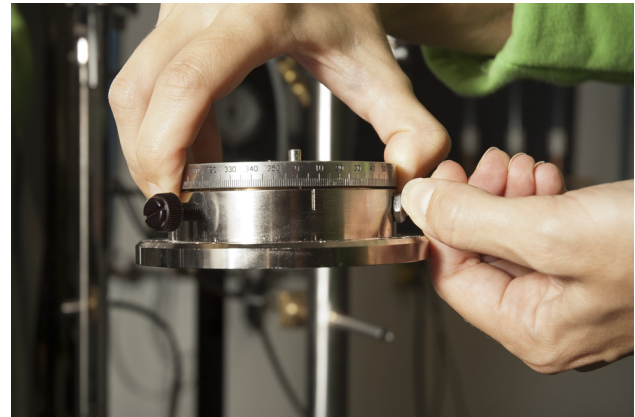
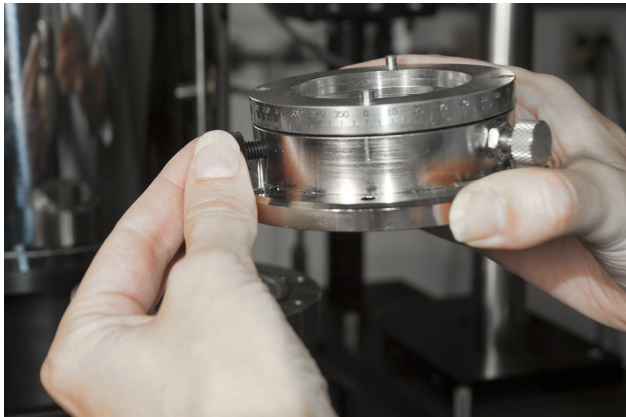


FIGURE 4-24 *Left: Friction lock; Right: Pull out the locking pin and rotate it*

NOTE

If you release the pin while you are rotating the insert, as long as it is not locked, the pin will automatically engage in the next indexed location.

4. Once the insert is at the desired angle, release the locking pin and turn the friction lock clockwise to tighten it.

4.3.5 Evacuating the Standard Module for High Resistance Samples

NOTE

Follow these procedures to prepare the sample space for high resistance samples by evacuating and backfilling it with argon exchange gas.

1. Connect the vacuum line using the steps below.
 - a. Attach one end of the line to the port located on the gas source.
 - b. Attach the other end to the vacuum port located on the standard module.
2. On the sample space gas handler, toggle the gas switch to the off position.
3. Connect the standard module sample space inlet line to the sample space gas handler sample space port.

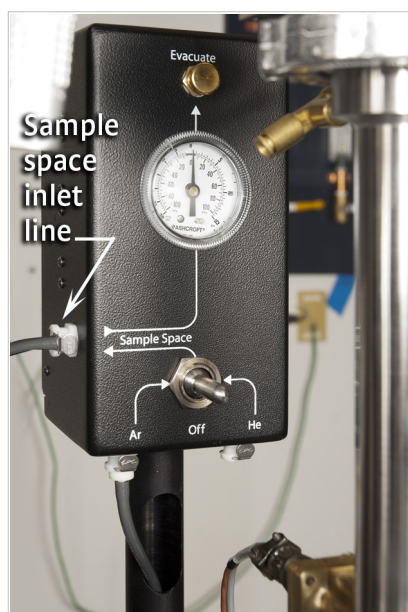


FIGURE 4-25 Sample space gas handler with the gas switch in the off position and the standard module sample space inlet line connected to the gas handler sample space port

4. Confirm the regulator on the Ar tank is set to deliver 379 kPa (55 psi).

CAUTION

The regulator must be set to 379 kPa (55 psi) or damage to the gas handler could occur.

5. Open the gas supply valve on the Ar tank.
6. On the sample space gas handler, toggle the gas switch to the Ar position.
7. On the sample space gas handler, press and hold down the **Evacuate** button for at least 10 s.
8. Repeat step 7 at least three times, for a total of four cycles, to ensure the standard module is free of air and filled with argon gas.

4.4 Operating the Magnet Hardware

This section explains procedures that are specific to the magnet hardware. The introduction to each section will explain when or in what circumstance you need to perform the action.

4.4.1 Changing the Air Gap Setting

Sometimes it is necessary to adjust the air gap setting when you are switching from one sample module to another. Use TABLE 4-2 to determine if you need to change the air gap setting. If you do need to change the air gap, start by turning off the magnet power supply and removing the existing sample module using the procedures in section 4.3.1.3.

Gap setting	Air gap	Option
1	25 mm	Standard module
2	38 mm	Not used
3	50 mm	Model 84016 CCR, Model 84017 oven, and Model 84015
4	75 mm	Optical CCR

TABLE 4-2 Gap settings

4.4.1.1 Changing the Air Gap

Follow this procedure to change the air gap.

1. Ensure the magnet power supply is turned off.
2. Using the 8 mm hex driver, loosen all four screws on the first pole adjustment plate.
3. One at a time, unscrew each screw completely, then screw it back in two full turns (FIGURE 4-26).



WARNING

Be sure to screw each screw back in two full turns. This prevents the pole from coming out of the magnet yoke. Never pull the pole completely out of the magnet yoke. Failure to comply may result in bodily injury.



NOTE

Step four ensures sufficient clearance between the pin and pin adjustment holes (FIGURE 4-26, right).

4. Grasp the pole adjustment plate at the relief area, and pull it out until it is stopped by the screws. You will be able to see the ends of the pins (FIGURE 4-26).

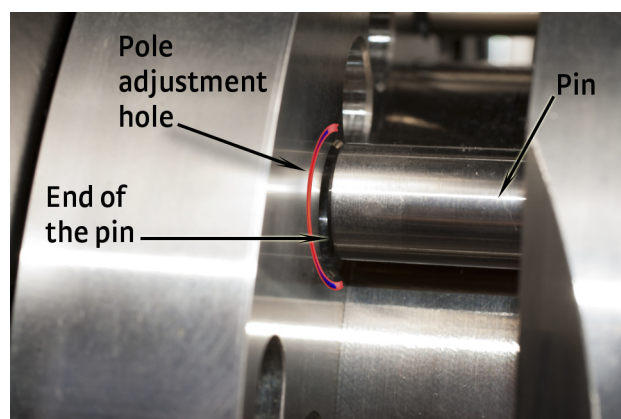


FIGURE 4-26 Left: Loosen and pull out all four screws and screw back in two full turns; Right: Pull out the pole adjustment plate, so that the pins clear the pole adjustment ring

5. Move the selector on the first pole adjustment plate to change the gap setting. The gap setting should correspond to the desired air gap. Refer to TABLE 4-2 to determine the appropriate gap setting.

6. Visually align the pole adjusting pins with the holes on the pole adjustment ring (FIGURE 4-27).
7. Ensure that there is no obstruction in the gap.



Ensure that there is no obstruction in the gap—including your fingers. Failure to comply with this warning could result in bodily injury.

8. Push the plate in until it seats against the pole adjustment ring; there will be a gap between the plate and the ring when setting air gaps two through four (FIGURE 4-27).

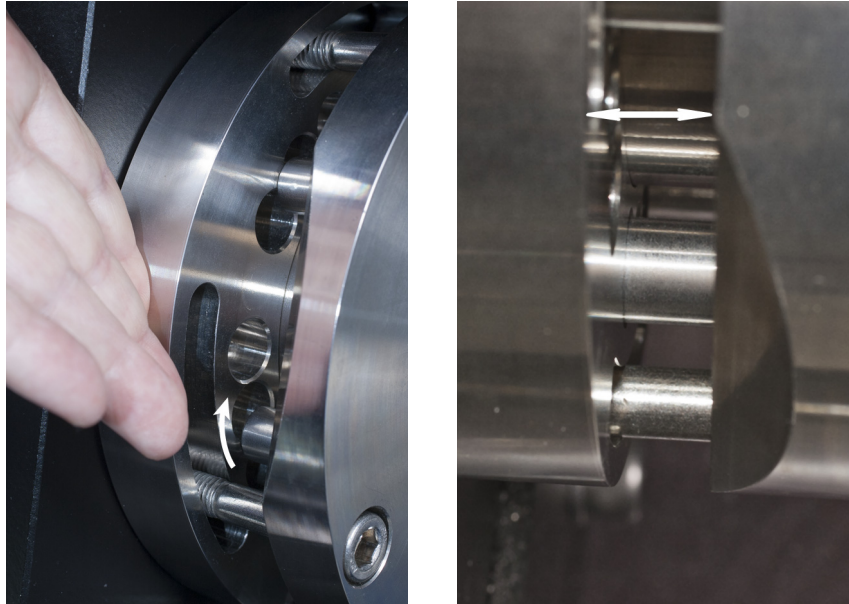


FIGURE 4-27 *Left: Fine tune the pole adjusting pins to align with the appropriate hole on the ring—in this image, the operator would need to adjust the plate a little to the right, in the direction of the arrow, to seat the pin into the closest hole; Right: Push in the pole adjustment plate; there will now be a gap between the plate and the ring (the gap is indicated by the arrow in this picture).*

9. Using the 8 mm hex driver, tighten all four screws on the pole adjustment plate.
10. Repeat steps 1 through 9 for the opposite magnet pole. Be aware that the adjustment plate on the opposite magnet pole will move in the opposite direction from the first.

4.4.1.2 Preparing the System for Use After Changing the Air Gap

After changing the air gap, you can install the selected option, turn on the electromagnet power supply, and start up the system (section 4.2.1). After performing these functions, be sure to recalibrate the system before taking measurements (section 5.2.12).

4.4.2 Exchanging the Pole Caps

When purchased with a Model EM4-4PB high uniformity option, or the Model 84060 optical access magnet option, an additional set of magnet pole caps is available. The customer may elect to change the pole caps installed on the system. For highest field uniformity, the larger, 100 mm (4 in) pole caps may be used. For highest field strength, 50 mm (2 in) pole caps may be used. For compatibility with optical access bodies, a set of 100 mm (4 in) pole caps with optical access may be used. This choice may be determined by the option that you will be using and the options' air gap requirements (TABLE 4-2).

This section describes how to remove and install pole caps. If you need to change the pole caps, start by turning off the magnet power supply, and removing the existing sample module using the procedures in section 4.3.1.3.

4.4.2.1 To Remove the Pole Caps

1. Using the 8 mm hex driver, loosen all four screws on the first pole adjustment plate.
2. One at a time, unscrew each screw completely, then screw it back in two full turns (FIGURE 4-26).



Be sure to re-insert the screw and thread it back in two threads. This prevents the pole from coming out of the magnet yoke. Never pull the pole completely out of the magnet yoke. Failure to comply may result in bodily injury.

3. Grasp the pole adjustment plate at the relief area, and pull it out until it is stopped by the screws. You will be able to see the ends of the pins (FIGURE 4-26). This will provide you space to access the pole caps.
4. Repeat steps 1 through 3 on the other pole cap.
5. Using the $\frac{3}{16}$ in hex driver (or ratchet if you have one), unscrew the three screws from one pole cap (FIGURE 4-28). Set the screws aside in a safe place.



FIGURE 4-28 Unscrew the three screws from one pole cap



Be sure to support the weight of the pole cap as shown in FIGURE 4-29 so that it does not drop. Failure to comply with this warning could result in damage to the instrument or bodily injury.

6. Remove the pole cap from the pole (FIGURE 4-29).
7. Repeat steps 4 through 6 on the other pole cap.

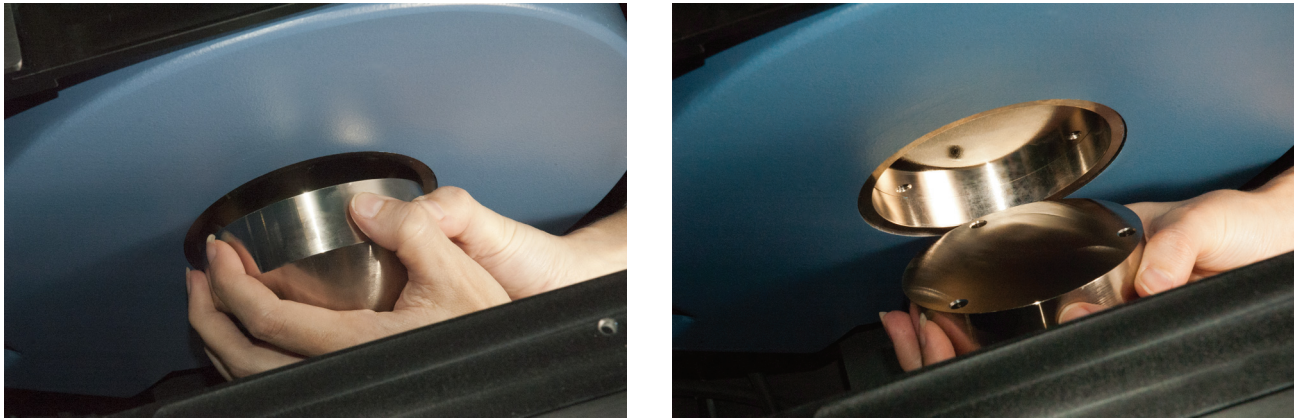


FIGURE 4-29 Pull the pole cap off its post being sure to support its weight with both hands

4.4.2.2 To Install the Pole Caps

1. Locate the pole caps you wish to use, and their associated mounting screws, if you are changing pole cap face diameter.
2. Lift the first pole cap so it is flush against the magnet pole.
3. Hand-start each of the three screws onto each pole cap.
 - a. Thread each screw in, but do not tighten all the way.
 - b. Using the $\frac{3}{16}$ in hex driver, tighten each screw to secure the pole cap.
4. Repeat steps 1 through 3 on the other pole cap.
5. Reset the air gap using TABLE 4-2 as a guide.
6. Visually align the pole adjusting pins with the hole on the pole adjustment ring (FIGURE 4-27).
7. Ensure that there is no obstruction in the gap.

WARNING

Ensure that there is no obstruction in the gap—including your fingers. Failure to comply with this warning could result in bodily injury.

8. Push the plate in until it seats against the pole adjustment ring (FIGURE 4-27).
9. Using the 8 mm hex driver, tighten all four screws on the pole adjustment plate.

4.4.2.3 Preparing the System for Use After Changing the Pole Caps

After changing the pole caps, you can install the selected option, turn on the electromagnet power supply, and start up the system (section 4.2.1). After performing these functions, be sure to recalibrate the system before taking measurements (section 5.2.12).

NOTE

Failure to recalibrate the system after changing pole cap or air gap will result in significant measurement error.

4.5 Operating the Temperature Options

This section provides basic operation instructions for the Model 84015 single point LN₂ option, the Model 84017 oven option, and the Model 84016 closed cycle refrigerator option, as well as how to operate the sample space gas handler.

4.5.1 Operating the Single Point LN₂ Module

This section explains how to position the single point LN₂ module for measurements and operation.

4.5.1.1 Moving the Single Point LN₂ Module into the Measurement Position

The single point LN₂ body was set up on one of the storage positions during installation. For this procedure, it is assumed that the standard insert is already in the body, and the module is mounted on the storage position.

1. The first part of setting up the single point LN₂ module is the same as it is for the standard module. Follow the procedure in section 4.3.1.1 to set up the LN₂ module.



FIGURE 4-30 Left: Sliding the LN₂ module into the measurement position;
Right: Finger tighten the captive screws on the exchange plate

2. Follow these warnings concerning cryogen handling before preparing the single point LN₂ body for LN₂.

! WARNING

Wear cryogenic gloves, safety glasses, long sleeves, and long pants. Due to the extremely low temperatures of liquid nitrogen (77 K), caution should be exercised when handling or transferring it. Failure to comply may result in severe frostbite injury.

! WARNING

All cryogen Dewars should be clearly labeled and operated in accordance with the manufacturer's instructions. The pressure relief devices should be periodically inspected and any ice formation removed.

! WARNING

Do not use cryogenic gases in confined spaces; ensure that the room is ventilated. As liquid cryogen vaporizes, it expands and displaces oxygen. Failure to vent large quantities of vaporized cryogen can result in a loss of consciousness or death.

3. Remove the standard insert (section 4.3.3.1).
4. Obtain the funnel and place it in the single point LN₂ body.
5. Using a pour-filled nitrogen Dewar, pour approximately 100 cc (0.1 L) of LN₂ into the single point LN₂ body through the funnel.
6. Wait until the vigorous boiling subsides (approximately 1 min).
7. Slowly pour the LN₂ into the LN₂ body until it is filled. The recommended fill point is between the bottom of the top chamber and the bottom of the funnel.

! WARNING

It is important to perform step 7 slowly and with great caution as the LN₂ can boil over and the vaporized cryogen can cause injury to the operator.

8. Remove the funnel.
9. Slowly and carefully replace the standard insert (section 4.3.3.2), being sure not to cause an LN₂ overflow.

! CAUTION

Inserting the standard insert into the body filled with LN₂ will create large amounts of LN₂ vapor.

4.5.1.2 Vacuum Pump Out Procedure

The single point LN₂ module requires regular service approximately every 12 months, or if excessive LN₂ consumption is observed when using the single point LN₂ body. If this condition exists, the single point LN₂ body vacuum isolation space has been compromised. Refer to section 5.2.2 for the vacuum pump out procedure.

|| NOTE

The LN₂ body may condense water vapor from the atmosphere onto its exterior when operating in high humidity environments. This is a normal occurrence and nothing to be alarmed about.

4.5.1.3 Electrical Connections

The single point LN₂ module uses the standard insert; therefore, refer to section 4.3.1.2 for electrical connections.

4.5.1.4 Removing the Single Point LN₂ Module from the Measurement Position

This text is written assuming you have finished running sample measurements and there is still a sample inside the standard insert. These steps will assist you in removing the single point LN₂ module in order to place a different module on the measurement position.

|| NOTE

If you are changing to the standard module, do not remove the cables from the standard insert, as they will continue to be used.

1. Place the system in neutral by pressing **Abort** on the HMS software ribbon (section 4.2.3).
2. Ensure a storage position is available on the measurement platform.

! WARNING

It is important to break the connections in the order listed below, as hazardous live voltage may exist on the triaxial connectors. Failure to comply may result in death or injury to personnel.

3. Holding onto the silver locking sleeve of the multifunction cable, disconnect it from the standard insert.
4. Disconnect all triaxial cables from the top of the standard insert.
5. If desired, remove the standard insert and sample card from the single point LN₂ body (section 4.5.1.5).
6. Loosen both captive thumbscrews on the exchange plate.
7. Carefully slide the single point LN₂ body out of the measurement position, ensuring that you do not hit the bottom of the body on the measurement platform.
8. Carefully place the module on the designated storage position.

4.5.1.5 Standard Insert Install and Removal (from the LN₂ Body)

The procedures for installing and removing the standard insert from the single point LN₂ body is the same as for installing and removing the standard insert from the light tight body. However, since you may be performing these steps after cooling down the system, all cryogenic safety precautions will apply.

! WARNING

Wear cryogenic gloves, safety glasses, long sleeves, and long pants. Due to the extremely low temperatures of liquid nitrogen (77 K), caution should be exercised when handling or transferring it. Failure to comply may result in severe frostbite injury.

Section 4.3.3 provides instructions for sample exchange. Those procedures assume that you have already set up the single point LN₂ module according to section 3.6.2.

NOTE

Condensation will form on the insert when it is removed. Either wait for it to melt, and the insert to dry off, or use a heat gun to dry the insert before making the next measurement. Low to medium heat is recommended. High heat will damage the insert and possibly the sample.

4.5.2 Operating the Oven

The Model 84017 oven with oven insert (Model 84017-I) features and specifications are given in Chapter 1. Stable operation at a range of temperatures is made possible by balancing the cooling power provided by the ambient environment against a heater circuit powered by a temperature controller. An assembly overview is shown in section 2.3.1.4.

! WARNING

The outer surface of the oven module around the sample area can be very hot during operation. Do not touch the oven outer surface during operation above 400 K.

Section 4.5.2.1 through section 4.5.2.8 explain using the oven from setting it up, to basic operation, including sample exchange. This section assumes that the measurement position is empty of any sample module and that the oven insert is installed in the oven. For removing the standard module from the measurement position, refer to section 4.3.1.3.

4.5.2.1 Moving the Oven into the Measurement Position

The oven module was set up on one of the storage positions during installation. For this procedure, it is assumed that the oven insert is already in the oven, and the module is mounted on the storage position.

1. Place the system in neutral by pressing **Abort** on the HMS software ribbon (section 4.2.3).
2. Use TABLE 4-2 to determine the air gap setting. Follow the procedures in section 4.4.1 to change the air gap setting if necessary.
3. If the magnet air gap or pole caps have changed, calibrate the system (section 5.2.12).
4. Move the oven module into the measurement position (FIGURE 4-31):
 - a. Position the oven module so that the captive screws are to the outside of the measurement system.
 - b. Slide the oven module into the measurement position slot and push it all the way back, using the alignment guide, until the captive screws line up with their corresponding holes in the alignment guide (FIGURE 4-3).

- c. Finger tighten the captive screws on each side of the exchange plate.

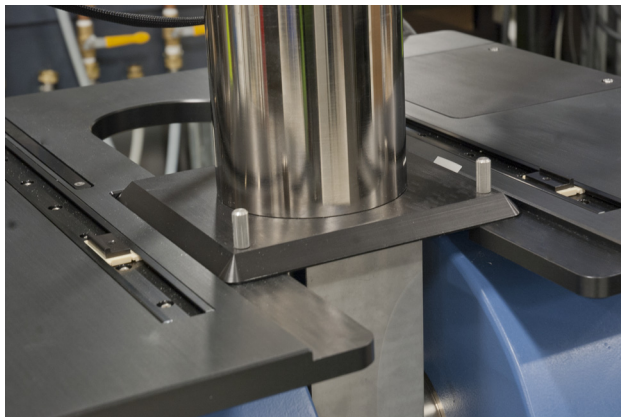


FIGURE 4-31 *Oven in the measurement position*

4.5.2.2 Vacuum Pump Out Procedure (for the Oven)

These directions assume that the vacuum pump has been assembled and installed according to section 3.6.6.

The customer must supply a vacuum pump and connections to evacuate the heater space in the oven to a pressure of 0.1 Pa (7×10^{-4} Torr) or lower prior to initial operation. Vacuum pressure gauging must be provided or purchased with the PS-E2M option or the pump kit option. The oven heater space must be pumped continuously during operation.

1. The oven should be at room temperature for initial vacuum pumpout.
2. Confirm that the 3-way purge valve is closed (Store position).
3. Confirm that the plastic flexible vacuum line is connected to the 3-way purge valve on the vacuum port of the oven (FIGURE 4-32).
4. Connect the plastic, flexible vacuum line to the top NW 25 port of the vacuum supply bracket located on the rear structural post on the measurement platform.

! CAUTION

Ensure that you use the PVC line provided with the option for the top NW 25 port of the vacuum supply bracket. Failure to comply may result in damage to the oven.



FIGURE 4-32 *Plastic flexible vacuum line connected to the 3-way purge valve*

5. If you are using a turbo vacuum pump, verify that it is turned off and properly vented (close the manual vent valve).
6. Start the pumping system. If you are using the Model TPS-FRG, turn on the power switch located on the rear of the unit.

NOTE

If you are using a turbo pump, observe to be sure it starts rotating up to its maximum operational speed. The vacuum gauge should begin reading in approximately 3 min when the pressure reaches approximately 10^{-3} Torr. The turbo pump should reach full speed in approximately 5 min.

NOTE

If you are using a rotary pump an operating pressure of 0.1 Pa (7×10^{-4} Torr) should be achieved in a leak-free system within 20 min. Use a foreline trap valve when it is in the storage position.

CAUTION

Introducing atmosphere too quickly to a turbomolecular vacuum pump operating at a high RPM can result in pump damage.

NOTE

The oven should pump below 1.3 Pa (10 mTorr or $10 \mu\text{m}$) in approximately 30 min to 60 min. If it does not, refer to section 5.3.6 for troubleshooting.

7. Slowly open the 2-way isolation valve to the Run position, with the handle pointing down.

4.5.2.3 Electrical Connections

Follow these procedures to complete the electrical connections for the oven module. For this procedure, it is assumed that the intermediate cables are still attached to the oven. Refer to section 3.6.3 if they are not attached.

1. Attach the cable mounting ring onto the hook located on the cable boom's horizontal post.

WARNING

It is important to make the connections in the order listed below, as hazardous live voltage may exist on the triaxial connectors. Failure to comply may result in death or injury to personnel.

WARNING

All cable connectors must be connected to their respective receptacle or taped off to prevent contact with high voltage during operation.

2. Connect the primary triaxial cables, labeled 1 through 4 and 7 and 8, to the oven insert. Connect them according to the number on each connector that corresponds to the numbers on the oven insert (FIGURE 4-4).
3. Connect the 22-pin oven insert cable to the oven insert (FIGURE 4-4).
4. Connect the 18-pin oven cable to the VT control port located at the rear of the measurement platform (FIGURE 4-33).



FIGURE 4-33 Oven cable connected to the VT control port

4.5.2.4 Preparing the Sample Space Gas Handler and the Sample Space Environment

Follow these procedures to prepare the sample space by evacuating and backfilling it with argon exchange gas.

1. On the sample space gas handler, toggle the gas switch to the off position.
2. Connect the oven sample space inlet line to the sample space gas handler sample space port.

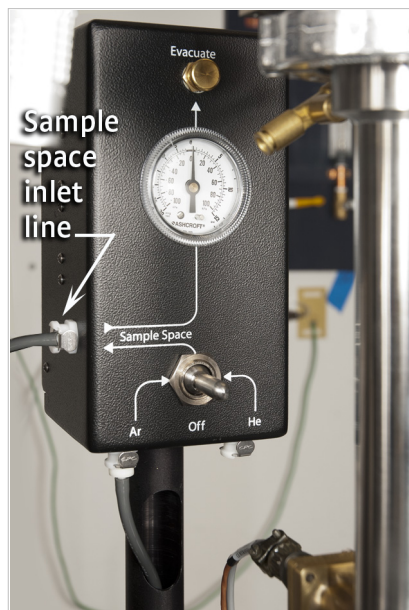


FIGURE 4-34 Sample space gas handler with the gas switch in the off position and the oven sample space inlet line connected to the gas handler sample space port

3. Confirm the regulator on the Ar tank is set to deliver 379 kPa (55 psi).

CAUTION

The regulator should be set to a pressure less than 413 kPa (60 psi) or damage to the gas handler could occur.

4. Open the gas supply valve on the Ar tank.
5. The pressure/vacuum gas in the box should show a positive reading (approximately 0.5 to 1 psi).
6. On the sample space gas handler, toggle the gas switch to the Ar position.
7. Hold down the **Evacuate** button till the gauge shows a 15-20 reading (should take approximately 15 to 20 seconds).
8. Release the button and repeat step 7 at least three times, for a total of four cycles.

4.5.2.5 Removing the Oven Module from the Measurement Position

This text is written assuming you have finished running sample measurements and there is still a sample inside the oven insert. These steps will assist you in removing the oven module in order to place a different module on the measurement position.

1. Place the system in neutral by pressing **Abort** on the HMS software ribbon (section 4.2.3).
2. Looking at the HMS software, wait for the system to reach 300 K before removing the insert.

WARNING

It is important to break the connections in the order listed here, as hazardous live voltage may exist on the triaxial connectors. Failure to comply may result in death or injury to personnel.

3. When the system reaches room temperature, disconnect the 7-pin VT-control cable on the oven (FIGURE 4-35).
4. On the oven insert, disconnect the 22-pin multifunction cable and then disconnect the six triaxial cables (FIGURE 4-35).
5. Unscrew the two captive thumbscrews on the oven insert (FIGURE 4-35).
6. If you desire to remove the sample, do the following:
 - a. Remove the oven insert from the oven (section 4.5.2.6).
 - b. Remove the sample.
 - c. Replace the oven insert in the oven (section 4.5.2.7).
7. Set the sample space gas handler toggle switch to the off position.

NOTE

If the sample space gas handler toggle switch is not in the off position, failure to replace the oven insert or to use the oven sample space plug will result in excessive argon consumption.

8. Close the gas supply valve on the gas supply.
9. Prepare to disconnect the vacuum line from the NW 25 port of the vacuum supply bracket by performing the following:
 - a. Set the 3-way purge valve to Store, with the handle at the horizontal position.
 - b. Turn off the pump.
 - c. If you are using a turbo pump, vent the pump by opening the vent valve.
 - d. Close the vent valve.
10. Disconnect the vacuum line from the NW 16 port of the vacuum supply bracket located on the rear structural post on the measurement platform.
11. Loosen both captive thumbscrews on the exchange plate.
12. Carefully slide the oven out of the measurement position, ensuring that you do not hit the bottom of the oven on the measurement platform.
13. Carefully place the module on the designated storage position.

4.5.2.6 Oven Insert Removal

Use the procedure below to remove the oven insert from the oven. These procedures assume that the oven module was set up according to section 4.5.2.

1. Place the system in neutral by pressing **Abort** on the HMS software ribbon (section 4.2.3).
2. Looking at the hardware pane on the HMS software, wait for the system to reach 300 K before removing the insert.

WARNING

After operation, use heat protective gloves when touching the oven insert's internal parts or the oven, including the portion that extends below the exchange plate and behind the guard.

WARNING

Do not touch the oven insert's internal parts or the oven, including the portion that extends below the exchange plate and behind the guard, at any temperatures above 50 °C (122 °F). The surfaces will be hot and can cause injury to personnel.

WARNING

It is important to break the connections in the order listed here, as hazardous live voltage may exist on the triaxial connectors. Failure to comply may result in death or injury to personnel.

3. When the system reaches room temperature, disconnect the VT-control cable on the oven (FIGURE 4-35).
4. On the oven insert, disconnect the 22-pin multifunction cable by pulling on the silver locking sleeve, and then disconnect the six triaxial cables (FIGURE 4-35).
5. Unscrew the two captive thumbscrews on the oven insert (FIGURE 4-35).

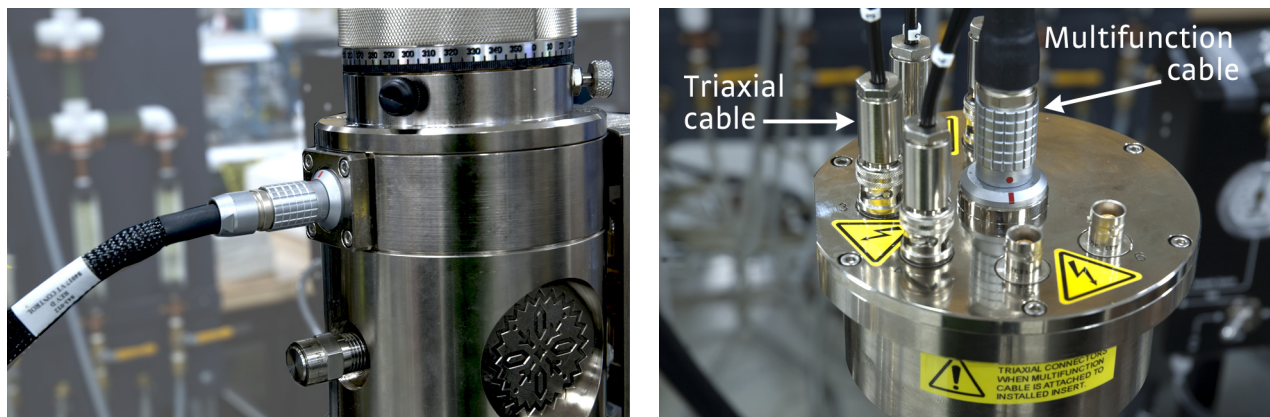


FIGURE 4-35 Left: Disconnect the VT-control cable on the oven;
Right: Disconnect the multifunction cable and then Disconnect the triaxial cables from the oven insert

6. Lift the oven insert carefully out of the oven. Raise it vertically until the sample card has cleared the opening of the oven. Set the insert aside momentarily.

! CAUTION

Find a safe place to rest the oven insert, as it is delicate. Failure to comply could cause damage to the oven insert.

4.5.2.7 Replacing the Oven Insert into the Oven and Operation with Argon

Use the procedure below to replace the oven insert into the oven.

1. Clean the oven insert to remove any dust or dirt accumulated on its surface.
2. Mount the sample using the procedures in section 4.5.3.
3. Using both hands, pick up the oven insert and carefully place it into the oven, lowering it vertically with a hand over hand motion, so that you do not bump the sample card along the opening of the oven.
4. Align the oven insert with the oven, using the 0° alignment marks on both components to assist you.
5. Finger tighten both captive thumbscrews on the oven insert, and press down the insert to seat the o-ring.
6. Set the rotation stage to the appropriate angle for your measurement (standard Hall measurements are made at 0° with the sample perpendicular to the applied magnetic field).
7. On the sample space gas handler, press and hold down the **Evacuate** button for at least 10 s.
8. Repeat step 7 at least three times, for a total of four cycles, to ensure the oven is free of air and filled with argon gas.

4.5.2.8 Accelerated Oven Cool Down

1. Ramp the oven temperature down to room temperature.

! CAUTION

Do not ramp the oven temperature faster than 10 degrees per minute. Failure to comply could cause damage to the oven.

2. When the system reaches 200 °C (392 °F), switch the heater space valve from Run to Cool.
3. When the system reaches room temperature, return the heater space valve to the Run position.

4.5.3 Oven Sample Mounting

Mount samples by following the prober pin sample card sample mounting instructions given in section 4.3.2.6 with these considerations:

- The sample mounting portion of the oven insert is permanently attached, not removable like the prober pin sample card used in the standard insert.
- The sample mounts in the center of a ceramic mounting plate that is centered between prober pins. The prober pins are not numbered, but they are arranged in a counterclockwise direction, starting with one at the bottom left and ending at four.
- After using the high temperature option, remove the screws holding the measurement probes and clean the screws to remove any loose material from the threaded area before reassembling the fasteners for the next measurement. To clean the screws, use a soft brush, followed by compressed air.

NOTE

For a sample which may contaminate or react to the alumina mounting plate at the measurement temperature, it is recommended that the sample be mounted on the provided 12 mm x 16 mm sapphire plate before locating it on the mounting plate.

NOTE

Threaded fasteners used in the measurement area are made with nickel alloy Inconel 600. At temperatures above 800 °C (1472 °F), oxidation can form on the surface and cause flaking. When this foreign material gets caught between the threads of probe mounting screws, it can prevent the screws from turning, and thus makes the measurement unit inoperable. For proper operation, it is important to keep the threads of the fasteners clean.

NOTE

There is no sample identification space on the oven insert sample mounting plate. If desired, attach a removable note to the oven's exchange plate with the sample identification and other relevant information.

4.5.4 Preparing the Closed Cycle Refrigerator for Operation

Section 4.5.4.1 through section 4.5.5.5 explain using the CCR module from setting it up, to basic operation, and including sample exchange. This section assumes that you have installed the system according to procedures in section 3.6.4, the measurement position is empty of any sample module, and the insert is locked inside the CCR. For removing the standard module from the measurement position, refer to section 4.3.1.3.

4.5.4.1 Moving the CCR to the Measurement Position

1. Place the system in neutral by pressing **Abort** on the HMS software ribbon (section 4.2.3).
2. Use TABLE 4-2 to determine if you need to change the air gap setting; then, if necessary, use the procedures in section 4.4.1 to change the air gap setting.
3. If the magnet air gap or pole caps have changed, calibrate the system with this magnet geometry (section 5.2.12).
4. Move the CCR module into the measurement position:
 - a. Pull up and hold to release the locking pin located at the rear of the CCR mounting plate.
 - b. Pull the CCR module forward, and let go of the locking pin. When the CCR module reaches the measurement position, you will hear the locking pin engage.

4.5.4.2 Electrical Connections

Follow these procedures to complete the electrical connections for the CCR module.

1. Attach the cable mounting ring of the sample insert cable onto the hook located on the cable boom's horizontal post.

WARNING

It is important to make the connections in the order listed here, as hazardous live voltage may exist on the triaxial connectors. Failure to comply may result in death or injury to personnel.

2. Connect the triaxial cables to the CCR insert. Connect them according to the number on each connector that corresponds to the numbers on the CCR insert (FIGURE 4-36). Triaxial cables 7 and 8 have no corresponding connector.



FIGURE 4-36 Attach the primary triaxial cables to the CCR insert

3. Connect the 22-pin CCR insert cable to the CCR insert (FIGURE 4-37, left).
4. Connect the 18-pin CCR cable to the VT control port located at the rear of the measurement platform (FIGURE 4-37, right).

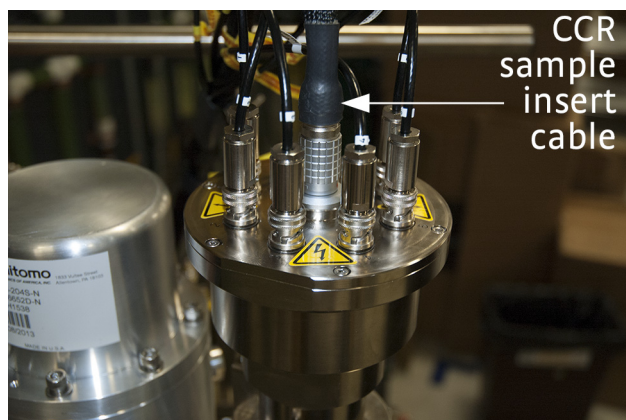


FIGURE 4-37 Left: Connect the CCR insert cable to the 22-pin intermediate CCR insert cable;
Right: Connect the CCR cable to the VT control port

4.5.4.3 Vacuum Connections

The customer is supplied a 1 meter (40 in) long stainless steel bellows with NW 25 ends for evacuating the CCR body. When the TPS-FRG option is purchased, vacuum pressure gauging is provided. If you choose to buy your own vacuum pump, you will need to provide your own vacuum pressure gauging.

CAUTION

Do not use rotary oil vacuum pumps as they may contaminate the vacuum space with pump oil.

1. Verify that the vacuum pump is connected to the bottom NW 25 port of the vacuum supply bracket located on the rear structural post on the measurement platform.
2. Connect the CCR option stainless steel vacuum line to the top NW 25 port of the vacuum supply bracket located on the rear structural post on the measurement platform.

NOTE

The CCR option stainless steel vacuum line will remain with the CCR when it is not in use.

4.5.4.4 Sample Space Gas Handler Connections

Follow these procedures to prepare the sample space gas handler for the sample space.

1. On the sample space gas handler, toggle the gas switch to the off position.
2. Connect the CCR sample space inlet line to the sample space gas handler sample space port.

4.5.5 Operating the Closed Cycle Refrigerator

This section explains the procedures you need to do each time you operate the CCR. These procedures are written assuming that you have prepared the CCR as described in section 4.5.4. Initiating the cooling sequence requires that you perform the procedures provided in section 4.5.5.1 through section 4.5.5.3.

4.5.5.1 Vacuum Pump Out Procedure (for the Option Body)

These directions assume that the CCR has retained moderate vacuum quality and has not been vented to air.

The CCR must be pumped continuously during operation.

1. The CCR should be at room temperature for initial vacuum pumpout.
2. Confirm that the isolation valve on the vacuum port of the CCR is closed.

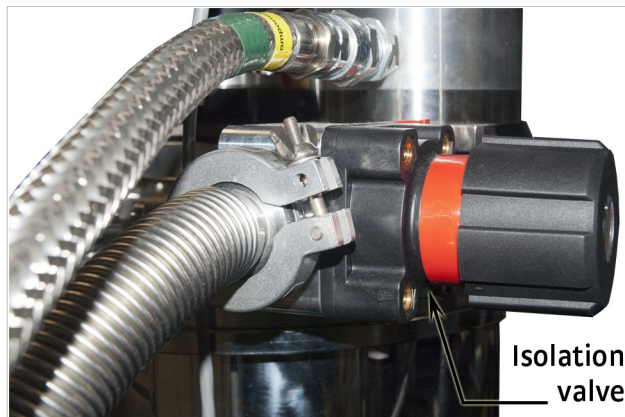


FIGURE 4-38 Stainless steel vacuum line connected to the closed isolation valve

3. Verify that the vacuum pump is turned off and properly vented.
4. Close the manual vent valve.
5. Start the turbo pumping system. If you are using the Model TPS-FRG, turn on the power switch located on the rear of the unit.

NOTE

The stainless steel vacuum line should immediately begin to stiffen. Observe to be sure the pump starts rotating up to its maximum operational speed. The turbo pump should reach full speed in approximately 5 min.

6. Slowly open the vacuum isolation valve by turning the large black knob counter-clockwise.

CAUTION

Introducing atmosphere too quickly to a turbomolecular vacuum pump can result in pump damage.

The CCR should pump below 1.3 Pa (10 mTorr or 10 μ m) in approximately 30 to 60 min. If it does not, see section 5.3.6 for troubleshooting.

4.5.5.2 Purging the CCR Sample Space

Follow these procedures to evacuate and backfill the sample space.

1. Confirm the regulator on the He tank is set to deliver 379 kPa (55 psi).

! CAUTION

The regulator must be set to 379 kPa (55 psi) or damage to the gas handler could occur.

2. Open the shut off valve to the sample space, see FIGURE 4-39.
3. On the sample space gas handler, toggle the gas switch to the He position.
4. Open the regulator on the He tank.
5. The pressure/vacuum gas in the box should show a positive reading (approximately 0.5 to 1 psi).
6. Hold down the Evacuate button until the gauge reads between 20 and 25 in Hg (this should take approximately 15 to 20 seconds).
7. Release the button and repeat this step at least two times, for a total of three cycles.
8. Wait until the pressure gauge reads 0.5 to 1 psi, then close the shut off valve to the sample space.



FIGURE 4-39 Left: Shut off valve in the open position
Right: Shut off valve in the closed position

! CAUTION

This procedure removes water vapor from the sample space and replaces it with helium gas. This prevents water vapor and other gases in the sample space from freezing and expanding. Failure to perform this procedure could result in damage to the sample space.

4.5.5.3 Powering on the CCR

When cooling the CCR below 300 K, ensure the vacuum pump remains on and the isolation valve remains open.

NOTE

The CCR may condense water vapor from the atmosphere onto its exterior when operating in high humidity environments. This is a normal occurrence and nothing to be alarmed about.

1. Verify that the cooling water flowing to the CCR compressor is on.
2. Turn on the CCR compressor using the rocker switch on the rear of the unit.
3. Allow the system to cool to base temperature. This will take approximately 2 hours.

4. When the CCR has achieved base temperature, use the monitor pane to enter your first setpoint.
5. When the system settles at the first setpoint, the system is ready for measurement.

4.5.5.4 Removing the CCR Insert

These procedures assume that you have already setup the CCR according to section 4.5.4.1 through the end of section 4.5.5.1.

1. Ensure the system is set to zero field.
2. On the 8400 Series software, set the setpoint to 300 K. Wait for the system to reach 300 K before removing the CCR insert.

⚠ WARNING

It is important to break the connections in the order listed below, as hazardous live voltage may exist on the triaxial connectors. Failure to comply may result in death or injury to personnel.

3. When the system reaches room temperature, open the shut off valve to the sample space, see FIGURE 4-39.
4. Disconnect the 22-pin sample insert cable and the six triaxial connectors from the CCR insert (FIGURE 4-40).

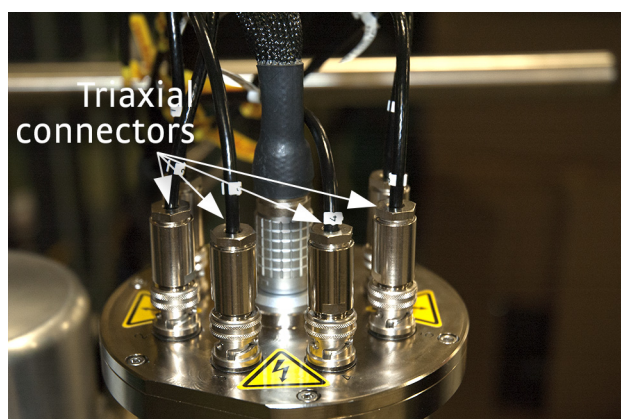
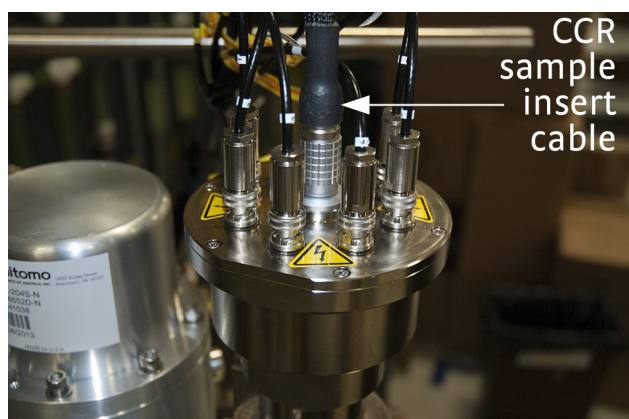


FIGURE 4-40 Left: Disconnect the sample insert cable; Right: Disconnect the triaxial connectors

5. Unscrew the two captive thumbscrews securing the insert to the rotation stage.
6. Once you feel the thumbscrews disengage, use both hands to lift the insert straight up, using a hand over hand motion to accommodate the length of the insert tube.

⚠ WARNING

Wear protective gloves when removing the sample insert. The lower portions of the insert will be sufficiently cold to cause harm to unprotected skin.

7. Pull the insert all the way out, taking care not to impact the sample holder on the edges of the CCR. Set the insert aside momentarily.
8. Insert the Model 84016 cap (see FIGURE 4-41). Tighten the thumbscrews to seal the sample space.
9. Install the 22-pin CCR insert cable. This will set the software to sample exchange mode. The cap has a digital ID that maintains the sample space heater at 300K. This prevents cryopumping of atmosphere during the reinstallation process which can lead to ice plug formation.

⚠ CAUTION

If the heaters do not turn on, contact Lake Shore service for trouble shooting. See section 5.5 for contact information.

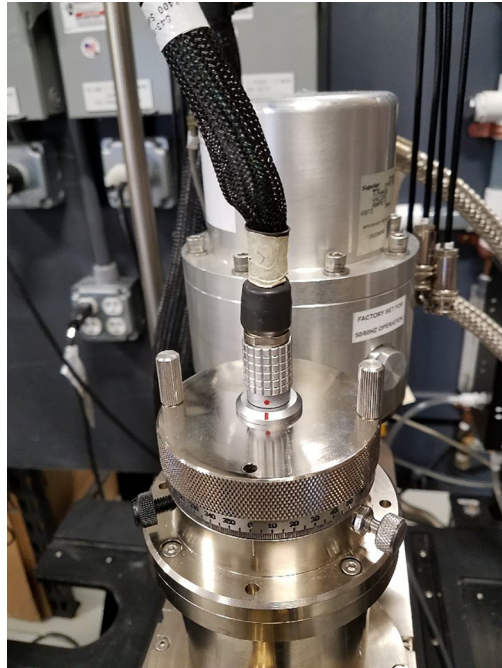


FIGURE 4-41 Model 84016 cap installed with the 22-pin CCR insert cable attached

10. Hold down the **Evacuate** button until the gauge reads between 20 and 25 in Hg (this should take approximately 15 to 20 seconds).
11. Release the button and repeat this step at least three times, for a total of four cycles.
12. Wait until the pressure gauge reads 0.5 to 1 psi, then close the shut off valve to the sample space.

If you are ready to mount the sample, continue to section 4.5.7.

4.5.5.5 Replacing the CCR Insert into the CCR

Use the procedure below to replace the CCR insert and to avoid contamination or condensation from air.

1. Clean the CCR insert of any dust or dirt accumulated on its surface. Verify that the CCR insert is completely dry. We suggest leaving the sample insert out to warm up and fully dry for a minimum of 1 hour. In high humidity environments, it may take longer for the insert to fully dry. Fully inspect the insert for signs of condensation prior to reinstalling into the sample space.

CAUTION

Frost or condensation on the G10 portion of the insert may not be readily visible. Carefully inspect the entire insert for signs of condensation and/or frost.

2. Open the shut off valve to the sample space, see FIGURE 4-39.
3. Remove the 22-pin CCR insert cable.
4. Remove the Model 84016 cap by loosening the two thumb screws and pulling the cap assembly vertically out of the rotation stage.
5. Carefully install the CCR insert into the sample space.
6. Fully tighten the two captive thumbscrews to lock the insert onto the rotation stage.
7. The pressure/vacuum gas in the box should show a positive reading (approximately 0.5 to 1 psi).
8. Hold down the **Evacuate** button until the gauge reads between 20 and 25 in Hg (this should take approximately 15 to 20 seconds).

9. Release the button and repeat this step at least three times, for a total of four cycles.
10. Wait until the pressure gauge reads 0.5 to 1 psi, then close the shut off valve to the sample space.
11. Set the rotation stage to 0 ° so the sample is perpendicular to the applied magnetic field.

4.5.6 Removing the CCR Module from the Measurement Position

This text is written assuming you have finished running sample measurements and there is still a sample inside the CCR insert. Steps 1 through 7 below will assist you in finishing your daily operation with the CCR, and if you wish to change modules, you can continue through the remaining steps.

1. If you desire to remove the sample, do the following:
 - a. Remove the CCR insert from the CCR (section 4.5.5.4).
 - b. Remove the sample.
 - c. Replace the CCR insert into the CCR (section 4.5.5.5).
2. Turn off the CCR compressor by pressing the power switch on its front panel.
3. Turn off the CCR cooling water, if necessary.



It is important to break the connections in the order listed below, as hazardous live voltage may exist on the triaxial connectors. Failure to comply may result in death or injury to personnel.

4. Set the sample space gas handler toggle switch to the off position.
5. Close the gas regulator on the gas supply.
6. Turn off and vent the vacuum pump.
7. Place the system in neutral by pressing **Abort** on the HMS software ribbon (section 4.2.3).



If the sample space gas handler toggle switch is not in the off position, then, failure to replace the CCR insert or to use the CCR sample space plug will result in excessive helium consumption.

8. Remove the CCR sample space inlet line from the sample space gas handler sample space port.
9. Close the vacuum isolation valve.
10. Remove the vacuum line from the top NW 25 port of the vacuum supply bracket located on the rear structural post on the measurement platform.



The following steps are necessary only if you are switching modules.

11. Pull and hold the locking pin on the rear of the slide plate while simultaneously sliding the CCR module toward the rear of the measurement position.
12. After sliding the module approximately halfway back, release the locking pin.
13. Push the CCR module back into its storage position; when it reaches the storage position, you will hear the locking pin engage.

4.5.7 CCR Sample Mounting

Mount samples by following the sample mounting instructions given in section 4.3.2.4.2 and, section 4.3.2.4.3, but with these considerations:

- The sample mounting portion of the CCR insert is permanently attached, not removable like the sample card used in the standard module.
- The sample mounts in the center of a sapphire mounting plate centered between solder posts. The sapphire mounting plate is glued to the G-10 plate with rubber cement. Normally, it should not be removed. A thin layer of vacuum grease may be applied to mount the sample to the insert if desired. Lake Shore recommends Apiezon N grease for this application.

- The solder posts around the sapphire mounting plate are numbered, and are laid out in a counterclockwise pattern.
- There is no sample identification space on the CCR insert sample mounting plate. If desired, attach a removable note to the sample insert junction box with the sample identification and other relevant information..

4.6 Operating the Measurement Options

4.6.1 Probe Setup for the DC Closed-Loop Field Control Option

This section explains probe handling, probe orientation zeroing the probe, removing and replacing the probe, and probe accuracy. The probe that is used for DC closed-loop field control is mounted in the probe holder that is supplied with the system as shown below.



FIGURE 4-42 *Control probe*

The probe should be aligned adjacent to the left pole cap face, as close to the center as possible. The Lake Shore logo should face left.

4.6.1.1 Probe Handling

Although every attempt has been made to make the probes as sturdy as possible, they are still fragile. While manipulating the probe, be careful not to place pressure on the probe tip.

⚠ CAUTION

Care must be exercised when handling the probe. The tip of the probe is very fragile. Stressing the Hall sensor can alter its calibration. Any excess force can easily break the sensor. Broken Hall sensors are not repairable.

The cardboard and foam container that Lake Shore probes are shipped in should be retained for probe storage or shipment. For further details on accessories and probes, refer to the Magnetics Catalog.

4.6.1.2 Probe Orientation

Probe readings are dependent on the angle of the sensor (Hall sensor) in relation to the magnetic field. Maximum output occurs when the flux vector is perpendicular to the plane of the sensor. This is the condition that exists during calibration at Lake Shore. The greater the deviation from orthogonality (field perpendicular to the plane of the sensor), the larger the error of the reading. For example, a 5 ° variance on any one axis causes a 0.4% error, a 10 ° misalignment induces a 1.5% error, etc.

In the DC mode of operation, the orientation of the probe affects the polarity reading of the gaussmeter. On a transverse probe, the Lake Shore name indicates the side for positive (+) flux entry (probe orientation for positive measurement).

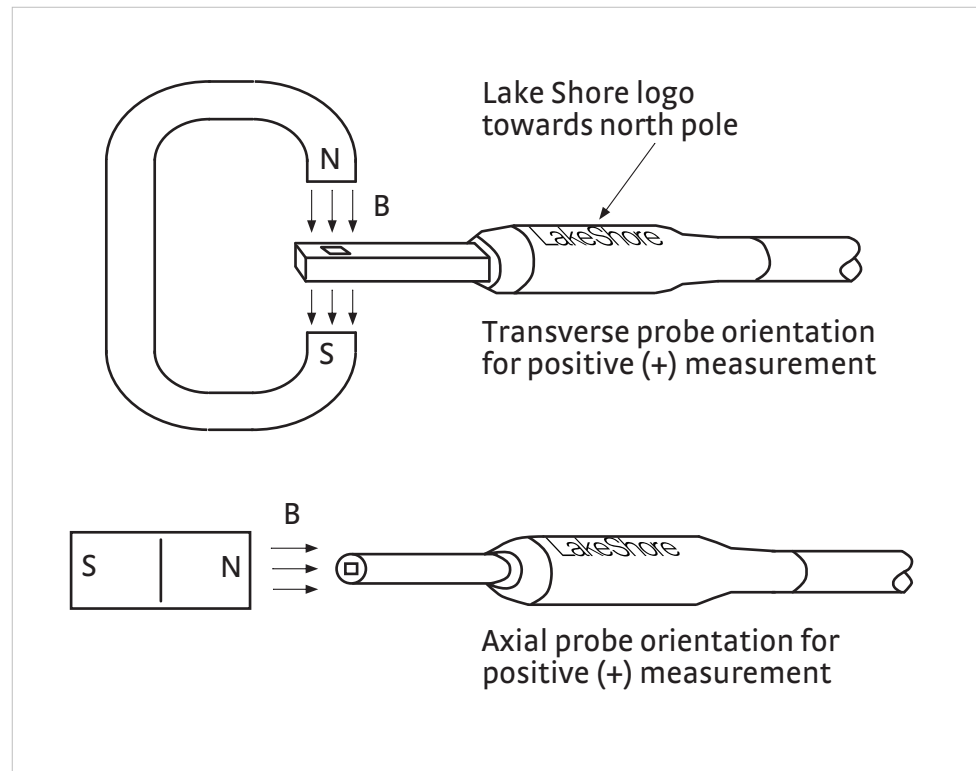


FIGURE 4-43 Probe orientation for positive measurement

4.6.1.3 Zeroing the Probe

Both the probe and gaussmeter have accuracy specifications that may impact the actual reading. The probe should be zeroed before making critical measurements. The zero probe function is used to null (cancel) the zero offset of the probe or small magnetic fields. It is normally used in conjunction with the zero gauss chamber. (Otherwise, field readings will be offset by any local field present during the zeroing process—such as the earth's local magnetic field or the remanent magnetization of the electromagnet.

CAUTION

Use care to ensure the zero gauss chamber does not become magnetized. Using a magnetized chamber to zero a probe can lead to erroneous field readings. It is a good practice to periodically degauss the chamber. A bulk tape degausser (Verity VS250, Data Devices PF211, or equivalent) may be used.

1. To zero the Hall probe, remove the probe and probe holder from its position between the magnet coils.
2. Place the Hall probe tip inside the zero gauss chamber.

NOTE

The probe should be at least 3 feet from sources of magnetic field—such as the electromagnet.

4.6.1.4 Replacing the Hall Probe

An electrically erasable programmable read only memory (EEPROM) is included in each probe. The EEPROM stores specific information that the gaussmeter requires for operation. The information includes serial number, probe sensitivity, and field compensation data.

! CAUTION

Be certain to turn the power off before connecting the probe to the rear of the gaussmeter. Probe memory may be erased if connected with power on.

When the instrument is powered up, the probe memory is downloaded to the gaussmeter. This is how the gaussmeter knows which ranges are available and which error correction to apply. Normal operation may continue after the new probe offset is nulled using the zero probe operation. If the instrument is powered up with no probe attached, the Hall software will report an error message.

1. Place the system in neutral by pressing Abort on the HMS software ribbon.
2. Turn off the power supply.

4.6.1.5 Probe Accuracy

Tolerance of instrument, probe and magnet must be considered for making critical measurements.

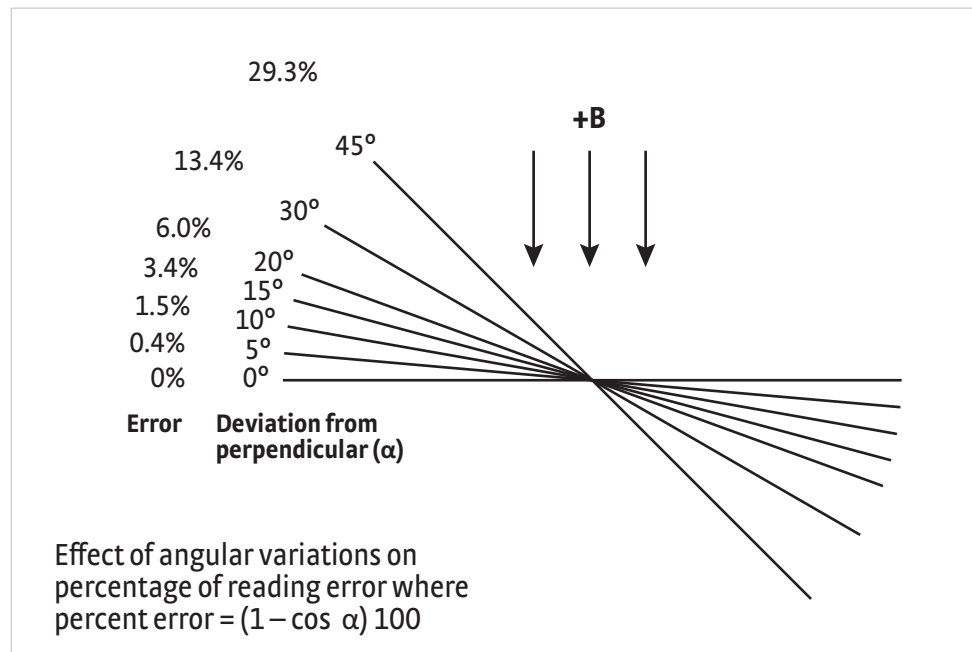


FIGURE 4-44 Effect of angle on measurements

For best results, the instrument and probe should warm up for at least 5 min before zeroing the probe and at least 30 min for rated accuracy. The probe and the zero gauss chamber should be at the same temperature.

Chapter 5: Maintenance and Troubleshooting

5.1 General

This chapter covers maintenance, troubleshooting and field service instructions. Customer service of the product is limited to the information presented in this chapter. Factory trained service personnel should be consulted if the instrument requires further repair. Damage to the 8400 Series Hall effect measurement system (HMS) can result if these procedures are not done properly. Instructions for contacting Lake Shore and arranging product service are in section 5.5.

5.2 Maintenance

This section describes maintenance you can do to keep your 8400 Series HMS operating at its best.

5.2.1 Preventive Maintenance Schedule

Use this table as a foundation in developing a time table for 8400 Series HMS component maintenance. Tailor the schedule to fit your own system use.

Maintenance	Every use	3 months	6 months	12 months	As needed
Maintain a safe, clean work space	x				
Clean the sample holder		x			
Single point LN ₂ vacuum pump out				x	
Standard insert middle wiring board replacement					x
Sample card retainer replacement					x
Prober pin replacement					x
Clean the sample card					x
Clean the electromagnet surface				x	
Clean the measurement platform surface		x			
Clean the sliding plate track		x			
Clean the water filter		x			
Replace fuses					x
Check CCR compressor helium pressure					x
Check CCR compressor cooling water quality			x		
Lubricate o-rings					x
Charge CCR compressor helium gas					x
Replace expander's valve disc, valve stem, and/or displacer seals					Every 10,000 h of operation
Cold head—return to factory for maintenance					Every 10,000 h of operation
Replace CCR compressor adsorber					Every 12,000 h of operation
Stainless steel gas lines: Nycoil hoses					x

TABLE 5-1 Preventive maintenance schedule

5.2.2 Single Point LN₂ Vacuum Pump Out Procedure

These directions assume that the single point LN₂ body has retained moderate vacuum quality and has not been vented to air. It also assumes that the turbo-molecular vacuum pump has been assembled according to section 3.6.6.

You will need the following equipment:

- Vacuum pump with blank-off capable of 0.1 Pa (7×10^{-4} Torr) or lower blank-off pressure. If a two-stage rotary oil pump is used, it must have an anti-backstreaming filter to prevent oil from the pump contaminating the vacuum isolation space in the single point LN₂ body.
- Pump out port operator (this was shipped with the Model 84015).

Follow this procedure to pump out the single point LN₂ body.

1. Place the single point LN₂ body in a convenient location such as a storage position on the measurement platform.
2. Set up the vacuum pump. A vacuum gauge is useful, but not necessary.
3. Connect a vacuum line from the vacuum pump to the NW 16 port on the pump-out port operator (adapter fittings may be required).
4. Remove the rubber cap from the single point LN₂ body's pump-out port.
5. Attach the pump-out port operator to the single point LN₂ body's pump-out port. You will need to rotate the handle on the operator clockwise to engage the valve on the port.
6. Turn on the vacuum pump and wait for a good vacuum to be established.
7. Slowly pull the handle of the pump out port operator to open the port.

CAUTION

Damage to the pump may occur if atmosphere is rapidly introduced to the pump inlet.

8. Pump for 24 hours or until the vacuum gauge reads $< 5 \times 10^{-5}$ Torr.
9. Push the handle of the operator in to close the valve on the pump-out port.
10. Rotate the handle on the operator counterclockwise and disengage it from the pump-out port.
11. Turn off the vacuum pump and remove associated lines.
12. Remove the pump-out port from the vacuum line. Store the operator so it will be available for the next use.
13. Replace the rubber cap on the pump-out port.

5.2.3 Standard Insert Maintenance

This section describes maintenance for the standard insert. There are a couple maintenance procedures for the standard insert which can be done in the field, including replacing the middle wiring board and the sample card retainer.

5.2.3.1 Middle Wiring Board Replacement for the Standard Insert

You may need to replace the middle wiring board due to wear, damage, or deterioration in measurement performance. You will need a hex key set, gloves, and a clean workspace for the standard insert to perform this procedure.

NOTE

Wear gloves while performing this procedure to avoid contaminating the middle wiring board and other standard insert components with oils.

1. Place the system in neutral by pressing **Abort** on the HMS software ribbon (section 4.2.3)
2. If the standard insert is installed on the measurement position, disconnect the sample insert cables from the sample insert.
3. Remove the standard insert from the single point LN₂ body or the light tight body (section 4.3.3).
4. Remove the sample card from the standard insert (section 4.3.3.1).
5. Rest the flat edge of the top of the standard insert on the table.

6. Using a 2.5 mm hex key, unscrew and remove the two M3 screws from either side of the card alignment guide.
7. Pull to remove the card alignment guide and the stem from the middle wiring board and set aside.
8. Pull out the middle wiring board from the insert outer tube.

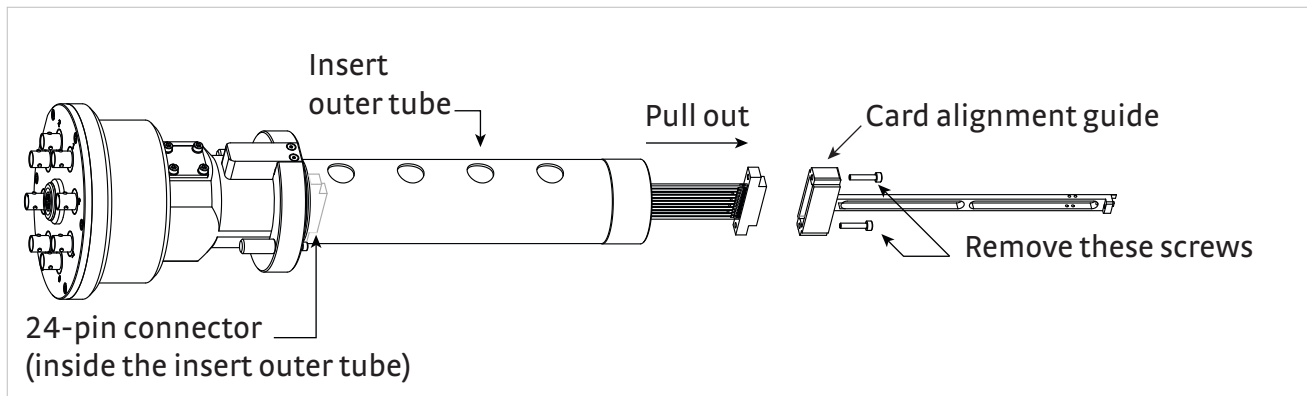


FIGURE 5-1 Remove the M3 screws from the card alignment guide, then pull out the middle wiring board

9. Obtain the new middle wiring board. Holding it by the connector, with the sample side up, put it into the insert outer tube.
10. Push to attach the bare end of the middle wiring board into the 24-pin connector at the bottom of the insert outer tube (FIGURE 5-1).
11. Align the card alignment guide (with stem) to the connector on the middle wiring board, so that the line on the side of the guide aligns with the line on the insert outer tube.
12. Using a 2.5 mm hex key, screw in the two M3 screws onto either side of the card alignment guide to secure the guide and stem to the connector on the middle wiring board.

5.2.3.2 Sample Card Retainer Replacement

This procedure assumes that the standard insert has been removed from the body, and the sample card has been removed according to section 4.3.3.1. When the sample card retainer replacement is shipped to you, it is shipped attached to the card alignment guide. To replace the guide, follow this procedure.

1. Align the card alignment guide (with stem) to the connector on the middle wiring board, so that the line on the side of the guide aligns with the line on the insert outer tube.
2. Using a 2.5 mm hex key, screw in the two M3 screws onto either side of the card alignment guide to secure the guide and stem to the connector on the middle wiring board.

5.2.4 CCR Module Maintenance

This section describes maintenance procedures for the CCR module. Maintenance for the CCR module is necessary for the expander, compressor and the stainless steel gas lines. Follow these guidelines to get optimum use from your compressor. For further details, consult with the cold head and compressor user manuals.

Expander: the expander may need maintenance after 13,000 hours for the valve disc, valve stem, and displacer seals. Instructions for removing and replacing these parts are in the Cold Head manual.

Compressor: the compressor needs maintenance after 30,000 hours. At that time, the adsorber should be replaced. Instructions for removing and replacing the adsorber are in the Helium Compressor manual.

5.2.5 Sample Card Maintenance

This section describes maintenance procedures for the sample card.

5.2.5.1 Prober Pin Replacement

Follow these procedures to replace the prober pin on the prober pin sample card. You will need a number 1 Phillips screwdriver and the 10 mm prober pin sample card replacement kit.

1. Lay the sample card on the card fixture with the prober pins facing up.
2. Using a number 1 Phillips screwdriver, unscrew the four screws attaching the prober pins to the card.
3. Remove the four old prober pins.
4. Obtain the new prober pins and appropriate screws from the prober pin replacement kit.
5. Place the prober pin on the card, and screw it in. Do this to all four prober pins.

5.2.5.2 Cleaning Sample Cards



Wear gloves while performing any procedures dealing with the sample cards to avoid contaminating the sample card or other internal components with oils.

To remove a sample mounted to a sample card with rubber cement, gently push the side of the sample with a wooden stick or other soft object to shear it from the adhesive.



Prying the sample up with tweezers or a razor blade can damage the sample. Pushing on the sample with any hard, sharp object can also cause damage.

Remove lead wires from the sample with tweezers and a soldering iron. To reuse a card, remove any adhesive left on the card and remove all leads. Remove adhesive gently to avoid scratching the card. Remove typical “permanent” inks from the card with isopropyl alcohol or acetone.

We recommend cleaning sample cards between uses. Considering the many possible methods used to mount samples onto the sample cards, a variety of methods are necessary to clean them.

Chemical solvents are recommended over mechanical removal methods. The top surface of many sample cards is delicate and will not hold up to abrasives, scrubbing or scratching.

Be sure that all chemicals are compatible with the materials in the sample card. Sample cards also contain G-10/FR-4, copper.

5.2.6 Electromagnet Maintenance

This section describes maintenance procedures for the electromagnet.

5.2.6.1 Cleaning the Electromagnet Surfaces

All exposed surfaces of the electromagnet are either painted or plated, and therefore, do not require any rust preventive measures. Wipe clean all pole and pole cap surfaces with a clean, lint-free cloth. Keeping these parts free from contamination is a good preventive measure.

5.2.6.2 Condensation

If condensation is seen on the exterior of the electromagnet, wipe it away with a soft, clean, dry cloth to prevent corrosion.

5.2.6.3 Foreign Matter

Remove all traces of foreign matter from pole caps with a soft clean cloth. Do not let foreign material fall into the sleeve of the electromagnet between the coil and pole. Due to tight pole-to-sleeve tolerances, any foreign matter introduced into the sleeve when the poles are retracted may cause future operating problems.

5.2.6.4 Storage

Precautions are necessary for long-term storage to prevent deterioration of the electromagnet and its components. High or low temperatures can cause soft and hard coolant lines to burst or fail. Freezing temperatures can cause water to freeze and burst—even the hard lines. Drain any coolant from the cooling lines. Additionally, use air pressure to force out any remaining water from the internal coil cooling lines. Desiccant packs may be stored with the magnet to reduce effects from a moist storage environment.

5.2.7 Electromagnet Power Supply Maintenance

Refer to the electromagnet power supply user's manual for maintenance questions and considerations.

5.2.8 Instrument Maintenance

Each instrument comes with its own manual. Refer to the specific instrument user's manual for maintenance questions and considerations.

5.2.9 Measurement Platform Maintenance

This section provides maintenance procedures for the measurement platform.

5.2.9.1 Cleaning the Measurement Platform Surfaces

The measurement platform should be kept generally clean and clear of dust and other contaminants. The measurement platform is made up of anodized aluminum surfaces; use cleaners safe for these surfaces.

Surfaces may be wiped down using damp, lint-free cloths like Kimwipes®. Isopropyl alcohol on a lint-free cloth is recommended to loosen adhesives and other residue. Dust on the exterior may also be removed with a commercially available compressed air product such as Dust Off®.

The measurement position slot should not be greased. The slot will remain smooth and efficient if you keep it clean. To clean the slot, remove any module that is in the measurement position, and use a non-abrasive cloth like Kimwipes®.

5.2.9.2 Cleaning the Sliding Plate Track

The sliding plate track (the track on which the CCR slides), is coated with anodized aluminum. The carriers on the track use lubricant-free bearing surfaces. As such, the track does not need to be lubricated. The track will remain smooth and efficient if you keep it clean. To clean the track, slide the CCR forward to clean the rear, and slide it back to clean the front. Use a non-abrasive cloth like Kimwipes®. Isopropyl alcohol on a lint-free cloth is recommended to loosen adhesives and other residue. Dust may also be removed with a commercially available compressed air product such as Dust Off®.

5.2.9.3 Cleaning the Water Filter

The water filter located at the back of the measurement platform on the internal water manifold will need to be cleaned periodically. To clean the water filter, follow this procedure.

1. Unscrew the water filter lid with a $1\frac{5}{16}$ in (24 mm) wrench.
2. Pull the strainer out.

3. Clean the strainer by running it through clean water, and rinsing out any debris that may have gotten lodged in it.
4. Replace the strainer.
5. Screw the water filter lid back on.

5.2.10 Chiller Maintenance

Refer to the chiller user's manual for maintenance questions and considerations.

5.2.11 Fuse Replacement

Fuses are installed in each instrument. When the fuse fails, before replacing it, first determine the cause for the failure. When replacing the fuse, it is important to replace it with the value and type indicated on the rear panel for the line voltage setting.



To avoid potentially lethal shocks, turn off the controller and disconnect it from AC power before performing these procedures.



For continued protection against fire hazard, replace only with the same fuse type and rating specified for the line voltage selected.



Test the fuse with an ohmmeter. Do not rely on visual inspection of the fuse.

1. Locate the line input assembly on the instrument rear panel.
2. Turn the power switch Off (O).
3. Remove the instrument power cord.
4. With a small screwdriver, release the drawer holding the line voltage selector and fuse.
5. Remove existing fuse(s).
6. Replace with the proper fuse with proper ratings. Refer to the manual for the specific instrument to determine the proper fuse rating.
7. Re-assemble the line input assembly in reverse order.
8. Verify the voltage indicator in the line input assembly window, and set it to the appropriate voltage.
9. Connect the instrument power cord.
10. Turn the power switch On (I).

When the fuse needs to be replaced, please read the particular instrument manual for instruction

5.2.12 Calibration

Calibration should be performed when you change the operating air gap or pole cap, which you may need to do when you change modules. Additionally, periodic calibration may be performed to meet your laboratory protocols.



Calibration must be performed with the field calibration card and the standard module regardless of the module you intend to use for your measurements. The air gap and pole caps should be those necessary for the module you intend to use.

Follow these procedures to perform an AC or DC field calibration.

1. Set up the standard module into the measurement position.
2. In the HMS software, navigate to the Toolbox level.
3. In the Toolbox level, under Hardware Configuration, click **Field Platform**.
4. Verify the summary in the Field Platform window matches the parameters of the magnet.

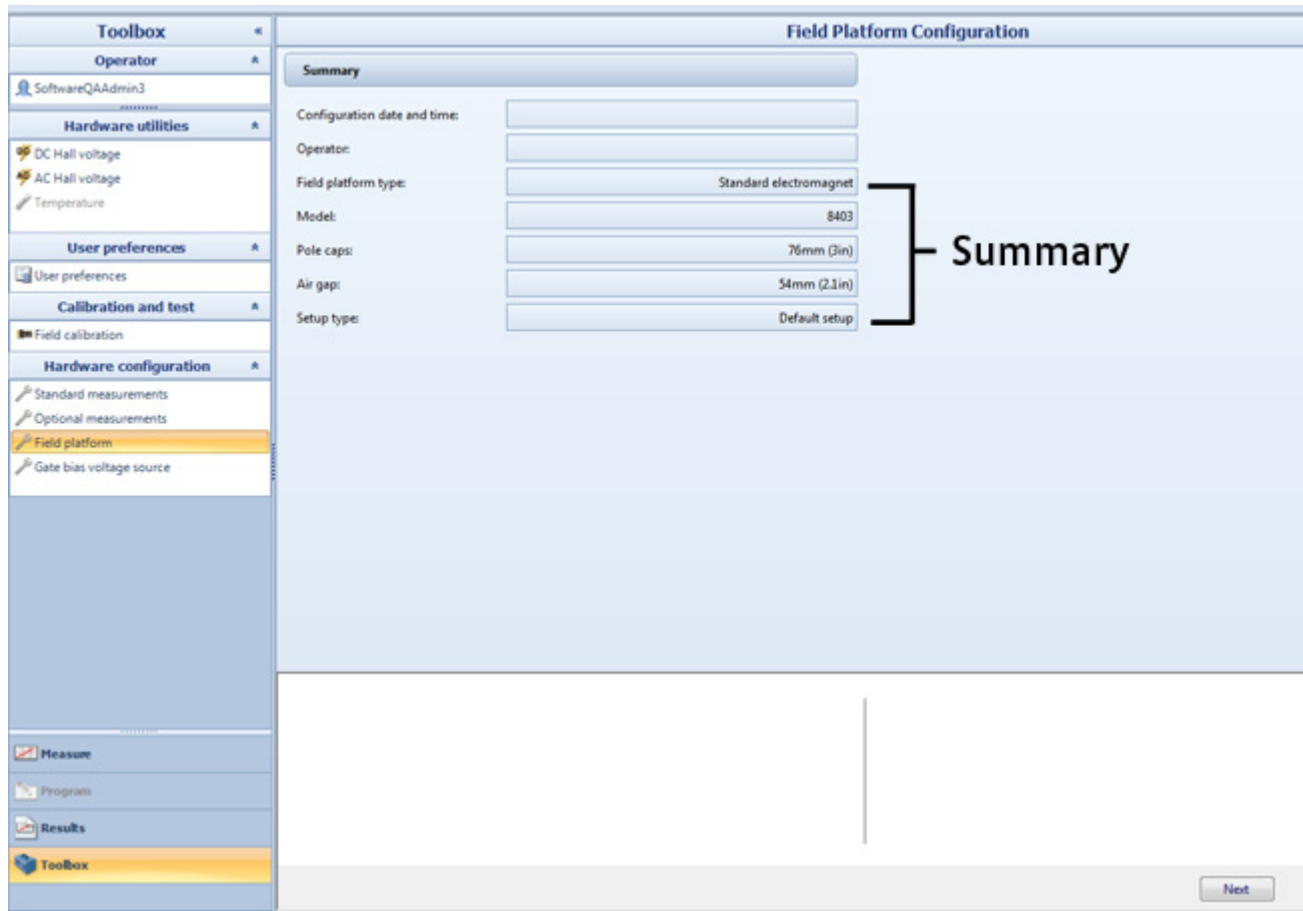


FIGURE 5-2 Verify field platform configuration

5. If you need to change the Field Platform parameters, click **Next** at the bottom of the window, change the parameters, and click **Finish**.
6. Under Calibration and Test in the second level navigation menu, click **Field Calibration** and then click **Next**.
7. Enter the sensor sensitivity value in the same units as provided in the software. The value can be found on the calibration card.
8. Enter any comments you wish to be retained with these results.
9. Insert the calibration card into the standard insert and install the standard insert in the standard module (section 4.3.1).

The screenshot shows the 'Field Calibration' interface. It is divided into two main sections: 'Current DC field calibration (uncalibrated)' and 'Current AC field calibration (uncalibrated)'. Each section has fields for 'Calibration date and time', 'Operation', 'Sensor sensitivity (V/T)', 'Pole cap size', 'Air gap', and 'Comments'. Below these is a 'Data' table. For DC, the table has columns for 'Drive current [A]' and 'Field [T]'. For AC, it has 'Frequency [Hz]', 'Field [T]', and 'Phase [deg.]'. At the bottom, there is a section titled 'Enter required information' with a 'Sensor sensitivity (V/T)' input field (containing '0.2950') and a 'Comments' field. To the right of this section are three radio buttons: 'Start both DC and AC field calibration', 'Start DC field calibration only', and 'Start AC field calibration only'. A 'Back' button is at the bottom right.

FIGURE 5-3 Field calibration screen

10. Click **Start both DC and AC field calibration**, **Start DC field calibration only**, or **AC field calibration only** depending on which you choose to do.



You can watch the status bar to view the calibration in progress.

11. When the calibration is finished, accept it or discard it. If you accept it, the calibration is saved immediately for future use. Discard the calibration if you see any anomalies with the data presented.

5.3 Troubleshooting

This section provides troubleshooting for AC and DC calibration and measurement.

5.3.1 DC Measurement Troubleshooting

This section provides troubleshooting for DC calibration (section 5.3.1.1) for the InAs sample and resistors that were tested for system verification (section 5.3.1.2 and section 5.3.1.3). You can also use section 5.3.1.2 and section 5.3.1.2 to troubleshoot your own sample measurements.

5.3.1.1 DC Calibration Troubleshooting

When performing DC calibration, you may confront two types of issues: those that materialize when attempting to run a calibration, and those that materialize in the data of the calibration.

If you attempt to run a calibration, and the software will not allow it, there may be a safety interlock condition. In this case, perform the following checks.

- Verify that the standard insert is fully engaged in the light tight body and the screws are fully tightened.
- Verify that the standard insert cable is fully attached. Check both the multifunction cable and all triaxial cables.

If you run a calibration, and you discover anomalies in the data, perform the following checks.

- Verify that the actual air gap matches the field platform parameters you set in the Toolbox.
- Verify that the pole cap size matches the field platform parameters you set in the Toolbox.
- Verify that the sample card was properly inserted with the retainer fully engaged.
- Verify that the field calibration card has not been damaged.
- If you recently changed the air gap, verify that the pole adjuster screws are fully tightened.
- If you recently changed the air gap, verify that the screws that hold the pole caps on the pole are fully tightened.

5.3.1.2 DC Measurement Verification Troubleshooting

During DC measurement verification, which is performed by the installer using the steps in Chapter 3, a test is made on an InAs sample, and a test is made on two resistors. The following sections provide troubleshooting for each of these tests.

5.3.1.2.1 InAs Sample Test Troubleshooting

If results show that the carrier type is p rather than n, check the contact of the triaxial cables and check the magnet wiring, and then re-run the magnetic field calibration.

If the InAs material values (resistivity, carrier density or mobility) have changed significantly from previous tests, inspect the InAs for cracks or other damage.

5.3.1.2.2 Resistor Troubleshooting

If the 10 M Ω or 0.01 Ω resistor test fails, perform the following checks.

- If current source is in compliance, check for broken cables or cables not connected.
- If the 10 M Ω resistor is in current compliance, ensure the current is less than 10 μ A for 100 V compliance and less than 2 μ A for 20 V compliance.
- If the value of resistances measured with the 8400 Series HMS is not within specifications, have the individual instruments re-calibrated.

5.3.1.3 Model 84031 High Resistance Troubleshooting

If there are anomalies in the data received from a high resistance measurement, perform the following checks.

- If the current leak error is detected, clean the sample card (section 5.2.5)
- Using inert, dry gas (Argon) in the sample space may help reduce leakage.

5.3.2 AC Measurement Troubleshooting

5.3.2.1 AC Calibration Troubleshooting

Troubleshooting issues with AC calibration is very similar to troubleshooting those with DC calibration. Perform the following checks if you are running an AC calibration.

- Verify that the hooks on the cable boom are situated on the cable boom according to section 3.5.3.2. Placing the hooks this way ensures that the cables are far enough away from stray fields on the electromagnet to avoid inductive pickup effects.
- If this is not the issue, then refer to section 5.3.1.1 to use the troubleshooting steps provided for DC measurements.

5.3.2.2 AC Noise Troubleshooting

If the AC noise is unacceptably large, perform the following checks.

- Ensure that all wires on the sample are as short as possible and do not have unnecessary loops.
- Ensure that the temperature of the sample is as stable as possible. Insert the sample into the magnet, wait 1 h, then re-run the test.

5.3.2.3 InAs Measurement Troubleshooting

If the InAs test shows up as p type in the AC mode, but n type in the DC mode, perform the following checks.

- If the InAs material values (resistivity, carrier density or mobility) have changed significantly from previous tests, inspect the InAs for cracks or other damage.
- Recalibrate the AC magnetic field.

5.3.2.4 AC/DC Comparison Troubleshooting

An AC/DC comparison should be made between the carrier density, mobility, and Hall coefficient. Do not directly compare Hall voltage since this depends on the magnetic field. The AC and DC test may be done at different fields. The calculation of Hall coefficient, density and mobility take into account the different magnetic fields. If the AC and DC Hall values do not agree, perform the following checks, and then re-run the field calibration.

- Make sure all wires on the sample are as short as possible and do not have unnecessary loops.
- Make sure the temperature of the sample is as stable as possible. Insert the sample into the magnet, wait 1 h, then re-run the test.

5.3.3 Temperature Troubleshooting

This section provides troubleshooting procedures for temperature issues that you encounter while heating or cooling your system, or errors in one of the instruments that monitors or controls your sensors.

If you are having difficulties reading the platinum sensor on the sample card in the standard module, refer to section 5.3.3.1. If you are having difficulties reading temperatures for the oven, refer to section 5.3.3.3. If you are having difficulties reading temperatures for the CCR, refer to section 5.3.3.4.

5.3.3.1 Standard Module Troubleshooting

This section applies to activities using the platinum sensor in the standard module, which is monitored by the Model 336. Therefore, troubleshooting activities for this involve checks on the standard insert, Model 336, and associated cabling. If you are having difficulties reading the platinum sensor that results in an error message on the Model 336, or if the 8400 Series HMS shuts down due to a temperature error, perform the following checks.

- Verify that the sample insert cables are fully attached to the insert. Check both the multifunction cable and all triaxial cables.
- Verify that there is a platinum sensor on the sample card.
- Verify that the sensor cable is installed on the rear of the Model 336 to Input C.

In the HMS software, navigate through Toolbox, Hardware Utilities to Temperature and follow these procedures.

1. If the secondary loop temperature is in error, then visually check the sensor to ensure it is not damaged.
2. Use a multimeter on the CCR insert, specifically at the location of the 10-pin connector, to confirm sensor resistance and wiring.
3. If there is an “open” at this location, either the wiring on the insert has failed, or the sample sensor has failed. It is most likely the sample sensor. In this case, contact Lake Shore (section 5.5.1) for the best way to handle this.

5.3.3.2 Sample Space Gas Handler Troubleshooting

If the gas cylinder tank seems to empty quickly, it may be due to a leakage in the system. Use these procedures to troubleshoot this issue.

1. Verify that the sample insert is in place. If the oven is connected, verify that the heater space valve is set in Run position.
2. Set the gas cylinder regulator output pressure to 379 kPa (55 psi) and open any valves, if present, in the path to the sample space gas handler.
3. Push the Valve button on the front of the sample space gas handler, and check that the compound gauge in the unit shows 20” Hg vacuum (9.8 psi; 67.7 kPa) or better. If it shows less than 15” Hg vacuum (7.4 psi; 50.8 kPa), there could be a leak in the system.
4. Release the button. The compound pressure gauge on the sample space gas handler should show a small positive value.



The regulator in the gas handler is set at 0.5 psi for the gas output pressure to the sample space. If it does not show any positive pressure, there could be a leak in the system. If the pressure is greater than 3 psi (20.7 kPa), the regulator could be defective.

5. Listen for any leaks or hoses popping off.
6. Check for slow leaks by closing the gas cylinder valve and watching the regulator supply pressure gauge.



The pressure should not drop more than 1000 kPa (145 psi) within 10 min, and is more typically one tenth this leak-down rate.

7. Correct any leakage problems.
8. Contact Lake Shore Service if the problem persists.

The sample space will fill with He gas until the gauge shows a small positive value. The regulator in the sample space gas handler is set at 3.45 kPa (0.5 psi) for the gas output pressure. If the balloon fills with gas, the sample space pressure regulator will be in the open position. Adjust the pop off valve to assure it is in the closed position.

5.3.3.3 Oven Troubleshooting

Errors on the Model 336 that read SOVER or SUNDER indicate that there is a sensor failure. You will need to perform further diagnosis to confirm the type of failure.

- In the HMS software, navigate through Toolbox, Hardware Utilities, to Temperature.
- If the sample sensor shows Error or Fault, this indicates there is an error in the sample insert.
- If the Primary Loop shows “Temperature error” this indicates there is a sensor failure in the body.

5.3.3.4 CCR Troubleshooting

If you have a temperature system shutdown from a temperature sensor error, follow these procedures to troubleshoot it.

1. On the 8400 Series software interface, navigate through Toolbox, Hardware Utilities, to Temperature.
2. Look at the temperatures under secondary loop and primary loop.
3. If one of these is in error, then follow these checks to further troubleshoot this.
 - a. Ensure the multifunction cable is connected to the CCR insert.
 - b. Ensure the VT control cable is connected to the VT control port.
 - c. Ensure that the opposite ends of the multifunction cable and the VT control cable are connected inside the rear of the console. Use the wiring diagram in FIGURE 5-7 to determine this.
 - d. Ensure the 10-pin and 8-pin Mil-C connectors on the intermediate cable are connected to the CCR insert.
 - e. On the VT control cable, ensure the 10-pin and 4-pin cables are attached to the CCR.
4. If the secondary loop temperature is in error, then check the condition of the secondary loop temperature sensor.
5. Visually check the sensor to ensure it is not damaged.
6. Use a multimeter on the CCR insert, specifically at the location of the 10-pin connector to confirm sensor resistance and wiring.
7. If there is an “open” at this location, either the wiring on the insert has failed, or the sample sensor has failed. It is most likely the sample sensor. In this case, contact Lake Shore (section 5.5.1) for the best way to handle this.

5.3.4 Field Troubleshooting

If you have an unexpected interruption in your water flow, you will receive a message on the HMS software screen indicating a “magnet power supply flow switch error.” This error may be due to a simple inadvertent shutdown of the water, an overheated coil, or a faulty flow switch.

To troubleshoot this, start by checking the water source. If it was inadvertently shutdown, follow the procedures in section 5.3.4.1 to reset the magnet power supply. If the water source was not inadvertently shutdown, follow the troubleshooting procedures in section 5.3.4.2 to diagnose the situation.

5.3.4.1 Water Flow Interruption Recovery

If your water source was inadvertently shutdown and you received a message indicating a “magnet power supply flow switch error,” use these procedures to reset the magnet power supply.

1. Click OK to clear the error dialogue box.
2. Exit the software.
3. Check for obvious interruptions in the water flow and fix them.



If the solenoid valve is connected in your magnet power supply, the water flow interruption may have triggered the valve to close. In this case, if you manually reset the water flow at the supply valve, the flow meter will not register that the water source is flowing again. You must set the field again in the HMS software, to open the solenoid valve.

4. On the magnet power supply, press **Status** (the number 7 key). A message indicating a “flow switch fault” will appear on the magnet power supply display screen.
5. Press **Status** again to clear the error message.

If the water flow was interrupted inadvertently, this procedure will clear the error message from the display screen, and you can return to normal operation. If the message does not clear, that is an indication that either you have an overheated coil, or the flow switch has been interrupted. Follow the procedure in section 5.3.4.2 to diagnose these.

5.3.4.2 Magnet Power Supply Interlock Troubleshooting

If the HMS software or magnet power supply reports a magnet power supply interlock error, it means that the system has an overheated coil, or the flow switch has been interrupted.

The most common condition is an interrupted flow switch. The flow switch can be interrupted by a low-flow condition. This means either the water flow has ceased, or it is insufficient, and is no longer allowing the water flow switch to engage. Follow these procedures to diagnose the status of the water flow.

1. Check the water flow meter to check for lack of, or insufficient flow.
2. If the water flow meter shows that there is no water flow, then perform the following:
 - a. Ensure the water is on.
 - b. Ensure there are no kinks or other restrictions in the water flow.
 - c. Visually inspect inline filters for clogging or other restrictions. There is one filter in the water manifold (refer to section 5.2.9.3 to clean it). Also inspect any user installed filters.
3. If the water flow meter shows that water flow is sufficient, then follow this procedure using an ohmmeter to check the water flow switch operation.
 - a. Place the system in neutral.
 - b. Exit the software.
 - c. Turn off the magnet power supply.
 - d. Turn off the water.
 - e. Remove the phoenix connector from the rear of the MPS.
 - f. Place the ohmmeter test leads between pin 1 and 2 T.
 - g. Confirm open contact (since the water is off).
 - h. Turn the water on, and confirm open contact with the ohmmeter test leads between pin 1 and 2.
4. When the water is on and sufficient flow exists as indicated by the flow meter, but the ohmmeter registers an OPEN contact, you must troubleshoot this condition. There are three conditions which may be at fault:
 - The magnet power supply interlock wiring has failed (see FIGURE 5-7 and TABLE 5-10 to verify)
 - The water flow switch has failed
 - The coil is overheated
 - The coil over-temperature switch has failed
5. To troubleshoot which one of the four conditions is the problem, follow this procedure:

- a. Remove the water manifold cover by loosening the four screws securing the cover onto the water manifold base.
- b. Use the MPS interlock wiring diagram to identify the wires coming from the individual coil over-temperature switches.
- c. Visually inspect the magnet power supply interlock wiring. If it appears to be intact, then the condition is likely one of the other three items listed in number 4 above.
- d. With the connector removed, place the ohmmeter across the water flow switch pins on the terminal block and confirm that they switch on and off. They should be closed if the water is flowing, and open if the water is not flowing.
 - If this does not occur, then the water flow switch has failed and needs to be replaced.
 - If this does occur, you may have an overheated coil; go onto the next step to determine if this is the case.
- e. If the water flow switch appears to be working according to your ohmmeter test, then follow this procedure to determine if the system has an overheated coil.
 - Allow water to flow to cool down the system. If the coil over-temperature switch resets itself then it is likely that the system had an overheated coil. This may be the result of clogged coil inner cooling lines. Contact Lake Shore (section 5.5.1) to determine the best possible solution for your coils.
 - If the coil over-temperature switch does not reset, then it is likely that the over-temperature switch has failed. Contact Lake Shore (section 5.5.1) to order a replacement and obtain procedures for replacing the switch.

5.3.5 Gate Bias and Sample Excitation Troubleshooting

If you are attempting to run a gate bias measurement or perform sample excitation, and you have a sample module interlock issue, there are two things that could happen. If you are in Idle mode, the Monitor pane on the HMS software may display the FAULT error. If you are in Run mode, you will receive the same FAULT error, but the system will shutdown, and a sample module interlock error message will appear in the HMS software interface. Use the following procedures to troubleshoot the situation.

1. Confirm that the sample insert is securely attached to the sample body.
2. Confirm that the sample insert cable is attached to the sample insert.
3. Use the wiring diagram to assist in the following checks.
 - a. Inside the console, confirm the sample insert cable is connected to the interlock cable with a D-sub connector.
 - b. Confirm that the other end of the sample insert cable is connected to the 6220 current source interlock terminals.
 - c. If you are running a gate bias measurement, the cable should also be connected to the voltage source (Keithley 6487) interlock connector.
4. If these checks fail to resolve the issue, contact Lake Shore for assistance (section 5.5.1).

5.3.6 Vacuum Troubleshooting

If your vacuum does not achieve the level suggested for each temperature option, the following sections describe some common problems and simple diagnostic procedures to remedy this. If the problem is caused by a very small leak it may be necessary to use a leak detector to troubleshoot it properly. Leak detector operation is not covered in this manual. Consult your leak detector user's manual.

Suspect poor vacuum if you observe any of the following symptoms:

- CCR will not cool to base temperature
- Cooling time increases
- Oven will not heat to maximum temperature

5.3.6.1 Test the Turbo Vacuum Pump Alone

Before going through an extensive troubleshooting process on the 8400 Series HMS, it is advisable to verify proper pump and gauge operation. The only components needed for this step are the turbo vacuum pump, an NW 40 to 25 adapter, an NW 25 T and an NW 25 vacuum blank-off plate. The turbo vacuum pump must also be equipped with a vacuum gauge capable of reading pressures down to 10^{-8} Torr.



FIGURE 5-4 Turbo vacuum pump NW 40 connection, T, and gauge

1. With the gauge located on a T at the inlet of the vacuum pump, place the NW 25 centering ring, blank-off plate, and clamp over the inlet of the vacuum pump T.
2. Ensure the manual vent valve is fully closed.
3. Power on the pumping system.
4. The turbo vacuum pump should start rotating up to its maximum operational speed. If you are using the TPS-FRG, the gauge will automatically turn on when the pressure reaches 10^{-3} Torr.
5. If the connections are all made securely, the vacuum gauge reading should come down to $<10^{-6}$ Torr within 10 min of pumping.
6. Do not continue to the next steps if this pressure is not achieved; contact Lake Shore or your vacuum pump manufacturer directly for technical assistance.
7. If 10^{-6} Torr is achieved, turn off the turbo pump and vent the turbo.

5.3.6.2 Test the Vacuum Pumping System Along with the Connections to the Sample Module

1. Remove and set aside the NW 25 blank-off plate from the inlet T on the vacuum pumping system.
2. Use the NW 25 centering ring and clamp to connect the NW 25 flexible stainless steel vacuum line to the inlet T of the vacuum pumping system.
3. The other end of the NW 25 line should be connected to the bottom opening of the NW 25 feedthrough on the vacuum supply bracket at the rear of the measuring platform.
4. Connect another length of NW 25 stainless steel flexible line from the upper opening of the vacuum supply bracket to the isolation valve at the inlet on the CCR's vacuum space.
5. Fully close the vacuum isolation valve; in this step we are only checking the vacuum of the connections up to the sample module.
6. Power on the pumping system.
7. Observe the vacuum gauge reading. If the connections are all made securely, the vacuum gauge reading should come down to $<10^{-5}$ Torr within 10 min of pumping.

8. Do not continue to the next steps if this pressure is not achieved; contact Lake Shore for technical assistance (see section 5.5 for contact information).
9. If 10^{-5} Torr is achieved, turn off the turbo pump.

5.3.6.3 Test the Vacuum Pumping System, the Connection to the Sample Module and Its Vacuum Space

1. Leave the vacuum pumping system connected to the sample module as in the previous section.
2. Make sure that the vacuum pumping system is vented to atmosphere (use the manual vent valve on the side of the turbo pump), and the sample module vacuum chamber is vented to atmosphere.
3. Open the vacuum isolation valve on the sample module.
4. Power on the pumping system.
5. If vacuum levels come down to $<10^{-2}$ Torr within 10 min of pumping, you can assume all the connections are made securely.
6. If vacuum levels come down to $<5 \times 10^{-4}$ Torr within 1 h of pumping (with the gauge located on the T inlet of the vacuum turbo pump), you can assume all connections are made securely and there are no large leaks.
7. If vacuum levels come down to $<5 \times 10^{-5}$ Torr within 2 h of pumping, you can assume all connections are made securely, there are no large leaks and the vacuum space is free of moisture.



If the vacuum space was open to atmosphere for an extended period of time, it may take 24 h to achieve $<5 \times 10^{-5}$ Torr vacuum levels.

8. If the pressure listed in step 7 is achieved then you have verified that the vacuum pumping system and sample module vacuum space are functioning properly.
9. If these pressures are not achieved, contact Lake Shore Service for technical assistance.

5.3.7 General Troubleshooting

5.3.7.1 Avoiding Cooling Water Condensation

If the temperature of the cooling water is too cool relative to the air temperature and humidity, condensation can occur. Condensation inside the power supply can cause severe damage. To avoid condensation, the power supply operator must remain cognizant of the ambient air temperature, cooling water temperature, and the relative humidity. Lake Shore defines the limits of these conditions as follows: ambient temperature = 18°C to 28°C (64°F to 82°F), cooling water temperature = 15°C to 24°C (59°F to 75°F), and humidity = 20% to 80% (non-condensing). Knowing the actual state of these conditions, the operator can calculate the dew point, or temperature at which condensation will occur. TABLE 5-2 and TABLE 5-3 are included to aid in dew point calculation.



Use of the solenoid valve will regulate water flow to the magnet power supply and avoid humidity-related issues in systems running on tap water with the solenoid valve enabled.

°C	% Relative Humidity																		
	100	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10
32	32	31	31	29	28	27	26	24	23	22	20	18	17	15	12	9	6	2	0
29	29	28	27	27	26	24	23	22	21	19	18	16	14	12	10	7	3	0	—
27	27	26	25	24	23	22	21	19	18	17	15	13	12	10	7	4	2	0	—
24	24	23	22	21	20	19	18	17	16	14	13	11	9	7	5	2	0	—	—
21	21	20	19	18	17	16	15	14	13	12	10	8	7	4	3	0	—	—	—
18	18	17	17	16	15	14	13	12	10	9	7	6	4	2	0	—	—	—	—
16	16	14	14	13	12	11	10	9	7	6	5	3	2	0	—	—	—	—	—

TABLE 5-2 Dew point calculation (in degrees Celsius)

	% Relative Humidity																		
°F	100	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10
90	90	88	87	85	83	81	79	76	74	71	68	65	52	59	54	49	43	36	32
85	85	83	81	80	78	76	74	72	69	67	64	61	58	54	50	45	38	32	—
80	80	78	77	75	73	71	69	67	65	62	59	56	53	50	45	40	35	32	—
75	75	73	72	70	68	66	64	62	60	58	55	52	49	45	41	36	32	—	—
70	70	68	67	65	63	61	59	57	55	53	50	47	44	40	37	32	—	—	—
65	65	63	62	60	59	57	55	53	50	48	45	42	40	36	32	—	—	—	—
60	60	58	57	55	53	52	50	48	45	43	41	38	35	32	—	—	—	—	—

TABLE 5-3 Dew point calculation (in degrees Fahrenheit)

For example, determine the actual air temperature and relative humidity. Find the closest air temperature in the left-hand column and the closest relative humidity across the top. If the air temperature is 24 °C (75 °F) and the relative humidity is 35%, the intersection of the two shows a dew point of 7 °C (45 °F). Therefore, for the given conditions, the cooling water must remain above 7 °C (45 °F) to prevent condensation.

5.3.7.2 Verifying the Water Flow

1. Turn on the water.
1. Check for water leaks in the supply and return lines.
2. Turn on the power supply.
3. On the power supply display screen, verify that there is NOT a message indicating a fault.
4. Turn off the water.
5. Verify that there IS a message indicating a fault. This fault message indicates that the water flow switch interlock is working properly.
6. To clear the fault, turn on the water and press **Status** on the Model 643 two times.

5.4 Service Reference

This section provides information for line voltage selection, electrical ground connection, ESD and safety information. It also provides wiring diagrams and tables for the various components and options for your reference.

5.4.1 Line Voltage Selection

The instrument chassis and cabinets are grounded for safety. The safety ground provides a true ground path for electrical circuitry and, in the event of internal electrical faults such as shorts, it carries the entire fault current to ground to protect users from electrical shock. If the earth ground connection is impaired, render the system inoperative and secure it against any unintended operation. The ground connection is likely impaired if the equipment exhibits any of these conditions:

- Shows visible damage
- Fails to perform the intended measurement
- Has been subjected to prolonged storage under unfavorable conditions
- Has been subjected to severe transport stresses
- Has been serviced by unqualified personnel

Do not use an apparatus exhibiting any of these conditions until qualified service personnel verify its safety.

! CAUTION

Each instrument and equipment in the console is individually adjusted to meet the specific location electrical requirement. The voltage requirement is listed on the label on the rear door of the console. If the system voltage has to be changed, each instrument and equipment in the console needs to be individually adjusted. Please follow each instrument manual provided to change the voltages.

When the instrument or equipment is removed from the system for service, make a note of its line voltage setting. When the item is returned, verify its line voltage setting with the voltage on the note before incorporating it into the system.

When the system is moved to a new location, before connecting the input power cord, verify that the system voltage setting is the same as the facility line voltage. When its necessary, adjust each instrument in the console to the correct voltage. Read each instrument manual provided for detail on voltage adjustment.

5.4.2 Electrical Ground Connection

All the instrument cases mounted in the electronic console are grounded to the ground lead of the power distribution strip through its input power cable. When you return the unit back to the console, and before turning on the power, verify that the original three conductor power cable is in place.

There is a safety ground cable built into the 22-pin connector on the multifunction cable for connection to the outer case of the sample insert to the instrument console chassis. Low impedance connections are maintained for safety purposes. This safety ground connection should be reestablished and maintained if any service is performed on the cable or measurement insert.



A protective earth terminal is present on the electronic console's rear rack mounting rail. Do not disturb or remove any wires connected to this terminal.

5.4.3 Electrostatic Discharge

Electrostatic Discharge (ESD) may damage electronic parts, assemblies, and equipment. ESD is a transfer of electrostatic charge between bodies at different electrostatic potentials caused by direct contact or induced by an electrostatic field. The low-energy source that most commonly destroys Electrostatic Discharge sensitive devices is the human body, which generates and retains static electricity. Simply walking across a carpet in low humidity may generate up to 35,000 V of static electricity.

Current technology trends toward greater complexity, increased packaging density, and thinner dielectrics between active elements, which results in electronic devices with even more ESD sensitivity. Some electronic parts are more ESD sensitive than others. ESD levels of only a few hundred volts may damage electronic components such as semiconductors, thick and thin film resistors, and piezoelectric crystals during testing, handling, repair, or assembly. Discharge voltages below 4000 V cannot be seen, felt, or heard.

5.4.4 Identification of Electrostatic Discharge Sensitive Components

The following are various industry symbols used to label components as ESD sensitive.



FIGURE 5-5 Symbols indicating ESD sensitivity

5.4.5 Handling Electrostatic Discharge Sensitive Components

Observe all precautions necessary to prevent damage to ESDS components before attempting installation. Bring the device and everything that contacts it to ground potential by providing a conductive surface and discharge paths. As a minimum, observe these precautions:

- De-energize or disconnect all power and signal sources and loads used with unit.
- Place unit on a grounded conductive work surface.
- Technician should be grounded through a conductive wrist strap (or other device) using 1 M series resistor to protect operator.

- Ground any tools, such as soldering equipment, that will contact unit. Contact with operator's hands provides a sufficient ground for tools that are otherwise electrically isolated.
- Place ESD sensitive devices and assemblies removed from a unit on a conductive work surface or in a conductive container. An operator inserting or removing a device or assembly from a container must maintain contact with a conductive portion of the container. Use only plastic bags approved for storage of ESD material.
- Do not handle ESD sensitive devices unnecessarily or remove them from the packages until they are actually used or tested.

5.4.6 Wiring Tables and Diagrams

This section provides the wiring diagrams and tables for the various components and options in the 8400 Series HMS.

5.4.6.1 CCR Module Wiring

Connector	Pin	Use
Triax #1	Center	Sensor pin #1
Triax #2	Center	Sensor pin #2
Triax #3	Center	Sensor pin #3
Triax #4	Center	Sensor pin #4
Triax #5	Center	Sensor pin #5
Triax #6	Center	Sensor pin #6
Triax #7	Center	Not used
Triax #8	Center	Not used
Multifunction cable 22-pin Lemo	1,2,3,4	Safety ground
	7	Sample temperature - I+
	8	Sample temperature - I-
	9	Sample temperature - V+
	10	Sample temperature - V-
	11	Sample heater +
	12	Sample heater -
	13	Safety interlock +
	14	Safety interlock -
	16	ID1-
	19	ID ground (GND1)
	20	Model 336 ground (drain)
CCR VT control cable 18-pin socket	1	Sample well temp V+
	2	Sample well temp V-
	3	Sample well temp I+
	4	Sample well temp I-
	5	Heater thermocouple +
	6	Heater thermocouple -
	7	Analog ID +
	8	Analog ID -
	9	Sample well heater +
	10	Sample well heater -
	11 to 18	Not used

TABLE 5-4 Wire connections for the CCR module

5.4.6.2 Oven Module Wiring

Connector	Pin	Use
Triax #1	Center	Probe #1
Triax #2	Center	Probe #2
Triax #3	Center	Probe #3
Triax #4	Center	Probe #4
Triax #5	Center	Not used
Triax #6	Center	Not used
Triax #7	Center	Not used
Triax #8	Center	Not used
Multifunction cable 22-pin Lemo	1,2,3,4	Safety ground
	5	Sample thermocouple +
	6	Sample thermocouple -
	13	Safety interlock +
	14	Safety interlock -
	15	ID0-
	16	ID1-
	19	ID ground (GND1)
Oven VT control cable 7-pin socket	20	Model 336 ground (drain)
	1	Heater thermocouple +
	2	Heater thermocouple -
	3	Analog ID +
	4	Analog ID -
	5	Heater +
	6	Heater -
	7	Not used

TABLE 5-5 Wire connections for the oven module

5.4.6.3 VT Control Cable Wiring

	Pin	Function	Console Connector	Pin
CCR VT control cable 18-pin socket	1	Sample well temperature V+	Model 336 Input A 6-pin DIN	4
	2	Sample well temperature V-		2
	3	Sample well temperature I+		5
	4	Sample well temperature I-		1
	Not connected	Cable shield		3
	5	Heater thermocouple +	Model 336 thermocouple Input C Bare wires	Bare wire +
	6	Heater thermocouple -		Bare wire -
	Not connected	Cable shield		eyelet
	7	Analog ID +	Model 336 Input B (ID) 6-pin DIN	4
	8	Analog ID -		2
	Not connected	Cable shield		3
	9	Sample well heater +	Model 336 Heater 1 Dual banana plug	Signal
	10	Sample well heater -		Ground
	Not connected	Cable shield		eyelet
	11 to 18	Not used	—	—

TABLE 5-6 Pinouts for the CCR VT control cable

	Pin	Function	Console Connector	Pin
Oven VT control cable 7-pin socket	1	Heater thermocouple +	Model 336 thermocouple Input C Bare wires	Bare wire +
	2	Heater thermocouple -		Bare wire -
	7	Cable shield		eyelet
	3	Analog ID +	Model 336 Input B (ID) 6-pin DIN	4
	4	Analog ID -		2
	7	Cable shield		3
	5	Heater +	Model 336 Heater 1 Dual banana plug	Signal
	6	Heater -		Ground
	7	Cable shield		eyelet

TABLE 5-7 Pinouts for the oven VT control cable

	Pin	Function	Control Connector	Pin
Multifunction cable 22-pin Lemo	1,2,3,4	Safety ground	Console safety ground (standard, oven and CCR)	eyelet
	5	Sample thermocouple +	Model 336 thermocouple Input D Bare wires (oven only)	Bare wire +
	6	Sample thermocouple -		Bare wire -
	7	Sample temperature - I+	Model 336 Input D 6-pin DIN (standard and CCR)	5
	8	Sample temperature - I-		1
	9	Sample temperature - V+		4
	10	Sample temperature - V-		2
	20	Model 336 ground (cable shield - drain)		3
	11	Sample heater +	Model 336 Heater 2 Dual banana plug (oven only)	Signal
	12	Sample heater -		Ground
	Not connected	Cable shield		eyelet
	13	Safety interlock +	Console, interlock 25-pin D-sub plug (standard, oven and CCR)	1
	14	Safety interlock -		14
	Not connected	Cable shield		25
	15	ID0-	Model 776 Digital ID 9-pin D-sub plug (standard, oven and CCR)	1
	16	ID1-		2
	17	ID2-		3
	18	ID3-		4
	19	ID ground (GND1)		9
	21,22	Not used	—	—

TABLE 5-8 Pinouts for the multifunction cable

		Pin	Function	Pin	Connector
843-011	Triaxial 1 through 8	Center	Signal	Center	Model 776 Contact 1 through 8 respectively triaxial
		Inner braid	Guard	Inner braid	
		Outer braid	Ground conductor	Outer braid	

TABLE 5-9 Pinouts for the primary triaxial cables

5.4.6.4 Water Manifold Wiring

	Pin	Color	Function	Pin	Connector
8404 water manifold terminal block	5	Black	Interlock –	1 Flow SW (COM)	Model 643 MPS magnet connector 4-pin terminal
	8	Red	Interlock +	2 Flow SW	
	1	Red	Coil overtemp	Term 1*	EM coil 1 overtemp sensor
	2	Black		Term 2*	
	6	Red	Coil overtemp	Term 1*	EM coil 2 overtemp sensor
	7	Black		Term 2*	
	3	Red	Flow switch	Lead 1*	Water flow switch bare wires
	4	Red		Lead 2*	
*Polarity independent					

TABLE 5-10 *Model 8404 water manifold wiring*

5.4.7 System Block Diagrams

This section provides the block diagrams and wiring diagrams for the Model 8404. It includes the block diagrams for the measurement platform level and the system level. This section also provides block diagrams for each module. Included are the standard module, LN₂ module, oven module, and the CCR module.

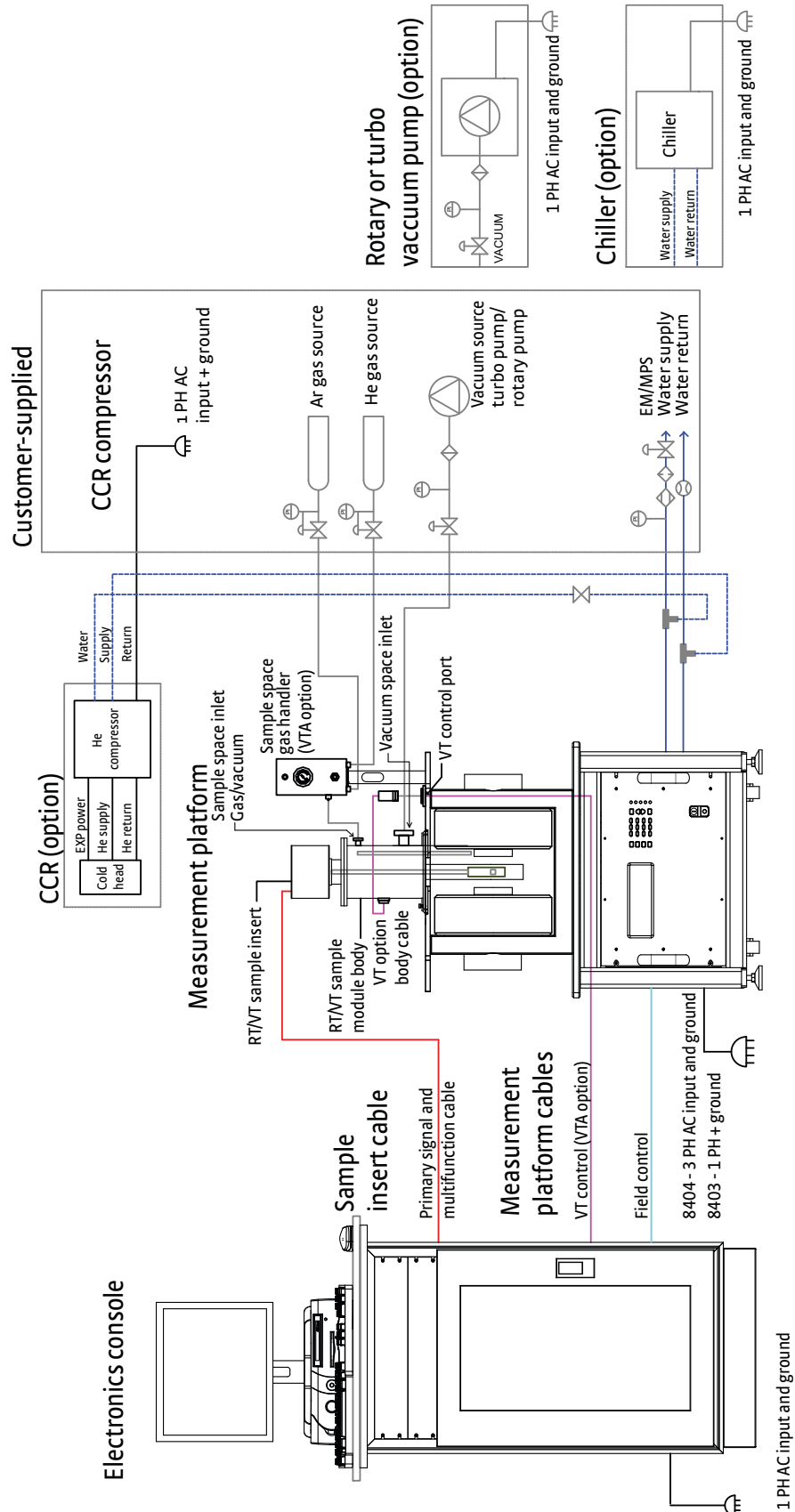


FIGURE 5-6 System level configuration

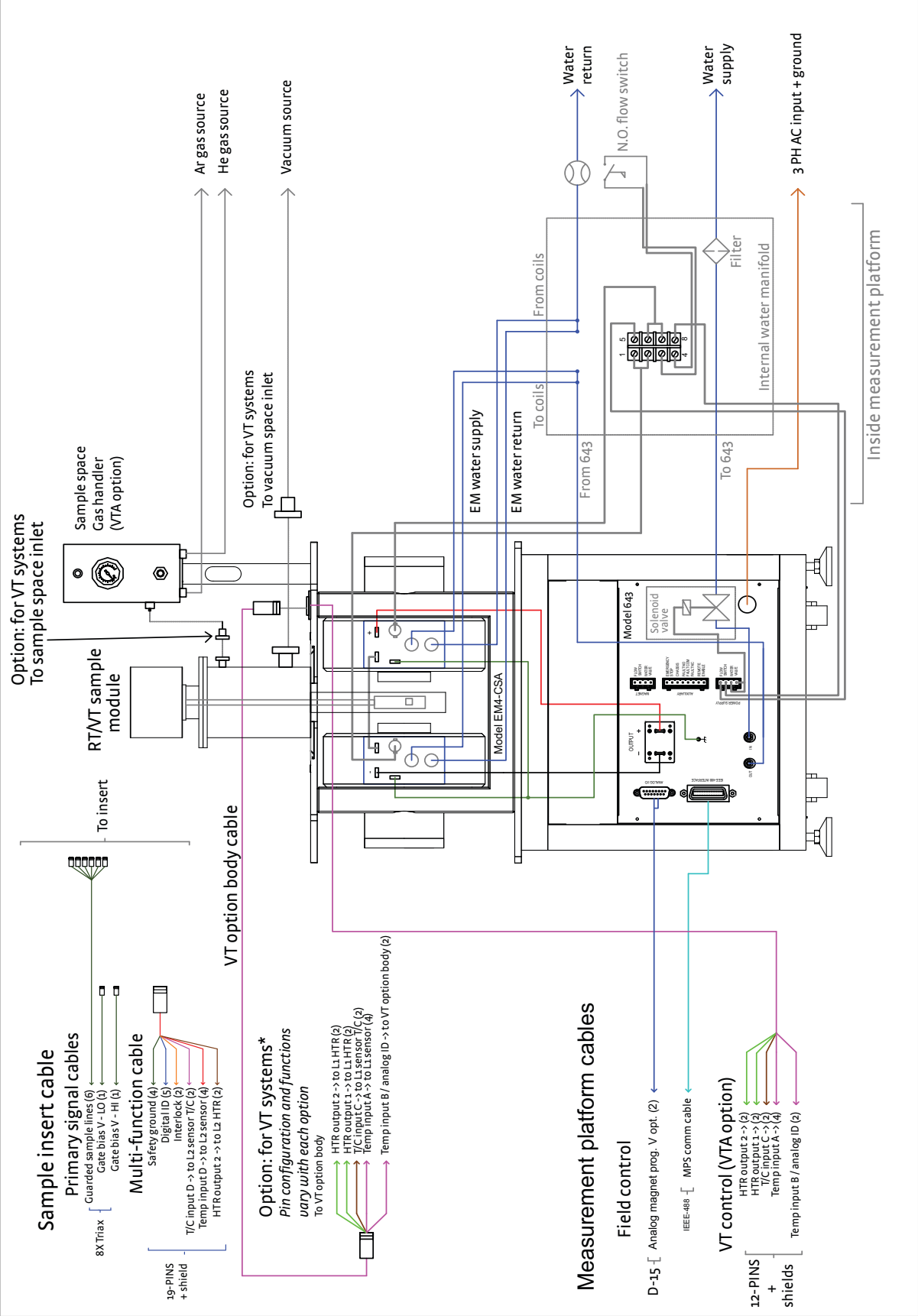


FIGURE 5-7 Model 8404 measurement platform configuration

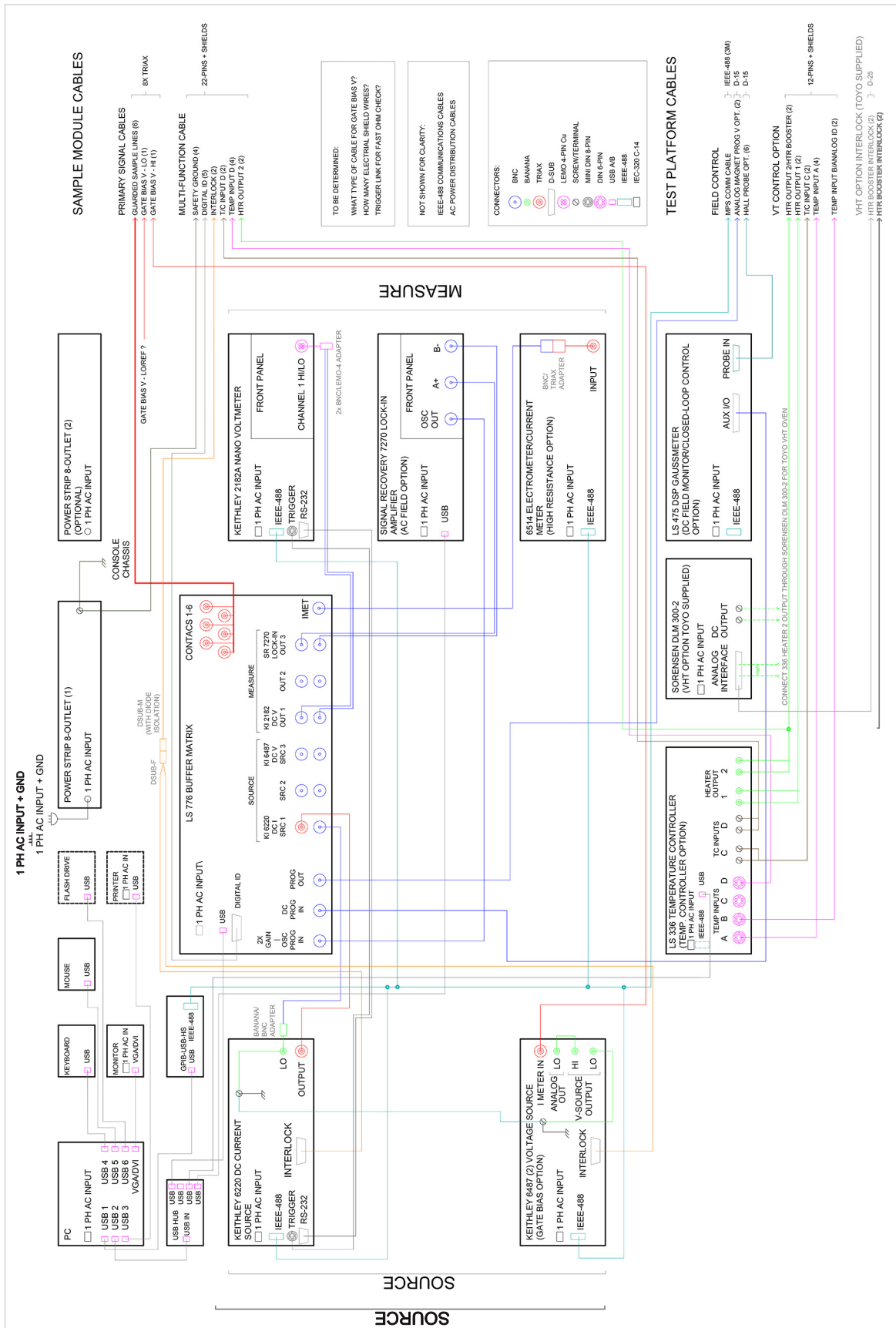


FIGURE 5-8 Electronics wiring diagram

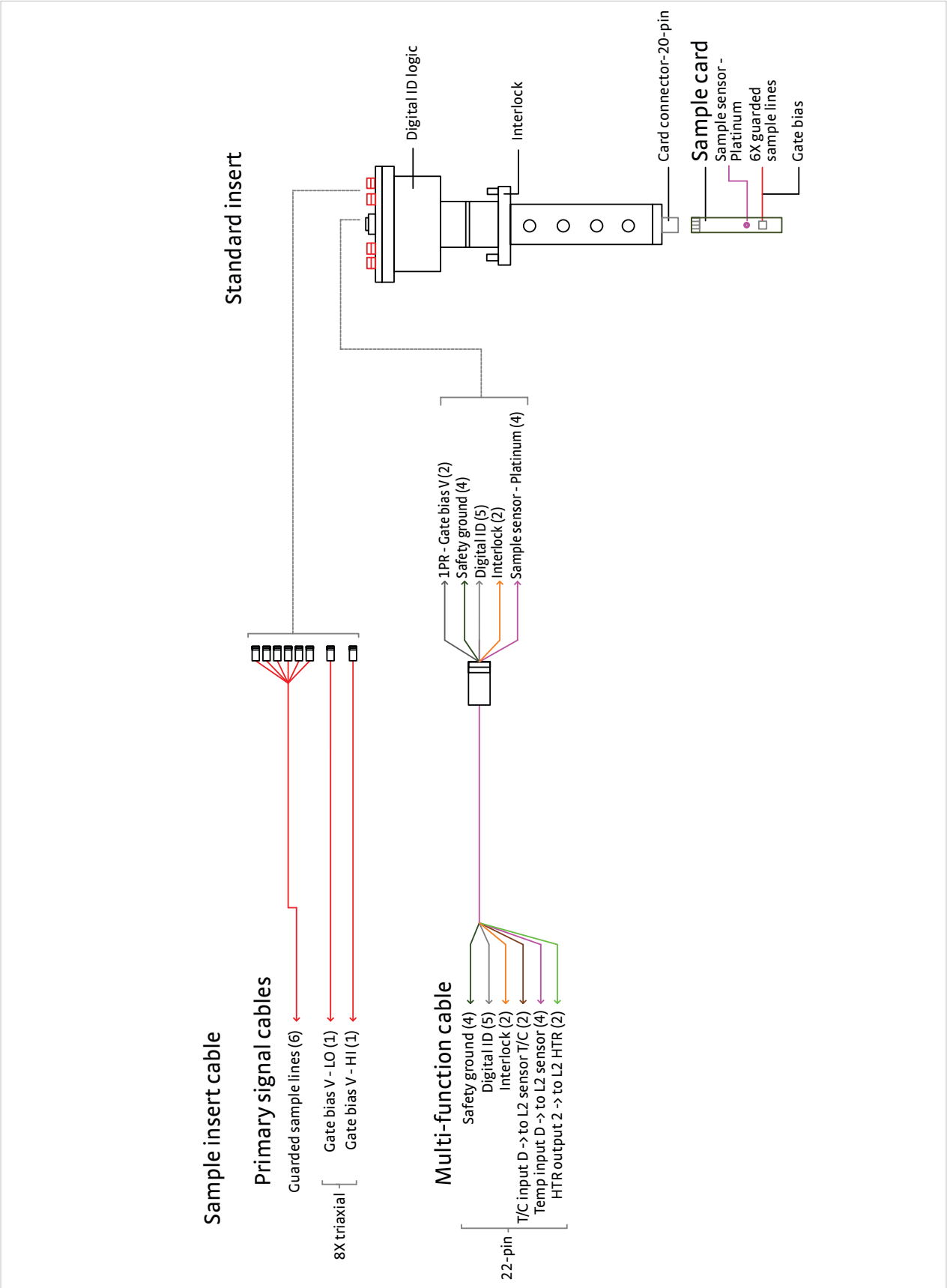
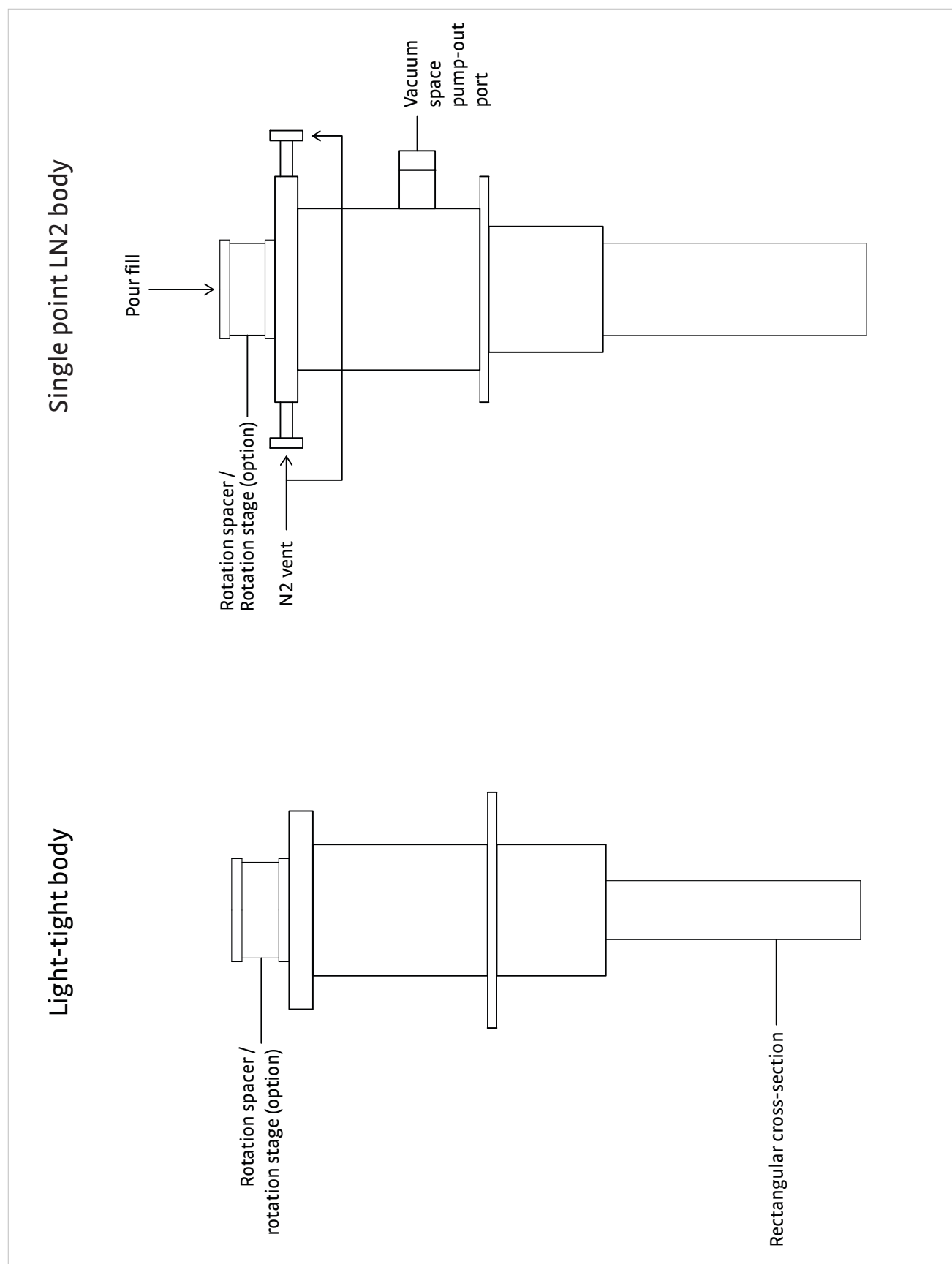


FIGURE 5-9 Standard insert and sample insert cable

FIGURE 5-10 *Light tight body and single point LN₂ body*

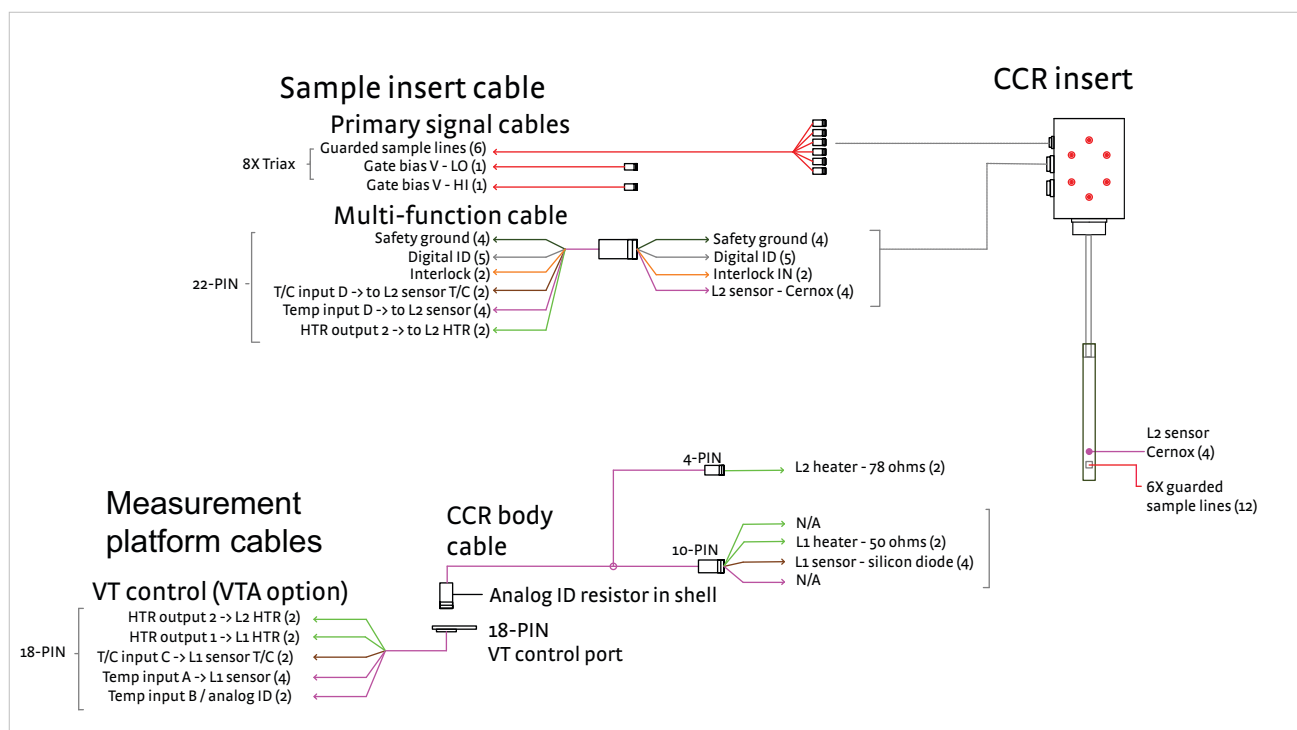


FIGURE 5-11 CCR operational schematic: sample insert cable, measurement platform cables and CCR insert

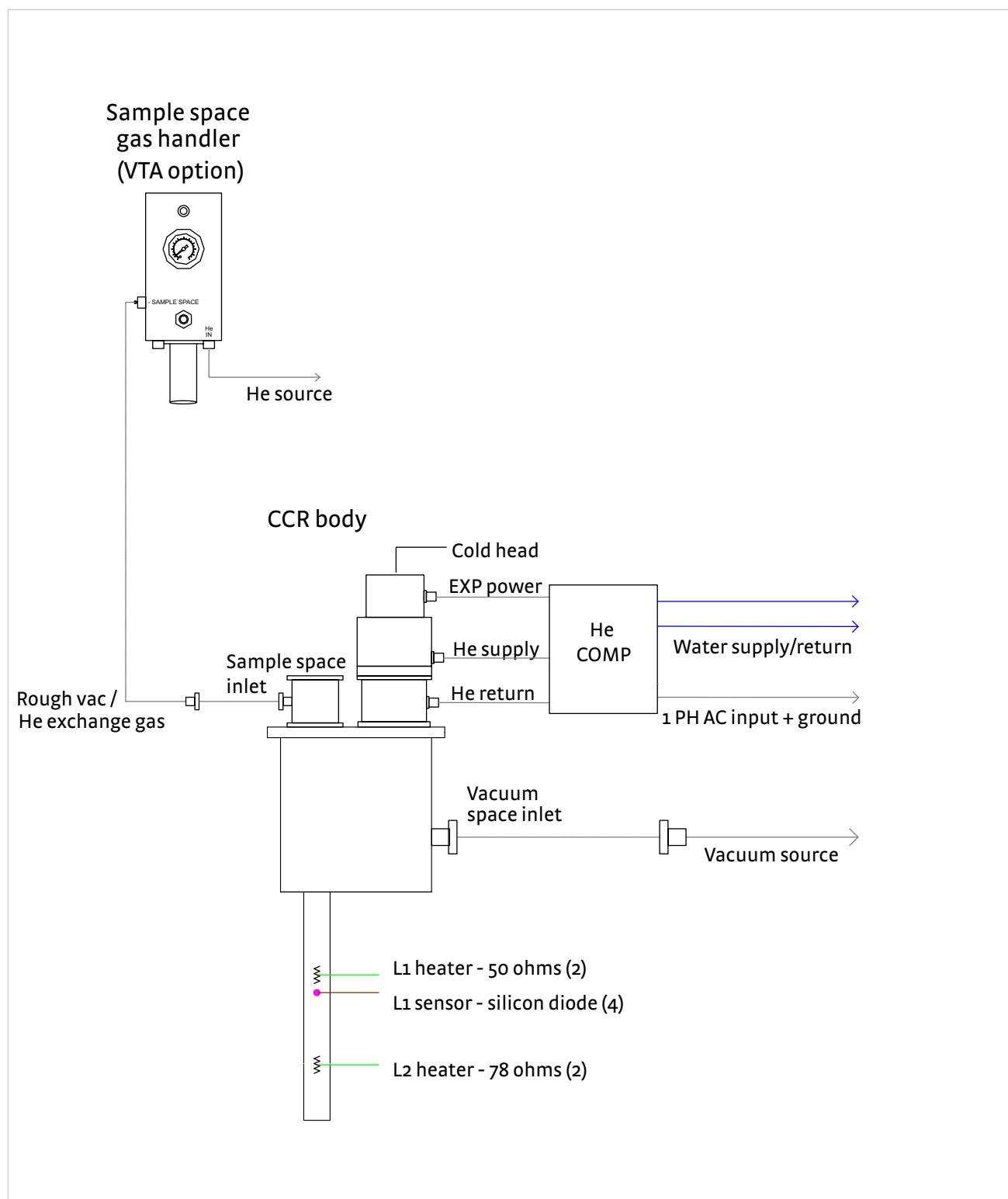


FIGURE 5-12 CCR operational schematic: CCR and sample space gas handler

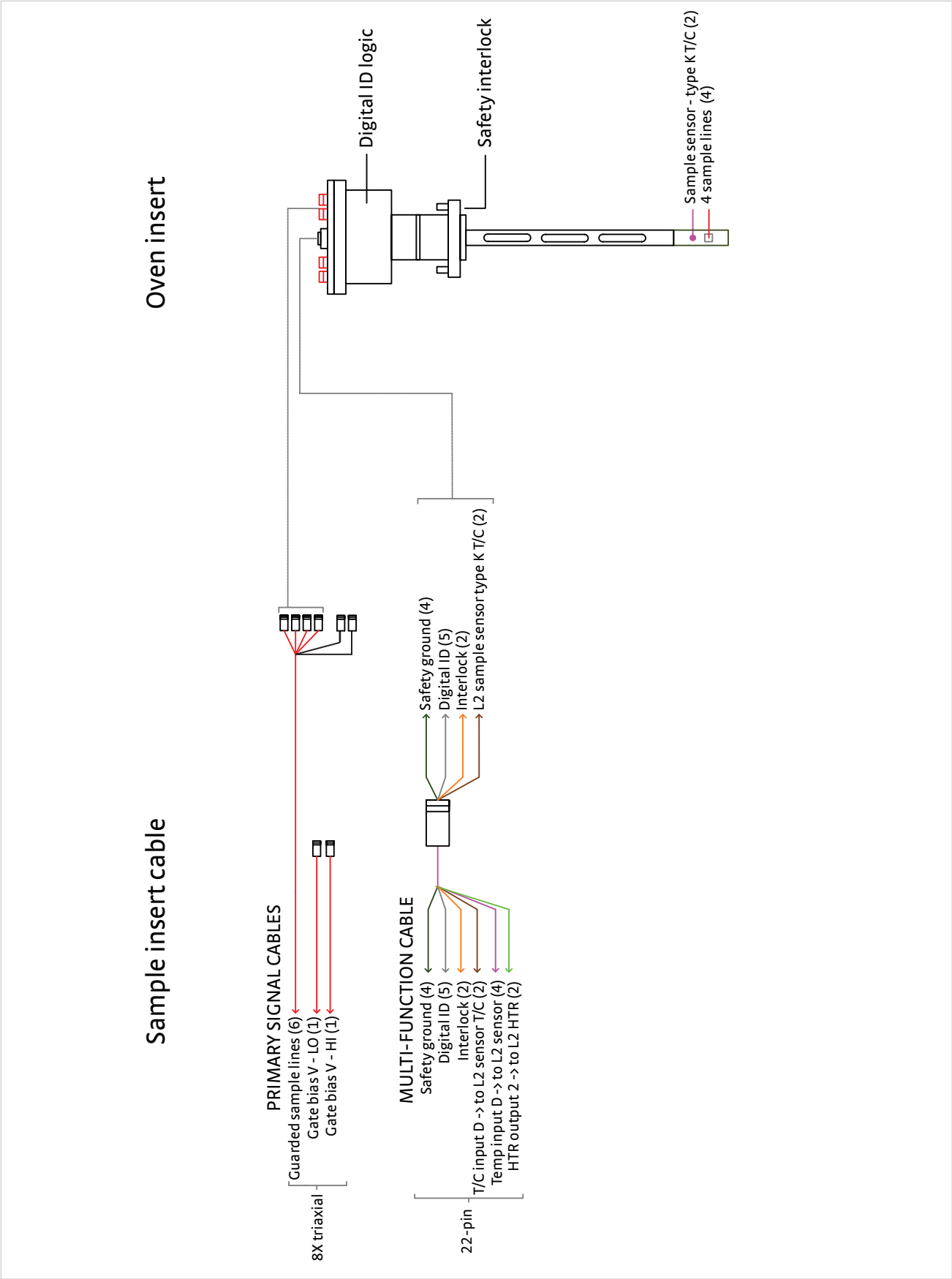


FIGURE 5-13 Oven insert and sample insert cable

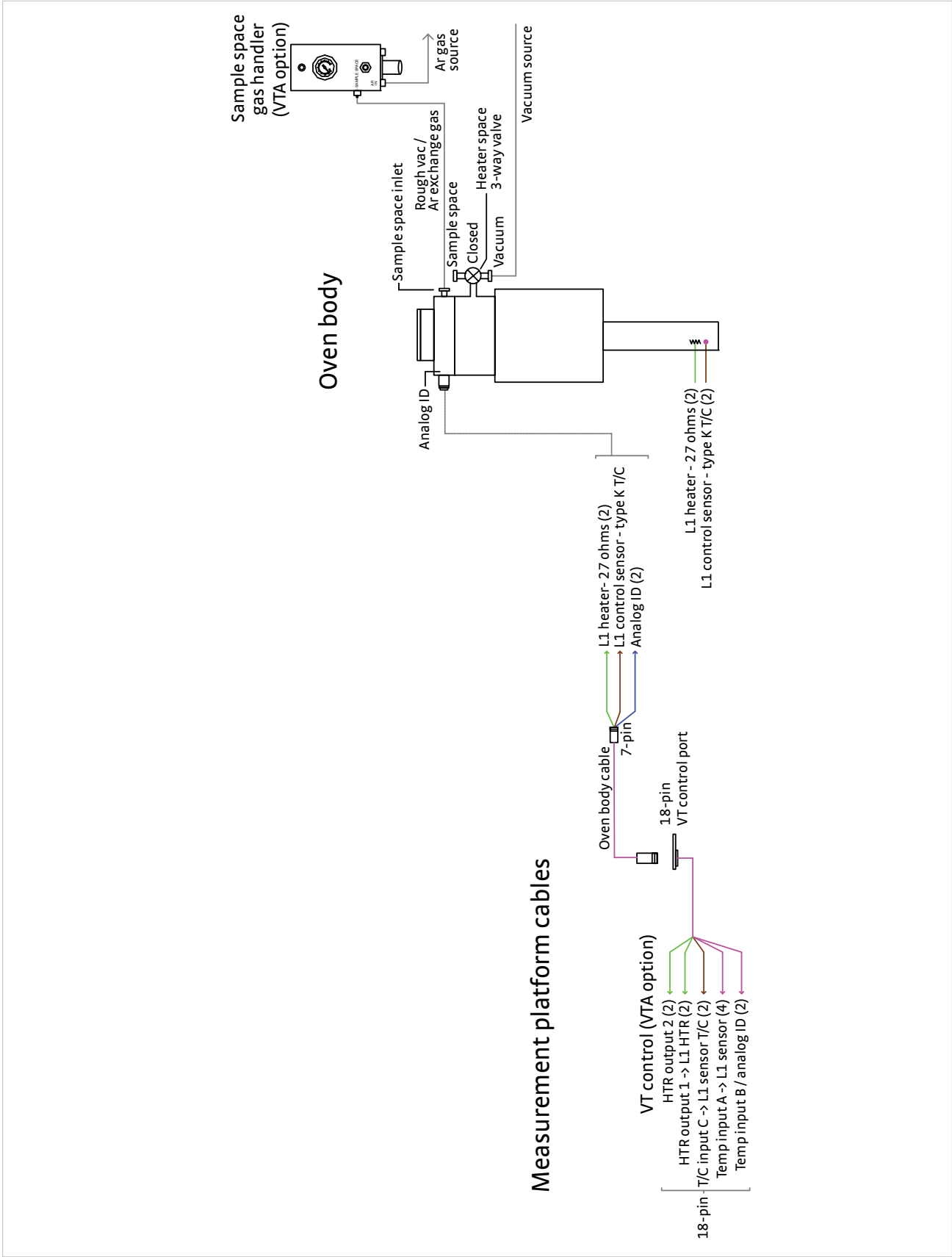


FIGURE 5-14 Oven with measurement platform cables

5.5 Technical Inquiries

Refer to the following sections when contacting Lake Shore for application assistance or product service.

5.5.1 Contacting Lake Shore

The Lake Shore Service Department is staffed Monday through Friday between the hours of 8:00 AM and 5:00 PM EST, excluding holidays and company shut down days.

Contact Lake Shore Service through any of the means listed below. However, the most direct and efficient means of contacting is to complete the online service request form at <https://www.lakeshore.com/Service/>. Provide a detailed description of the problem and the required contact information. You will receive a response within 24 hours or the next business day in the event of weekends or holidays.

If you wish to contact Service or Sales by mail or telephone, use the following:

Mailing address	Lake Shore Cryotronics Instrument Service Department 575 McCorkle Blvd. Westerville, Ohio USA 43082-8888	
E-mail address	sales@lakeshore.com support@lakeshore.com	Sales Instrument Service
Telephone	614-891-2244 614-891-2243 option 6	Sales Instrument Service
Fax	614-818-1600 614-818-1609	Sales Instrument Service
Web service request	https://www.lakeshore.com/Service/	Instrument Service

TABLE 5-11 *Contact information*

5.5.2 Returning Equipment

The HMS is packaged to protect it during shipment. Please use reasonable care when removing it from its protective packaging and inspect the HMS carefully for damage. If it shows any sign of damage, please file a claim with the carrier immediately. Do not destroy the shipping container; it will be required by the carrier as evidence to support claims. Call Lake Shore for return and repair instructions.

All equipment returns must be approved by a member of the Lake Shore Systems Service department. The service engineer will use the information provided in the service request form and will issue a Return Material Authorization (RMA). Once the RMA has been approved, you will receive appropriate documents and instructions for shipping the equipment to Lake Shore.

You will be given an RMA number. This number is necessary for all returned equipment. It must be clearly indicated on both the shipping carton(s) and any correspondence relating to the shipment.



The user should retain any shipping carton(s) in which equipment is originally received, in the event that any equipment needs to be returned.

5.5.3 RMA Valid Period

RMAs are valid for 60 days from issuance; however, we suggest that equipment needing repair be shipped to Lake Shore within 30 days after the RMA has been issued. You will be contacted if we do not receive the equipment within 30 days after the RMA is issued. The RMA will be canceled if we do not receive the equipment after 60 days.

5.5.4 Shipping Charges

All shipments to Lake Shore are to be made prepaid by the customer. Equipment serviced under warranty will also be returned shipping prepaid by the customer. Equipment serviced out-of-warranty will be returned FOB Lake Shore.

5.5.5 Restocking Fee

Lake Shore reserves the right to charge a restocking fee for items returned for exchange or reimbursement.