MASTER TABLE OF CONTENTS

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1. INTRODUCTION

Contents:

1.1 GENERAL

The Lake Shore 7500/9500 Series Hall Effect / Electronic Transport Measurement System is designed to measure electronic transport properties of electrically conductive materials. The system consists of advanced, integrated hardware and software.

7500/9500 Series systems are easy to operate using the Lake Shore Hall Measurement System Software. The Hall System Software controls system instrumentation during an experiment and determines sample resistance, resistivity, Hall coefficient, Hall mobility, carrier concentration, or current-voltage characteristics. The software can control and vary both temperature and magnetic flux density (field) during measurements.

The 7500 Series of electromagnet basedHall Measurement Systems (HMS) consists of the following models:

- 7504: HMS with 4-inch Electromagnet.
- 7507: HMS with 7-inch Electromagnet.
- 7512: HMS with 12-inch Electromagnet.

The 9500 Series of superconducting magnet based Hall Measurement Systems (HMS) consists of the following models:

- 9501: Cryogenic HMS with 1 tesla Superconducting Magnet.
- 9505: Cryogenic HMS with 5 tesla Superconducting Magnet.
- 9509: Cryogenic HMS with 9 tesla Superconducting Magnet.
- 9512: Cryogenic HMS with 12 tesla Superconducting Magnet.

Refer to section **1.2 System Standard Equipment and Specifications** for additional information about a specific system model.

The 7500 or 9500 Series model number is followed by a dash and characters indicating the measurement configuration. Refer to section **1.2.3.2** for a description of the measurement configurations.

1.1.1 Hall Effect Measurements

An introduction to Hall effect measurements is included in **Appendix A: Hall Effect Measurements**.

Hall effect measurements require four or more electrical contacts to the sample. The process for making good electrical contacts varies greatly depending on the sample material and geometry, factors out of Lake Shore control. Formation of adequate electrical contacts is the user's responsibility and can be the most difficult part of the measurement process. Some guidance is given in the sections pertaining to sample mounting in **Chapter 4: Sample Modules**, and in **Appendix B: Electrical Contacts to Semiconductors**.

1.1.2 Sample Materials and Applications

Hall effect and electronic transport measurements are invaluable to characterize properties of a wide variety of electronic conductors, including semiconductors, metals, and superconductors; thin films, heterostructures, bulk materials (single crystal or polycrystalline). Typical semiconductor materials include Si, Ge, GaAs, GaN, AlGaAs, CdTe, HgCdTe, SiC, etcetera. Other materials commonly tested include magnetoresistors, GMR films, and high temperature superconductors.

Measuring transport properties as a function of magnetic flux density (field) or temperature can reveal additional information about the nature of the charge carriers in the material. Information about individual carriers in a material with multiple carriers can be revealed by making variable magnetic flux density measurements of carrier mobility and then applying multi-carrier analysis techniques such as multi-carrier fitting or quantitative mobility spectrum analysis (QMSA).

Typical applications include materials research, product development, and quality control.

1.1.3 General Hall Effect Measurement System Features

- Measures Hall voltage, resistance, magnetoresistance, and current-voltage characteristics with one system.
- Calculates resistivity, Hall coefficient, carrier concentration and mobility.
- Allows contact characterization measuring current-voltage (I-V) curves in most configurations.
- Available with measurement configurations capable of measuring samples with resistances ranging from mΩ to hundreds of GΩ.
- Varies temperature and magnetic flux density (field) to determine the effects on materials.
- Reduces measurement time with a fully integrated, automated computer data collection system which makes measurements and calculates results.
- Displays real-time feedback of processed measurement data in both graphical and/or tabular format as the experiment is taking place.
- Controls, monitors, and changes instrument settings throughout the experiment using Hall System Software. The software includes individual instrument drivers for complete on-screen, virtual front panel control and operation of all instrumentation.
- Allows users to write custom programs in Visual BASIC or other languages to access the Hall System Software using the Object Linking and Embedding (OLE) interface.
- Produces more accurate, repeatable measurements by actively monitoring, controlling, and stabilizing magnetic flux density (field). Produces excellent field stability with water cooled magnet coils, feedback control, high quality sensors, and advanced electronics.
- Takes measurements for mobility spectrum analysis using a variable field electromagnet (7500 Series) or superconducting magnet (9500 Series). Mobility spectrum analysis allows users to evaluate multilayered materials and measure individual properties of multiple carriers.
- Offers several options for customization.

1.1.4 Hall System Software

Windows 95 menu driven, enhanced color-graphic software for system operation, data acquisition and analysis. System software includes individual instrument drivers for complete front panel operation and control of the magnet power supply and individual instruments. Real-time feedback of processed measurement data can be displayed in graphical and tabular format. The software controls the operation of the instruments during data acquisition and actively controls the magnetic field throughout a measurement. Hall System Software automatically records data for 4-lead van der Pauw structures and 6-lead Hall bar structures and stores data to the hard drive to be used for further processing, analysis, and display.

Computer System: Pentium computer with color monitor, Windows 95 and National Instruments IEEE-488 interface. Minimum requirement for monitor/video is 1024 x 768 resolution with 2 MB of video RAM.

1.2 SYSTEM STANDARD EQUIPMENT AND SPECIFICATIONS

General information about the 7500 Series Hall Effect Measurement System is provided in Table 1-1. Information about the 9500 Series Cryogenic Hall Effect Measurement System is provided in Table 1-2.

Table 1-1. 7500 Series Systems General Information

	System Model Number		
	7504	**7505**	**7512**
Measurement Configuration	Refer to Section 1.2.5		
Sample Module	Model 75013 Sample Card Sample Module is standard. Refer to Section 1.3 for other options.		
Electromagnet Model and Pole Face Sets	EM4-HV 4 inch	EM7-HV 3 and 6 inch	EM12-HV 12 inch
Magnet Power Supply	Model 647	Model 665	Model 665
Computer	Pentium HP provided with National Instruments IEEE-488 instrument interface or better.		
Software	MS Windows 95 or better and the Lake Shore menu driven, enhanced color-graphic software for system operation, data acquisition, and analysis.		
Shipping Dimensions*			
Computer & Console:	92 × 82 × 165 cm (36 × 32 × 65 in.)	92 × 82 × 165 cm (36 × 32 × 65 in.)	92 × 82 × 165 cm (36 × 32 × 65 in.)
Magnet Power Supply:	In Instrument Console	77 × 92 × 153 cm (30 × 33 × 60 in.)	76 × 92 × 178 cm (30 × 36 × 70 in.)
Electromagnet & Stand:	92 × 87 × 110 cm (36 × 34 × 43 in.)	86 × 122 × 120 cm (34 × 48 × 47 in.)	1) 92 × 92 × 122 cm (36 × 26 × 48 in.) 2) 92 × 92 × 82 cm (36 × 36 × 32 in.)
Shipping Weight			
Computer & Console:	182 kg (400 lbs.)	136 kg (300 lbs.)	136 kg (300 lbs.)
Magnet Power Supply:	In Instrument Console	295 kg (650 lbs.)	400 kg (880 lbs.)
Electromagnet & Stand:	248 kg (545 lbs.)	680 kg (1500 lbs.)	2744 kg (6050 lbs.)

* All dimensions given as Width × Depth × Height.

Table 1-2. 9500 Series Common Specifications

	System Model Number			
	9501	**9505**	**9509**	**9512**
Measurement Configuration	Refer to Section 1.2.5.			
Sample Module	Model 9500 Flow Cryostat Sample Module and Sample Insert; maximum sample size is 12 × 14 mm			
Superconducting Magnet	1 tesla parallel field	5 tesla parallel field	9 tesla parallel field	12 tesla parallel field
Magnet Power Supply	Model 620	Model 620	Model 620	Model 622
Computer	Pentium PC provided with National Instruments IEEE-488 instrument interface or better.			
Software	MS Windows 95 or better and the Lake Shore menu driven, enhanced color-graphic software for system operation, data acquisition, and analysis.			
Shipping Dimensions*				
Computer & Console:	92 × 82 × 165 cm (230 × 205 × 412 inches)			
Dewar, Cryostat & Magnet:	92 × 87 × 110 cm (230 × 217 × 275 inches)			
Shipping Weight				
Computer & Console:	185 kilograms (400 pounds)			
Dewar, Cryostat & Magnet:	248 kilograms (545 pounds)			

* All dimensions given as Width x Depth x Height.

1.2.1 Model 7504: HMS with 4 inch Electromagnet

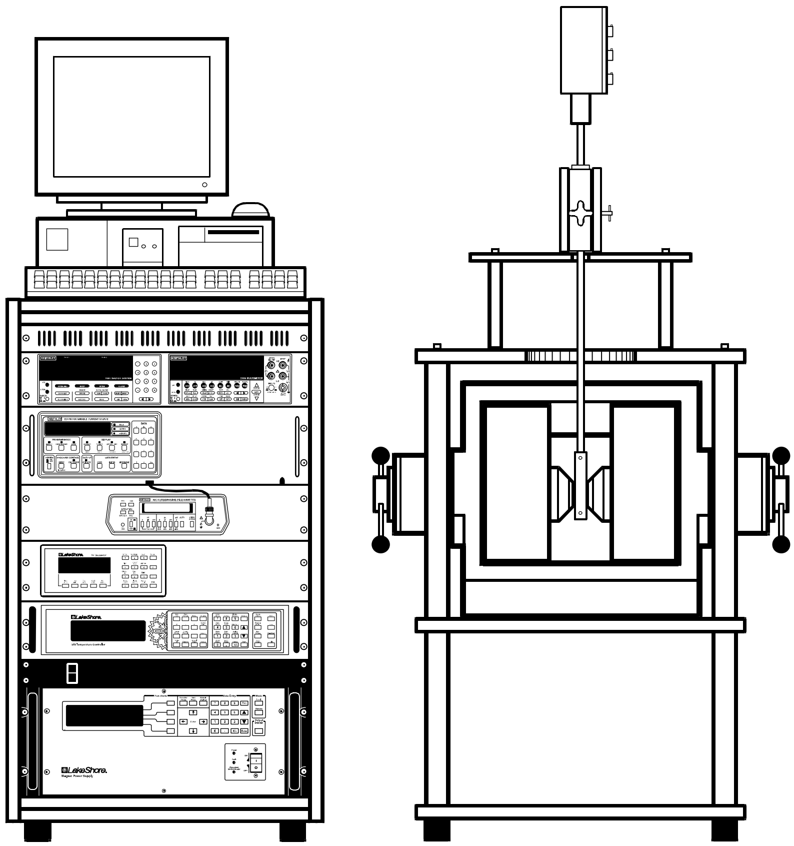


Figure 1-1. Typical Model 7504 System.
Configuration shown is a 7504-LVWR with 750TC temperature control option and standard Model 75013 Sample Card Sample Module mounted on electromagnet.

1.2.1.1 Model EM4-HV Electromagnet (Variable Gap)

One set of pole caps with 4 inch pole faces is provided standard with the EM4-HV (4 inch) electromagnet.

Pole diameter	10.2 cm (4 in.)	
Magnet Pole face diameter	10.2 cm (4 in.)	
Sample module setup (typical)	75013 SCSM, no dewar	dewar/oven/75014 CCR
Air gap	25 mm (1 in.)	51 mm (2 in.)
Maximum magnetic flux density	1.04 T (10.4 kG)	0.65 T (6.5 kG)
Magnetic field homogeneity: **over central 1 cm^3** **±1% centered cylindrical volume over central 1 cm^3**	±0.05% 6.4 cm dia. × 2.5 cm	±0.1% 3.8 cm dia. × 5.0 cm
Cooling water requirements	Tap water or closed loop cooling system (optional chiller available)	
Inlet temperature	32 °C (90 °F) maximum	
Supply pressure	240 to 700 kPa (35 to 100 psig) at rated flow	
Flow rate	3.8 liters per minute (1 gallon per minute)	
Water chiller cooling capacity	1.8 kW (6142 BTU/hr)	

1.2.1.2 Model 647 Four-Quadrant Magnet Power Supply

See the Model 647 MPS User's Manual for complete information. Some important characteristics are given in the following table.

INPUT	
Wiring and Frequency	2-wire, single phase plus ground, 50 to 60 Hz
Rating	2.8 kVA maximum, power factor > 0.95
Voltage	200, 208, 220 or 240 VAC (+10%, –5%)
Current	16 A (for 200 V) to 13 A (for 240 V)
OUTPUT	
Voltage	±32 V (2 kW maximum)
Current	±75 A (2 kW maximum)
Monitoring output accuracy	1% +100 mA after warm-up period at constant line/load
Overvoltage	Crowbars output if voltage at output exceeds +40 V
AMBIENT CONDITIONS	
Air Temperature	20 to 30 °C (15 to 35 °C with reduced accuracy)
Storage	0 °C to +50 °C
Relative Humidity	20–80%, no condensation
Cooling Method	Forced Air, altitude from sea level to 2.4 km (8000 ft.)
ENCLOSURE	
Type, Weight	Rack mount, 43.5 kg (96 lbs.)
Dimensions	483 mm wide × 178 mm high × 508 mm deep (19 × 7 × 20 inches)

1.2.2 Model 7507: HMS with 7 inch Electromagnet

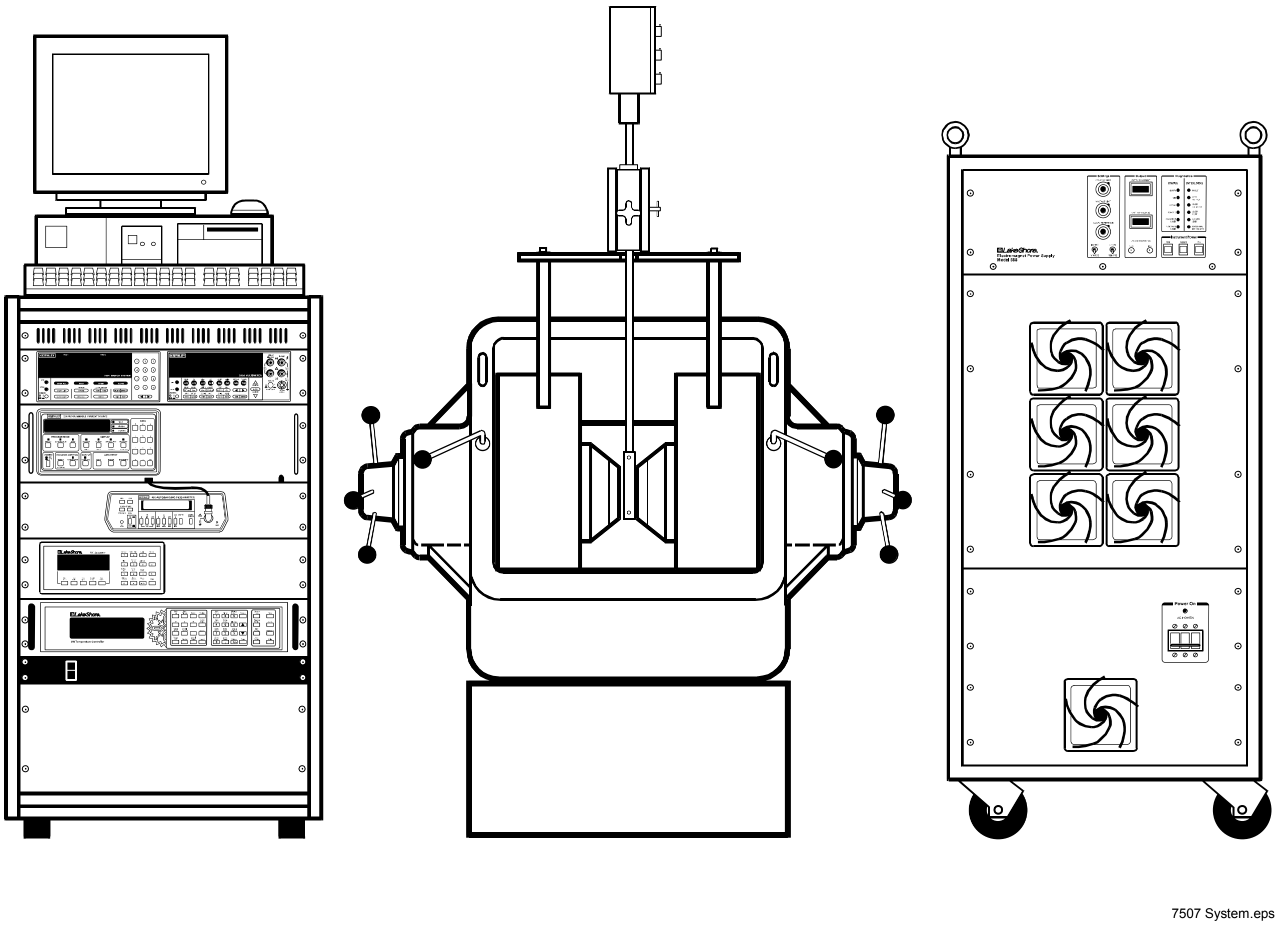


Figure 1-2. Typical Model 7507 System.
Configuration shown is 7507-LVWR with 750TC temperature control option, standard Model 75013 Sample Card Sample Module mounted on the electromagnet, and air-cooled power supply.

1.2.2.1 Model EM7-HV Electromagnet (variable gap)

Two sets of pole caps are provided with the standard EM7-HV (7 inch) electromagnet.

Pole Diameter	17.8 cm (7 in.)			
Magnet Pole Face Diameter	15.2 cm (6 in.)		7.6 cm (3 in.)	
Sample Module Setup (typical)	(73013 SCSM)	(dewar/oven)	(73013 SCSM)	(dewar/oven)
Air Gap	25 mm (1 in.)	51 mm (2 in.)	25 mm (1 in.)	51 mm (2 in.)
Maximum Magnetic Induction	1.5 T (15 kG)	1.0 T (10 kG)	2.0 T (20 kG)	1.2 T (12 kG)
Magnetic Field Homogeneity over Centered 5 cm (2”) Dia. Circle	±0.1%			
Cooling Water Requirements	Tap water or closed loop cooling system (optional chiller available)			
Inlet Temperature	32 °C (90 °F) maximum			
Supply Pressure	240 to 700 kPa (35 to 100 psig) at rated flow			
Flow Rate	11.4 liters per minute (3 gallons per minute)			
Water Chiller Cooling Capacity	5 kW (17,060 BTU/hr)			

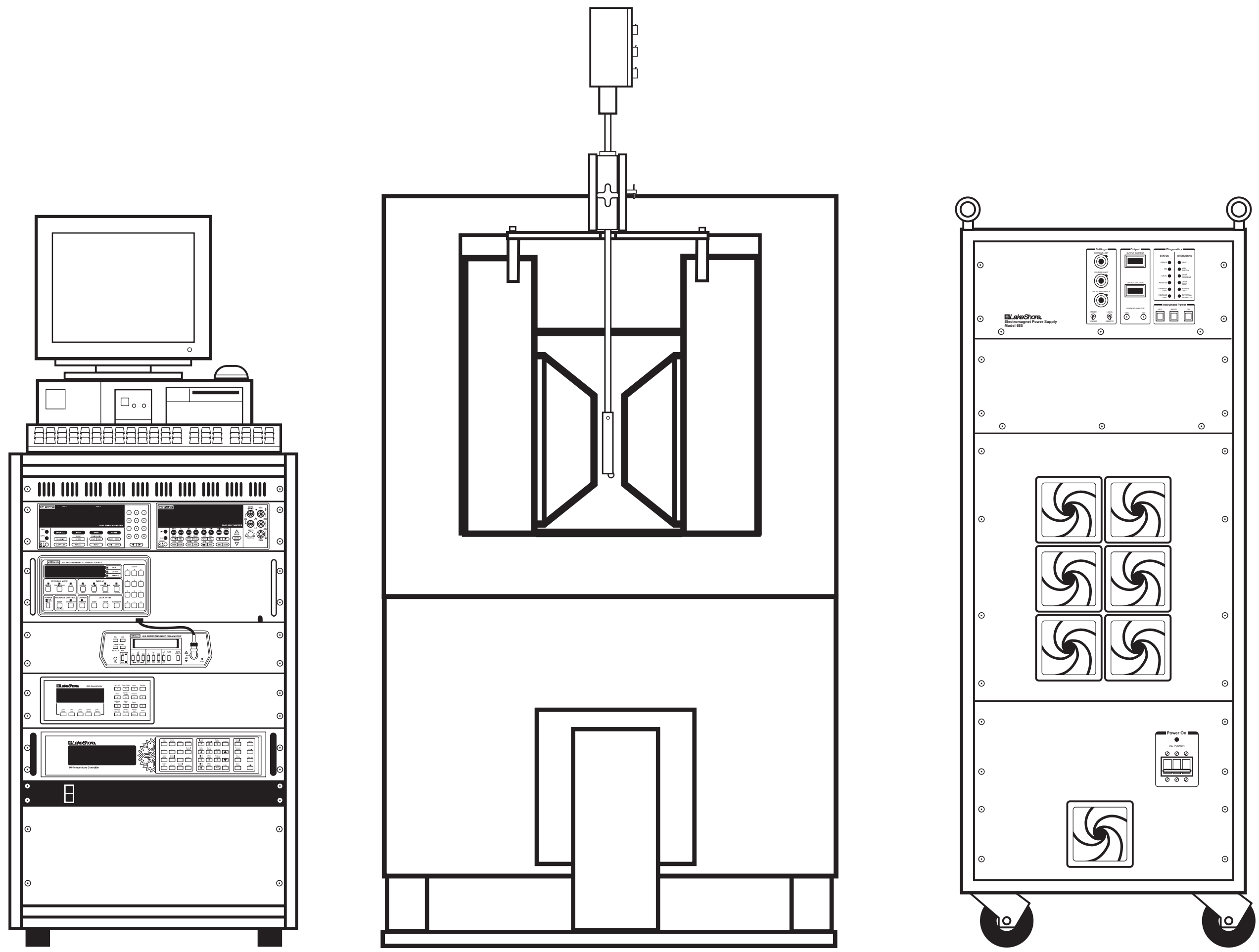
1.2.2.2 Model 665 Bipolar Magnet Power Supply (Air Cooled)

INPUT	
Wiring and Frequency	3 phases and ground, 50 or 60 Hz
Rating	8 kVA maximum
Voltage	208, 220, 240, 380, 400 or 480 VAC
Current	18 A per phase (for 208-230 V)
OUTPUT	
Voltage	±50 V
Current	±100 A
Total Current Regulation	10 mA + 0.02% of maximum after warm-up period at constant line/load
Overcurrent	110 Adc
Load Resistance	0.4 Ω to 0.5 Ω
Load Inductance	50 mH to 250 mH
AMBIENT CONDITIONS	
Air Temperature	+10 °C to +40 °C
Storage	0 °C to +50 °C
Max. Relative Humidity	90%
Cooling Method	**Forced Air**
ENCLOSURE	
Type, Weight	Free standing NEMA-1, 250 kg (550 lbs.)
Dimensions	560 mm wide × 1190 mm high × 620 mm deep (22 × 47 × 24.5 inches)

1.2.2.3 Model 665 Bipolar Magnet Power Supply (Water Cooled, CE marked)

INPUT		
Wiring and Frequency	3 phases and ground, 50 or 60 Hz	
Rating	7.6 kVA maximum	
Voltage	**208** ±10% VAC	**400** +6% -10% VAC
Current	21 A per phase (for 208-230 V)	11 A per phase (for 208-230 V)
Customer Fuses	25 A, 500 VAC, time lag, each phase	16 A, 500 VAC, time lag, each phase
OUTPUT		
Voltage	±50 V	
Current	±100 A	
Stability	0.01% of maximum after warm-up period at constant line/load/temperature	
Load Resistance	0.2 Ω minimum	
AMBIENT CONDITIONS		
Air Temperature	+10 °C to +30 °C	
Storage and Shipping	–10 °C to +50 °C (all remaining water must be removed for temperatures below +5 °C)	
Relative Humidity	65% or less (non-condensing)	
COOLING		
Coolant	Water, tap	
Temperature	+11 °C to +25 °C	
Flow Rate	8 l/min (2.1 gpm)	
Inlet Pressure	300 – 600 kPa (45 – 90 psig)	
Pressure Drop at rated flow	<300 kPa (45 psig)	
Connections	Male F ¼ for pipe with an internal diameter of 8 mm	
ENCLOSURE		
Type, Weight	19-inch cabinet, according to EMC requirements, 240 kg (528 lbs.)	
Dimensions	600 mm wide × 1350 mm high × 700 mm deep (23.6 × 53.2 × 27.6 inches)	

1.2.3 Model 7512: HMS with 12 inch Electromagnet



7512 System.eps

Figure 1-3. Typical Model 7512 System.
Configuration shown is a 7512-LVWR with 750TC Temperature Control Option, standard Model 75013 Sample Card Sample Module mounted on electromagnet, and air-cooled power supply.

1.2.3.1 Model EM12-HF Electromagnet (fixed gap)

One set of pole caps is provided with the standard EM12-HF (12 inch) electromagnet.

Pole Diameter	30.5 cm (12 in.)	
Magnet Pole Face Diameter	30.5 cm (12 in.)	15.2 cm (6 in.)
Sample Module Setup (typical)	(73013 SCSM/dewar/oven)	(73013 SCSM/dewar/oven)
Air Gap	51 mm (2 in.)	51 mm (2 in.)
Maximum Magnetic Induction	1.47 T (14.7 kG)	2.04 T (20.4 kG)
Magnetic Field Homogeneity over Centered 10 cm (4") Dia. Circle	±0.05%	±1.6%
Cooling Water Requirements	Tap water or closed loop cooling system (optional chiller available)	
Inlet Temperature	27 °C (81 °F) maximum	
Supply Pressure	205 to 700 kPa (30 to 100 psig) at rated flow	
Flow Rate	15–23 liters per minute (4–6 gallons per minute)	
Water Chiller Cooling Capacity	8.5 kW (29,000 BTU/hr)	

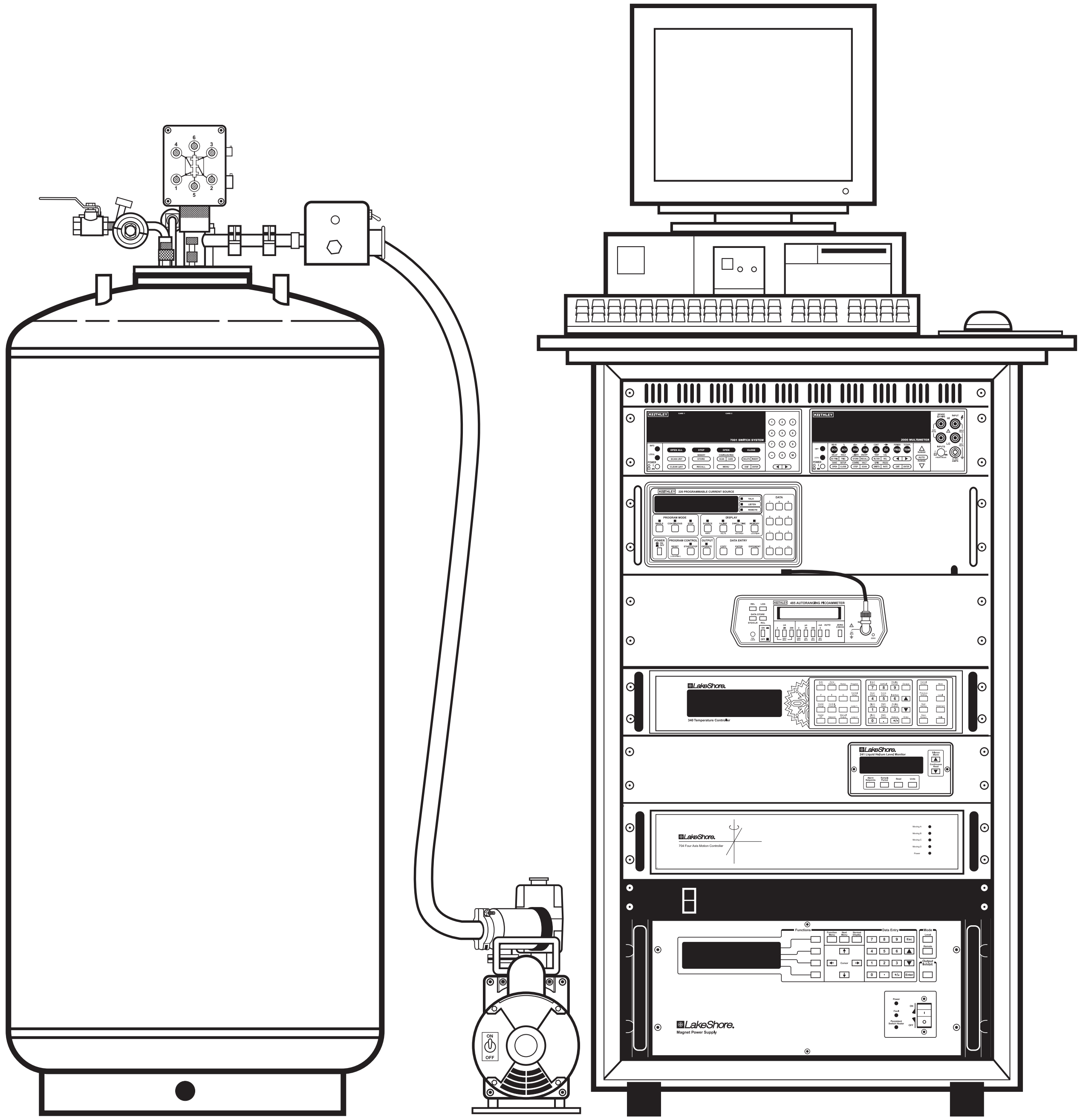
1.2.3.2 Model 668 Bipolar Magnet Power Supply (Air Cooled)

INPUT	
Wiring and Frequency	3 phases and ground, 50 or 60 Hz
Rating	12 kVA maximum
Voltage	208, 220, 240, 380, 400 or 480 VAC
Current	33 A per phase (for 208-230 V)
OUTPUT	
Voltage	±65 V
Current	±130 A
Total Current Regulation	10 mA + 0.02% of maximum after warm-up period at constant line/load
Overcurrent	145 Adc
Load Resistance	0.4 Ω to 0.5 Ω
Load Inductance	50 mH to 250 mH
AMBIENT CONDITIONS	
Air Temperature	+10 °C to +40 °C
Storage	0 °C to +50 °C
Max. Relative Humidity	90%
Cooling Method	**Forced Air**
ENCLOSURE	
Type, Weight	Free standing NEMA-1, 354 kg (780 lbs.)
Dimensions	530 mm wide × 1370 mm high × 700 mm deep (21.5 × 54 × 27.5 inches)

1.2.3.3 Model 668 Bipolar Magnet Power Supply (Water Cooled, CE marked)

INPUT		
Wiring and Frequency	3 phases and ground, 50 or 60 Hz	
Rating	12 kVA maximum	
Voltage	**208** ±10% VAC	**400** +6% -10% VAC
Current	21 A per phase (for 208-230 V)	11 A per phase (for 208-230 V)
Customer Fuses	25 A, 500 VAC, time lag, each phase	16 A, 500 VAC, time lag, each phase
OUTPUT		
Voltage	±65 V	
Current	±130 A	
Stability	0.01% of maximum after warm-up period at constant line/load/temperature	
Load Resistance	0.2 Ω minimum	
AMBIENT CONDITIONS		
Air Temperature	+10 °C to +30 °C	
Storage and Shipping	-10 °C to +50 °C (all remaining water must be removed for temperatures below +5 °C)	
Relative Humidity	65% or less (non-condensing)	
COOLING		
Coolant	Water, tap	
Temperature	+6 °C to +25 °C	
Flow Rate	8 l/min (2.1 gpm)	
Inlet Pressure	300 – 600 kPa (45 – 90 psig)	
Pressure Drop at rated flow	<300 kPa (45 psig)	
Connections	Male F ¼ for pipe with an internal diameter of 8 mm	
ENCLOSURE		
Type, Weight	19-inch cabinet, according to EMC requirements, 340 kg (749 lbs.)	
Dimensions	600 mm wide × 1350 mm high × 700 mm deep (23.6 × 53.2 × 27.6 inches)	

1.2.4 9500 Series Cryogenic Hall Effect Systems



9500 System.eps

Figure 1-4. Typical 9500 Series System.
Configuration shown is a 9509-LVWR in metal cabinet and with standard Model 9500 Flow Cryostat Sample Module mounted in dewar.

1.2.4.1 9500 Series Cryogenic Hall Effect Systems

	System Model Number			
	9501	9505	9509	9512
Measurement Configuration	Refer to Section 1.2.5			
Sample Module	Model 9500 Flow Cryostat Sample Module and Sample Insert			
Superconducting Magnet	1 tesla parallel field	5 tesla parallel field	9 tesla parallel field	12 tesla parallel field
Magnet Power Supply	Model 620	Model 620	Model 620	Model 622
Magnetic Field Homogeneity				
LHe to fill warm dewar	~50 L	~60 L	~80 L	~120 L
LHe consumption	less than 7 liters/day is typical			

1.2.4.2 Model 620/622 Superconducting Magnet Power Supply (SMPS)

See the SMPS User's Manual for complete information. Some important characteristics are given in the following table.

Model:	**620**	**622**
INPUT		
Wiring and Frequency	2-wire, single phase plus ground, 50 to 60 Hz	
Power Rating	1600 W maximum	1600 W maximum
Voltage	90–105, 108–126, 180–218, 198–231, or 216–252 VAC	
Current	18, 15, 9 8 or 7 A rms	18, 15, 9 8 or 7 A rms
OUTPUT		
Voltage	±5 V	±30 V
Current	±50 A	±125 A
Power, continuous	250 VA maximum	1000 VA maximum
Current monitoring output accuracy	1% +100 mA after warm-up period at constant line/load	
Overvoltage	Crowbars output if voltage at output exceeds +40 V	
AMBIENT CONDITIONS		
Air Temperature	15 to 35 °C (59 to 95 °F)	
Storage	0 °C to +50 °C	
Relative Humidity	20–80%, no condensation	
Cooling Method	Forced Air, altitude from sea level to 2.4 km (8000 ft.)	
ENCLOSURE		
Type, Weight	Rack mount, 43.5 kg (96 lbs)	
Dimensions	483 mm wide × 178 mm high × 508 mm deep (19 × 7 × 20 inches)	

1.2.5 Hall System Measurement Configurations and Specifications

The 7500/9500 Series model number is followed by a dash and characters indicating the measurement configuration. For example, the complete model number

7507-LVWR-HS-SWT

indicates a 7507 HMS with 7 inch electromagnet with the Low Voltage, Wide Resistance range measurement configuration, plus the High Sensitivity and fully automated Switching options. In this case, the measurement configuration is given by -LVWR-HS-SWT.

The configuration of the system for which this manual was prepared should be noted on the System Configuration page near the front of the manual (previous measurement configuration designations are also given).

Standard measurement configurations are listed in Table 1-3 along with measurement specifications and instrumentation. Additional information is given in Sections 1.2.6 and 1.5. Additional sample contacts, unsupported by the software, may be available depending on the measurement configuration and the sample module used.

Table 1-3. Measurement Configuration Specifications

		Specifications				
Measurement Configuration	**Description**	**V max. [V]**	**I max. [mA]**	**I min.** (resolution)	**R shunt**	**# sample contacts**
-HVWR	**High Voltage, Wide Resistance range**	100	100	500 fA	>5e12 Ω	4 or 6
-HVWR-HS (note 1)	+ High Sensitivity	100	100	500 fA	>5e12 Ω	4 or 6
-LVWR	**Low Voltage, Wide Resistance range**	8	100	500 fA	>1e14 Ω	4 (note 2)
-LVWR-HS	+ High Sensitivity	8	100	500 fA	>1e14 Ω	4 (note 2)
-LVWR-SWT (note 3)	+ Fully Automated Switching	8	100	500 fA	>1e13 Ω	4 or 6
-LVWR-HS-SWT (note 4)	+ High Sensitivity + Fully Auto. Switch.	8	100	500 fA	>1e13 Ω	4 or 6
-HVLR	**High Voltage, Low Resistance range**	100	100	500 fA	>1e9 Ω	4 or 6
-HVLR-HS (note 1)	+ High Sensitivity	100	100	500 fA	>1e9 Ω	4 or 6
-LVLR (note 1)	**Low Voltage, Low Resistance range**	3	3	30 nA	>1e8 Ω	4 or 6

Notes:
1. Check Lake Shore for availability.
2. Configurable for 6 contacts (Hall bar) with manual recabling.
3. Can also be configured as -LVWR with manual recabling.
4. Can also be configured as -LVWR-HS with manual recabling.

1.2.6 Measurement Instrumentation Specifications

Key specifications for measurement instrumentation used in 7500/9500 Series systems are provided below. For additional information, refer to each instrument's manual. Refer to Table 1-4 for a list of instruments in each measurement configuration.

Table **1-4. Measurement Instrumentation**

	Instrumentation									
75xx- or 95xx-	**KI 7001 Switch System**			**KI**	**KI**	**KI**	**KI**	**KI**	**LS**	**LS**
Measurement Configuration	**7012 4x10**	**7065 Hall**	**7152 4x5**	**6512 EL**	**220 CS**	**485/6 pA**	**2000 DVM**	**182/2182 NVM**	**340 TC**	**450 GM**
-HVWR			2	2	1	1	1			1
-HVWR-HS			2	2	1	1		1*		1
-LVWR		1			1	1	1			1
-LVWR-HS		1			1	1		1		1
-LVWR-SWT		1	1		1	1	1			1
-LVWR-HS-SWT		1	1		1	1		1		1
-HVLR	1				1		1			1
-HVLR-HS	1				1			1*		1
-LVLR	1								1	1

* requires a KI 2182 NVM

1.2.6.1 Keithley Instruments Model 7001 Switch System Mainframe

The KI 7001 Switch System Mainframe can hold one or two switch cards. Use the individual switch card's specifications when modeling system measurement performance. See the KI 7001 User's Manual for complete information.

1.2.6.2 Keithley Instruments Model 7012-S 4×10 Matrix Switch Card

Switches 4 rows by 10 columns of 2-pole, Form A contacts. See the user's manual for complete information. Some important characteristics for measurement system performance modeling are given in the following table.

Max. Voltage	110 V between any two pins
Max. Current	1 A switched
Isolation Resistance	Path: >1e9 Ω, Differential: >1e9 Ω, Common mode: >1e9 Ω
Offset or bias current, Io	<1e-10 A
Noise	<1e-8 V rms, 0.1 to 10 Hz bandwidth (estimated)

1.2.6.3 Keithley Instruments Model 7065 Hall Effect Switch Card

Switches 4 rows by 10 columns of 2-pole, Form A contacts. See the user's manual for complete information. Some important characteristics for measurement system performance modeling are given in the following table. High resistance mode is typically used when the sample resistance is greater than 100 kΩ.

	Measurement mode	
	Low R	High R
Max. Voltage	+8 to -8 V input	
Max. Current	0.1 A	
Isolation Resistance	>1e10 Ω	>1e14 Ω
Offset or bias current, Io	<1e-10 A	<1.5e-13 A at 23 C
Noise	<5e-8 V peak-to-peak (<1e-8 V rms), 0.1 to 10 Hz bandwidth	<1e-5 V peak-to-peak (<2e-6 V rms), 0.1 to 10 Hz bandwidth

1.2.6.4 Keithley Instruments Model 7152 4x5 Low Current Matrix Switch Card

Switches 4 rows by 5 columns of 2-pole, Form A contacts (Signal and Guard). Connections are block connectors for use with triaxial cables. See the user's manual for complete information. Some important characteristics for measurement system performance modeling are given in the following table.

Max. Voltage	200 V between any two of signal, guard or chassis
Max. Current	1 A carry, 0.5 A switched
Isolation Resistance	Path: >1e13 Ω, Differential: >1e11 Ω, Common mode: >1e9 Ω
Offset or bias current, Io	<1e-12 A (1e-14 A typical)
Noise	<1e-8 V rms, 0.1 to 10 Hz bandwidth (estimated)

1.2.6.5 Keithley Instruments Model 6512 Programmable Electrometer

See the user's manual for complete information. Some important characteristics for measurement system performance modeling are given in the following table.

		Accuracy (1 year)				
Range, full scale [V]	Resolution [V]	ppm of reading	offset [V]	offset or bias current, Io [A]	R shunt [Ω]	rms noise* [V]
0.2	1e-5	5	-	<5e-15	>2e14	1e-6
2	1e-4	5	-	<5e-15	>2e14	1e-6
20	1e-3	5	-	<5e-15	>2e14	1e-6
200	1e-2	5	-	<5e-15	>2e14	1e-6

* rms noise, 0.1-10 Hz, estimated

1.2.6.6 Keithley Instruments Model 220 Current Source

See the user's manual for complete information. Some important characteristics for measurement system performance modeling are given in the following table.

		Accuracy (1 year)				
Range, full scale [A]	Resolution [A]	ppm of reading	offset [A]	offset or bias current, Io [A]	R shunt [Ω]	rms noise* [A]
1.999e-9	5e-13	4000	2e-12	-	>1e14	8e-14
1.999e-8	5e-12	3000	1e-11	-	>1e14	4e-13
1.999e-7	5e-11	3000	1e-10	-	>1e14	2e-12
1.999e-6	5e-10	1000	1e-9	-	>1e14	2e-11
1.999e-5	5e-9	5000	1e-8	-	>1e14	2e-10
1.999e-4	5e-8	500	1e-7	-	>1e14	2e-9
1.999e-3	5e-7	500	1e-6	-	>1e14	2e-8
1.999e-2	5e-6	500	1e-5	-	>1e14	2e-7
1.01e-1	5e-5	1000	5e-5	-	>1e14	2e-6

* rms noise, 0.1-10 Hz at 10 PLC

1.2.6.7 Keithley Instruments Model 485/4853 Autoranging Digital Picoammeter with IEEE-488 interface

See the user's manual for complete information. Some important characteristics for measurement system performance modeling are given in the following table.

		Accuracy (1 year)				
Range, full scale [A]	Resolution [A]	ppm of reading	offset [A]	offset or bias current, Io [A]	R shunt [Ω]	rms noise* [A]
2e-9	1e-13	4000	4e-13	-	1e5	-
2e-8	1e-12	4000	1e-12	-	1e5	-
2e-7	1e-11	2000	1e-11	-	1e5	-
2e-6	1e-10	1500	1e-10	-	1e5	-
2e-5	1e-9	1000	1e-9	-	1e5	-
2e-4	1e-8	1000	1e-8	-	1e5	-
2e-3	1e-7	1000	1e-7	-	1e5	-

* rms noise, 0.1-10 Hz at 10 PLC

1.2.6.8 Keithley Instruments Model 486 and 487 Picoammeters (CE-Mark Systems)

See the user's manual for complete information. Some important characteristics for measurement system performance modeling are given in the following table.

		Accuracy (1 year)				
Range, full scale [A]	Resolution [A]	ppm of reading	offset [A]	offset or bias current, Io [A]	R shunt [Ω]	rms noise* [A]
2e-9	1e-14	3000	5e-13	-	1e5	-
2e-8	1e-13	2000	3e-12	-	1e5	-
2e-7	1e-12	1500	2e-11	-	1e5	-
2e-6	1e-11	1500	2e-10	-	1e5	-
2e-5	1e-10	1000	2e-9	-	1e5	-
2e-4	1e-9	1000	2e-8	-	1e5	-
2e-3	1e-8	1000	2e-7	-	1e5	-

* rms noise, 0.1-10 Hz at 10 PLC

1.2.6.9 Keithley Instruments Model 2000 Digital Multimeter

See the user's manual for complete information. Some important characteristics for measurement system performance modeling are given in the following table.

		Accuracy (1 year)				
Range, full scale [V]	Resolution [V]	ppm of reading	offset [V]	offset or bias current, Io [A]	R shunt [Ω]	rms noise* [V]
0.1	1e-7	50	3.5e-6	1e-10	>1e10	1.5e-6
1	1e-6	30	7e-6	1e-10	>1e10	1.5e-6
10	1e-5	30	5e-5	1e-10	>1e10	1.5e-6
100	1e-4	35	6e-4	1e-10	1e7	1.5e-6
1000	1e-3	45	1e-2	1e-10	1e7	1.5e-6

* rms noise, 0.1-10 Hz at 10 PLC

1.2.6.10 Keithley Instruments Model 182 Sensitive Digital Voltmeter

See the user's manual for complete information. Some important characteristics for measurement system performance modeling are given in the following table.

		Accuracy (1 year)				
Range, full scale [V]	Resolution [V]	ppm of reading	offset [V]	offset or bias current, Io [A]	R shunt [Ω]	rms noise* [V]
0.003	1e-9	60	4.8e-8	5e-11	>1e10	1.5e-8
0.03	1e-8	60	1.8e-7	5e-11	>1e10	2e-8
0.3	1e-7	55	1.8e-6	5e-11	>1e10	2e-7
3	1e-6	50	1.8e-5	5e-11	>1e10	2e-6
30	1e-5	50	1.8e-4	5e-11	>1e10	2e-5

* rms noise, 0.1-10 Hz at 10 PLC

1.2.6.11 Keithley Instruments Model 2182 Nanovoltmeter

See the user's manual for complete information. Some important characteristics for measurement system performance modeling are given in the following table for Channel 1. A less sensitive second channel is also provided in the KI 2182, but is not used by the Hall software.

		Accuracy (1 year)				
Range, full scale [V]	Resolution [V]	ppm of reading	offset [V]	offset or bias current, Io [A]	R shunt [Ω]	rms noise* [V]
0.01	1e-9	50	4e-8	5e-11	>1e10	3.5e-8
0.1	1e-8	30	4e-7	5e-11	>1e10	2.5e-7
1	1e-7	25	2e-6	5e-11	>1e10	6.5e-7
10	1e-6	25	2e-5	5e-11	>1e10	3.3e-6
100	1e-5	35	4e-4	5e-11	1e7	1.5e-4

* rms noise, 667 ms response time with 10 PLC filtering

1.2.6.12 Lake Shore Model 340 Temperature Controller

The Model 340 Temperature Controller is used in the -LVLR measurement configuration to source currents to the sample and measure voltages. Additional input cards can be installed to measure or control temperature.

See the user's manual for complete information. Some important characteristics for measurement system performance modeling are given in the following tables. The first table gives current source specifications and the second table gives voltage measurement specifications.

	Accuracy (1 year)				
Current [A]	ppm of reading	offset [A]	offset or bias current, Io [A]	R shunt [Ω]	rms noise* [A]
3e-8	2000	-	-	>1e10	-
1e-7	2000	-	-	>1e10	-
3e-7	2000	-	-	>1e10	-
1e-6	2000	-	-	>1e10	-
3e-6	2000	-	-	>1e10	-
1e-5	100	-	-	>1e10	-
3e-5	2000	-	-	>1e10	-
1e-4	2000	-	-	>1e10	-
3e-4	2000	-	-	>1e10	-
1e-3	2000	-	-	>1e10	-

* rms noise, 0.1-10 Hz at 10 PLC

		Accuracy (1 year)				
Range, full scale [V]	Resolution [V]	ppm of reading	offset [V]	offset or bias current, Io [A]	R shunt [Ω]	rms noise* [V]
0.001	1e-7	1000	2e-7	-	>1e10	1e-7
0.01	1e-7	50	2e-6	-	>1e10	1e-7
0.025	1e-7	50	5e-6	-	>1e10	1e-7
0.05	1e-7	50	1e-5	-	>1e10	1e-7
0.1	1e-6	50	2e-5	-	>1e10	1e-6
0.25	1e-6	50	5e-5	-	>1e10	1e-6
0.5	1e-6	50	1e-4	-	>1e10	1e-6
1	1e-5	50	2e-4	-	>1e10	1e-5
2.5	1e-5	50	5e-4	-	>1e10	1e-5
5	1e-5	50	1e-3	-	>1e10	1e-5

* rms noise, 0.1-10 Hz at 10 PLC, estimated

Selected temperature measurement and control specifications for the Model 340 temperature controller are given in the following table.

Temperature measurement accuracy	Sensor dependent Platinum PT-103: ±26 mK at 30 K; ±20 mK at 77 K; ±51 mK at 300 K; ±182 mK at 675 K Cernox CX-1050: ±6 mK at 1.4 K; ±6 mK at 4.2 K; ±110 mK at 77 K; ±450 mK at 300 K
Display resolution	0.001 K above 10 K; 0.0001 K below 10 K
Number of inputs	2 included, more optional
Control loops	2

1.2.6.13 Lake Shore Model 450 Gaussmeter

See the user's manual for complete information. Some important characteristics for measurement system performance modeling are given in the following table.

Resolution	±1 part out of 300,000
Ranges	Seven ranges from 300.000 mG to 300.000 kG (30 mT to 30 T) full scale
Precision	Up to 0.007% of full scale for 300 G and above ranges
Hall Probe	±30 kG (±3 T)

1.3 SAMPLE MODULES

Sample modules interface between the sample and the measurement instrumentation and locate and orient the sample in the electromagnet. Different interchangable sample modules are available for 7500/9500 Series Hall measurement systems. Following is a list of available sample modules and their key features.

1.3.1 Model 75013 Sample Card Sample Module (SCSM)

- Plug-in sample cards facilitate sample exchange and storage.
- Sample sizes to 60 × 60 mm with 4 to 6 contacts.
- Triaxial inputs for sample resistances up to 1 T Ω (1×10^{12} Ω).
- Room temperature (RT) operation with magnet poles at 25 mm (1 in.) gap for highest field.
- Dewar provided for operation at 77 K (–196 °C) with the sample immersed directly in liquid nitrogen or at room temperature with minimum temperature drift; nominal magnet pole gap is 56 mm (2.2 in.).
- Temperature monitoring ability with the 750TC temperature control option.

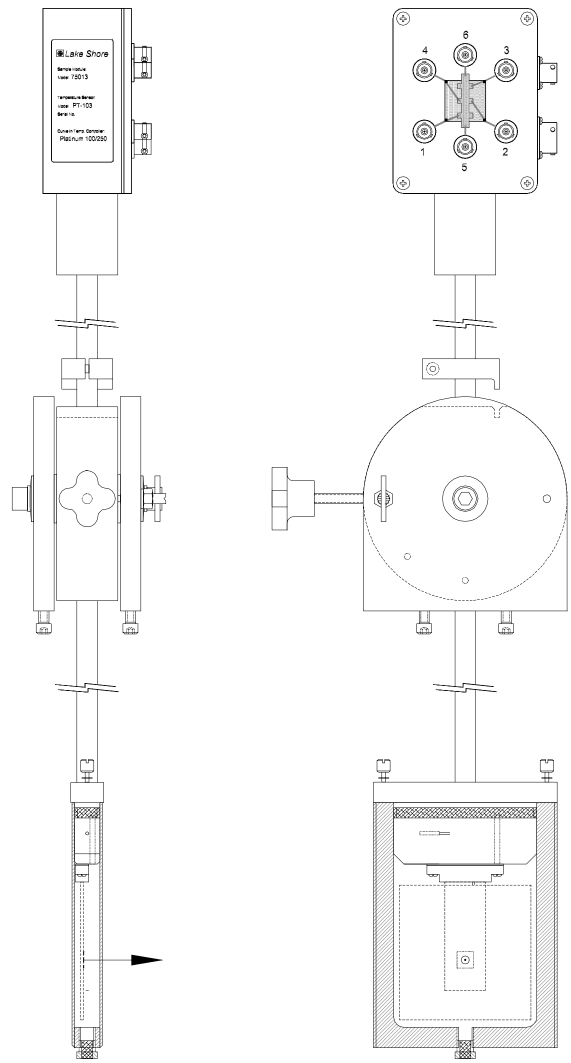


Figure 1-5. Model 75013 SCSM

Sample Size	12 mm square maximum on a 25 x 75 mm plug-in card (50 provided) or 60 mm square maximum on an 82 x 93 mm plug-in card (10 provided)
Sample Structure	Hall bar or van der Pauw
Temperature	Room temperature or 77 K (liquid nitrogen required for 77 K)
No. of Contacts	4 or 6

1.3.2 Model 75014 Closed Cycle Refrigerator Sample Module (CCRSM)

- Temperature controlled operation from 10 to 350 K (–273 to +77 °C) with required 750TC temperature control and 750PB20 power booster options.
- Sample well filled with helium gas allows rapid sample exchange, even when cold.
- Sample sizes to 12 x 15 x 1 mm with 4 to 6 contacts.
- Triaxial inputs for sample resistances up to 1 TΩ (1×10^{12} Ω).
- 38 mm (1.5 inch) OD tail fits into 41 mm (1.63 inch) electromagnet gap.
- Rotation stage for precise sample alignment or study of orientation effects.

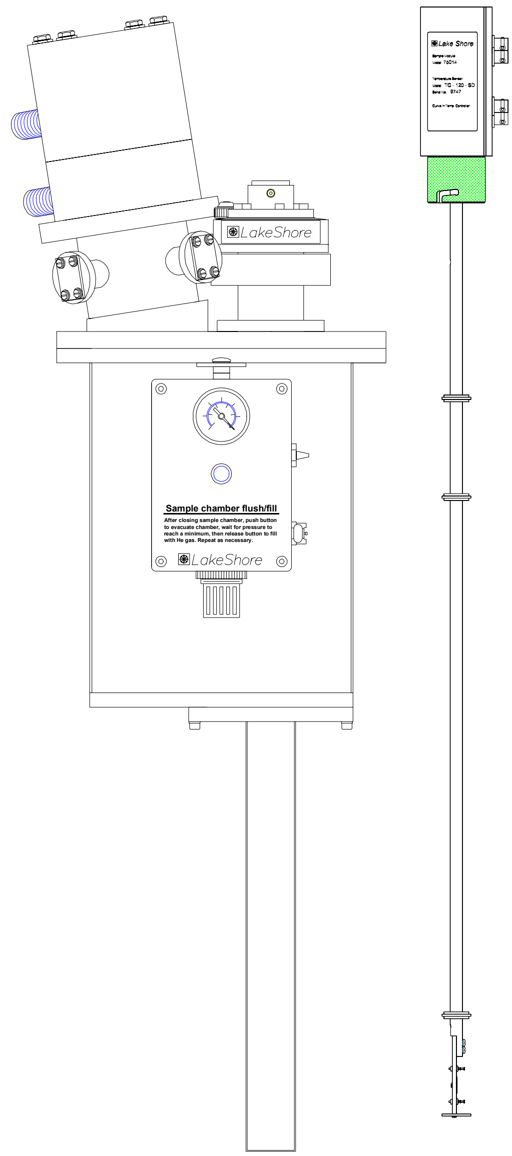


Figure 1-6. Model 75014 CCRSM (compressor & high-pressure helium hoses not shown)

Sample Size	12 × 15 × 1 mm (W×L×T) maximum
Sample Structure	Hall bar or van der Pauw
Temperature	15 K to 350 K
No. of Contacts	4 or 6

	Sample Module	Compressor
Weight	40 kg (88 lbs.)	90 kg (200 lbs.)
Dimensions (HxWxD)	90 × 36 × 36 cm (36 × 14 × 14 in.)	51.4 × 43.2 × 50.8 cm (20.25 × 17.0 × 20.0 in.)

1.3.3 Model 75016 Oven Sample Module (OSM)

- Temperature controlled operation from just above ambient to 800 K (527 °C) with required 750TC temperature control and 750PB20 power booster options.
- Sample sizes to 17 × 14 × 1 mm.
- 4 to 6 contacts with independently adjustable tungsten needle probes.
- Triaxial inputs for sample resistances up to 1 T Ω (1×10^{12} Ω).
- 35 mm (1.38 in.) OD tail fits into 38 mm (1.5 in.) electromagnet gap.
- Flush/fill unit can be used to provide an inert atmosphere for the sample.
- Rotation stage for precise sample alignment or study of orientation effects.

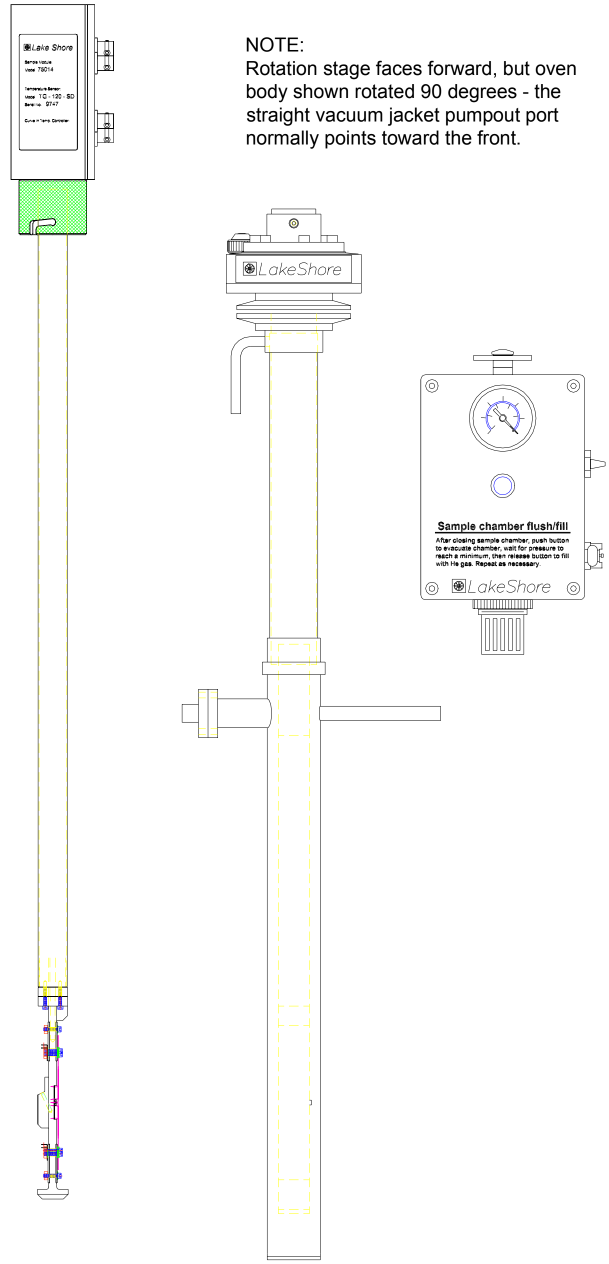


Figure 1-7. Model 75016 OSM

Sample Size	14 × 17 × 1 mm (W×L×T) maximum
Sample Structure	Hall bar or van der Pauw
Temperature	Room temperature to 800 K
No. of Contacts	4 or 6

1.3.4 Model 9500 Flow Cryostat Sample Module (FCSM)

- Temperature controlled operation from just below 2 K to 400 K (126 °C).
- Sample sizes to 12 × 14 × 1 mm.
- 4 to 6 contacts with solder posts.
- Triaxial inputs for sample resistances up to 1 TΩ (1×10^{12} Ω).

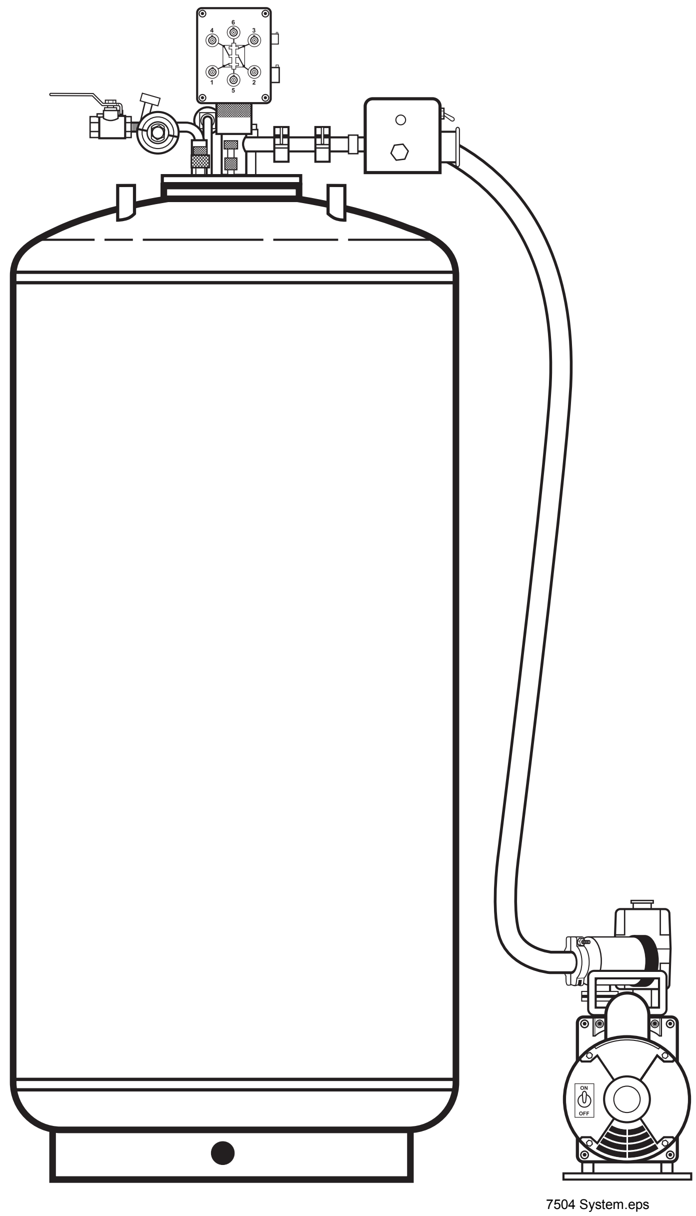


Figure 1-8. Model 9500 FCSM

Sample Size	12 × 14 × 1 mm (W×L×T) maximum
Sample Structure	Hall bar or van der Pauw
Temperature	from below 2 K to 400 K
No. of Contacts	4 or 6

1.4 OPTIONS

A list of options and systems to which they are applicable is given in Table 1-5. Extended descriptions of the individual options are given in the following sections.

Other measurement configuration options might be available. Contact Lake Shore regarding your needs.

Table 1-5. Options Available For 7500/9500 Series Systems

Option Model #	Applicable to Models	Description
750HS	75xx or 95xx -HVWR (note 1) -LVWR -LVWR-SWT -HVLR (note 1)	Adds High Sensitivity option to an existing system with a field upgrade kit.
750MB	all	Multiple Boot computer system for use with two significantly different configurations such as 7507 and 9505 (or with a VSM)
750PB20	750TC 75014 CCRSM 75016 OSM -LVLR 95xx	Power Booster for second loop heater output from a Model 340 temperature controller; maximum output 20 W, 40 V, 0.5 A.
750QMSA	all	Quantitative Mobility Spectrum Analysis software.
750SWT	75xx or 95xx -LVWR -LVWR-HS	Adds Fully Automated Switching option to an existing system or with a field upgrade kit.
750TC	75xx all except -LVLR	Adds a 340 temperature controller to an existing 7500 Series system at time of purchase or with a field upgrade kit.
75014VM	75014 CCRSM 75014-WT CCRSM	Adds vacuum monitoring to the 75014 at time of purchase or with a field upgrade kit.
75014WT	75014 CCRSM	Adds Windowed Tail option to an existing 75014 CCRSM as a field upgrade kit.
9500 FCSM	75xx	Flow Cryostat Sample Module
9500-OVEN	95xx	Oven Flow Cryostat Sample Module

Note 1. Requires KI 2182; check with Lake Shore for availability.

1.4.1 Model 750HS High Sensitivity Option

A sensitive digital nanovoltmeter (Keithley Model 182) and special input cabling provide much greater voltage sensitivity and accuracy—useful for measuring heavily doped, low mobility, and low resistance samples.

1.4.2 Model 750MB Multiple Boot Option

Multiple Boot computer system for use with two significantly different configurations such as 7507 and 9505 (or with a VSM). On starting (booting) the computer system, the user selects one of two or more setup configurations, allowing one computer to run two or more very different measuremtent systems.

1.4.3 Model 750PB20 Power Booster (40 V, 0.5 A) Option

Power booster, 20 W (40 V, 0.5 A) maximum, used to increase the Model 340 Temperature Controller's second loop heater output from its 1 W maximum.

1.4.4 Model 750QMSA Software

Analysis software provides quantitative mobility spectrum analysis (QMSA) for multi-carrier materials. This analysis derives a spectrum of conductivity vs. mobility, allowing a more complete characterization of the individual properties of multiple carriers. Supports multi-carrier fits and Beck & Anderson mobility spectrum analysis. Useful for analysis of conduction in multi-layer materials, heterostructures, or quantum wells, as well as intrinsically multi-carrier materials such as HgCdTe or anisotropic materials such as silicon. The software requires as input only the Hall coefficient and resistivity as a function of magnetic field.

1.4.5 Model 750SWT Fully Automated Switching Option

Adds a Keithley 7152 Low Current Switch Card with cabling and software to allow automated switching between sample types allows measurement of either 4-wire (van der Pauw) or 6-wire (Hall bar) samples. The current meter (2 mA maximum) also switches in and out automatically for operation from 500 fA to 100 mA without recabling. A larger current range can be especially important for samples whose properties vary widely with temperature. The additional switch card and cabling slightly reduces the maximum measurable sample resistances.

1.4.6 Model 750TC Temperature Controller Option

Add a Lake Shore Model 340 Cryogenic Temperature Controller to measure and record one or more temperatures. Many sample modules also allow control of the sample temperature with either one or two heater control loops.

1.4.7 Model 75014VM Vacuum Monitoring for the Model 75014 CCRSM

Adds vacuum monitoring to the 75014 at time of purchase or with a field upgrade kit. A thermocouple vacuum gauge mounts to a collar installed between the OmniPlex vacuum shroud and the vacuum valve.

1.4.8 Model 75014WT Windowed Tail for the Model 75014 CCRSM

Adds Windowed Tail option to an existing 75014 CCRSM as a field upgrade kit. Contact Lake Shore for further information.

1.4.9 Model 9500 Flow Cryostat Sample Module

Adds a dewar, flow cryostat, superconducting magnet, and sample insert to a 7500 Series system. Additional 9500 Sample Inserts can also be purchased for either 7500 or 9500 Series systems.

1.4.10 Model 9500-OVEN Oven Flow Cryostat Sample Module

Adds an Oven Flow Cryostat Sample Module to a 9500 Series system.

1.5 SYSTEM MEASUREMENT PERFORMANCE

The ability to make accurate Hall effect measurements is affected by many factors. The ablilty to measure quantities of common interest, such as resistivity, carrier concentration or mobility, cannot be completely specified because some factors, such as the sample thickness and the uncertainty of the thickness measurement, are user-controlled. Detailed discussions of Hall effect measurements and error sources are given in Appendix A to this manual.

Other than the accuracy of the magnetic flux density, B, Hall effect measurement accuracy is essentially determined by a measured voltage divided by a sourced current.

A computer model of the Hall effect measurement system developed at Lake Shore has been used to determine the ranges within which the system can be used to make accurate measurements. Instrument specifications were used along with the following assumed measurement conditions:

- Maximum power dissipation in the sample of 1 mW
- 295 K sample temperature
- No current leakage to sample holder
- 25 Ω resistance down each lead wire
- Resistivity measurement voltage efficiencies (V_out/V_in) of 0.1 for van der Pauw structures and 0.5 for Hall bar structures
- Zero misalignment voltage in Hall voltage measurements (see Appendix A for explanation)
- Hall scattering factor of 1.0 (see Appendix A for explanation)
- 1% magnetic flux density (B) uncertainty
- 1% sample thickness (t) uncertainty

Additional conditions may be specified for a particular instrumentation configuration. The system measurement performance is presented in two plots for each instrumentation configuration.

The relative accuracy of resistance measurements plots as a function of sample resistance. Current leakage to ground through cabling and instrumentation limits the maximum measurable resistance. Voltmeter sensitivity and the maximum excitation current limit the minimum measurable resistance.

The ability to measure mobility to within an uncertainty of 5% plots as a function of carrier density and sample resistance. Read these plots as showing an envelope within which the mobility can be measured to the stated accuracy. The minimum measurable carrier density is largely a function of the maximum voltage capability of the instrumentation. The maximum measurable carrier density is roughly proportional to the ratio B/t, so large magnetic flux density and thin samples can improve measurement range. Current leakage to ground through the cabling and instrumentation limits the maximum measurable resistance. Voltmeter sensitivity and the maximum excitation current limits the minimum measurable resistance.

See Section 3.4 for measurement configuration connection details.

The performance models have been checked at several points using standard resistors measured in production Hall effect measurement systems. Unfortunately, standards for carrier concentration or mobility measurements do not exist. Uncertainties in these quantities can be referenced to uncertainties in other basic measurements and the sample geometry. Hall measurements have also been performed on wafers purchased from suppliers and samples subjected to round-robbin testing at other laboratories. The system measurement specifications given in Table 1-5 resulted from a combination of modeling and verification. A more complete, but unverified, picture of a measurement configuration's capabilities can be gained from the following sections.

Table 1-6. Measurement Specifications for Hall Effect Measurement Systems

The maximum measurable carrier density is nearly identical for van der Pauw (vdP) and Hall bar sample geometries. The modeled measurement conditions are given in Note 1.

		Resistance Range (2% accuracy or better)			Hall Mobility Measurement (5% accuracy or better)
Measurement Configuration	**Description**	**R max.**	**R min. vdP**	**R min. Hall bar**	**Max. carrier density** [cm^{-3}] (note 2)
-HVWR	**High Voltage, Wide Resistance range**	70 GΩ	40 mΩ	10 mΩ	4e18
-HVWR-HS (note 4)	+ High Sensitivity	70 GΩ	0.4 mΩ	0.1 mΩ	3e20
-LVWR (note 3)	**Low Voltage, Wide Resistance range**	200 GΩ	1600 mΩ (40 mΩ)	400 mΩ (10 mΩ)	8e16 (4e18)
-LVWR-HS (note 3)	+ High Sensitivity	200 GΩ	20 mΩ (0.4 mΩ)	5 mΩ (0.1 mΩ)	6e18 (3e20)
-LVWR-SWT	+ Fully Automated Switching	100 GΩ	40 mΩ	10 mΩ	4e18
-LVWR-HS-SWT	+ High Sensitivity + Fully Auto. Switch.	100 GΩ	0.4 mΩ	0.1 mΩ	3e20
-HVLR	**High Voltage, Low Resistance range**	10 MΩ	40 mΩ	10 mΩ	4e18
-HVLR-HS (note 4)	+ High Sensitivity	10 MΩ	0.4 mΩ	0.1 mΩ	3e20
-LVLR (note 4)	**Low Voltage, Low Resistance range**	1 MΩ	200 mΩ	50 mΩ	6e17

Notes:

1. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation equal to the measurement configuration's maximum specified current and voltage, 295 K sample temperature, no current leakage to sample holder, 25 Ω resistance down each lead, assumed sample resistivity measurement voltage efficiencies (V_out/V_in) of 0.1 for van der Pauw and 0.5 for Hall bar structures, Hall factor of 1.0, magnetic field (B) and sample thickness (t) uncertainties of 1% each, and B/t ratio of 1 T/mm. Note that the maximum carrier density is roughly proportional to the ratio B/t, so high fields and thin samples can improve the measurement range.
2. Roughly 50% of the modeled maximum.
3. Maximum current of 2 mA or (100 mA), requires manual recabling.
4. Check Lake Shore for availability.

1.5.1 -HVWR: High Voltage, Wide Resistance Range Measurement Configuration

See section 3.4.1 for wiring instructions. Requires the following minimum Hall effect measurement system: –HVWR – High Voltage, Wide Resistance Range HMS.

Instrumentation summary:

Keithley 7001 Switch System Mainframe
Keithley 7152 4×5 matrix switch cards (2)
Keithley 2000 Voltmeter
Keithley 220 Current Source
Keithley 486 or 487 Picoammeter
Automated switching between Current Meter and Short

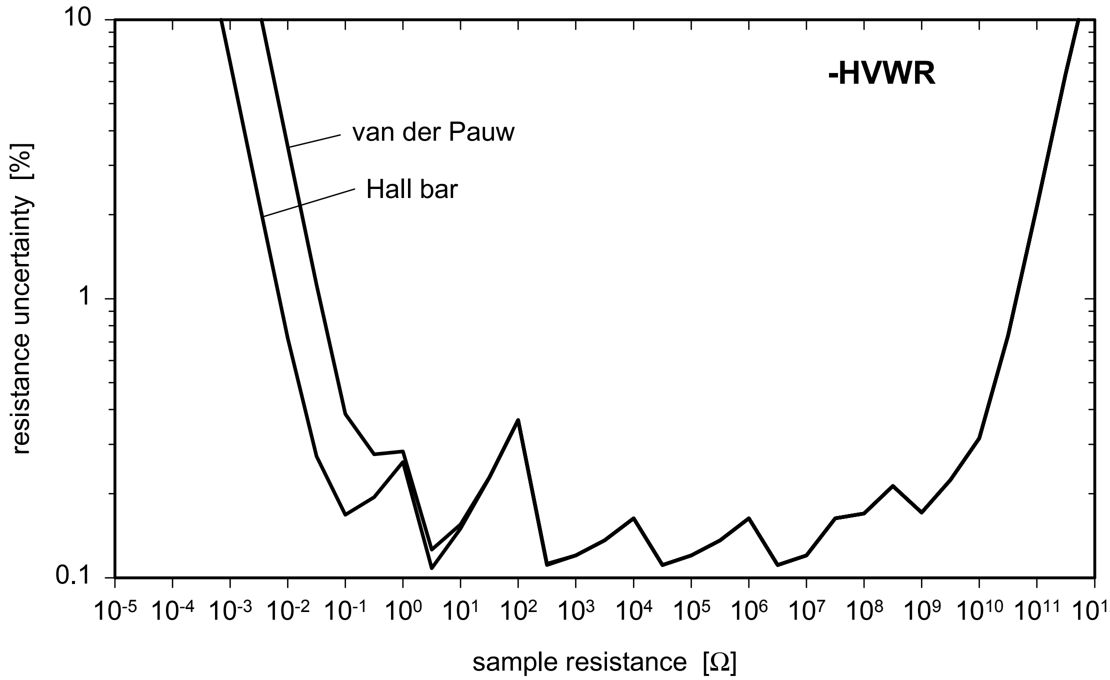


Figure 1-9. Resistance measurement uncertainty using the -HVWR measurement configuration. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 100 V, 100 mA maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, and 25 Ω resistance down each lead wire.

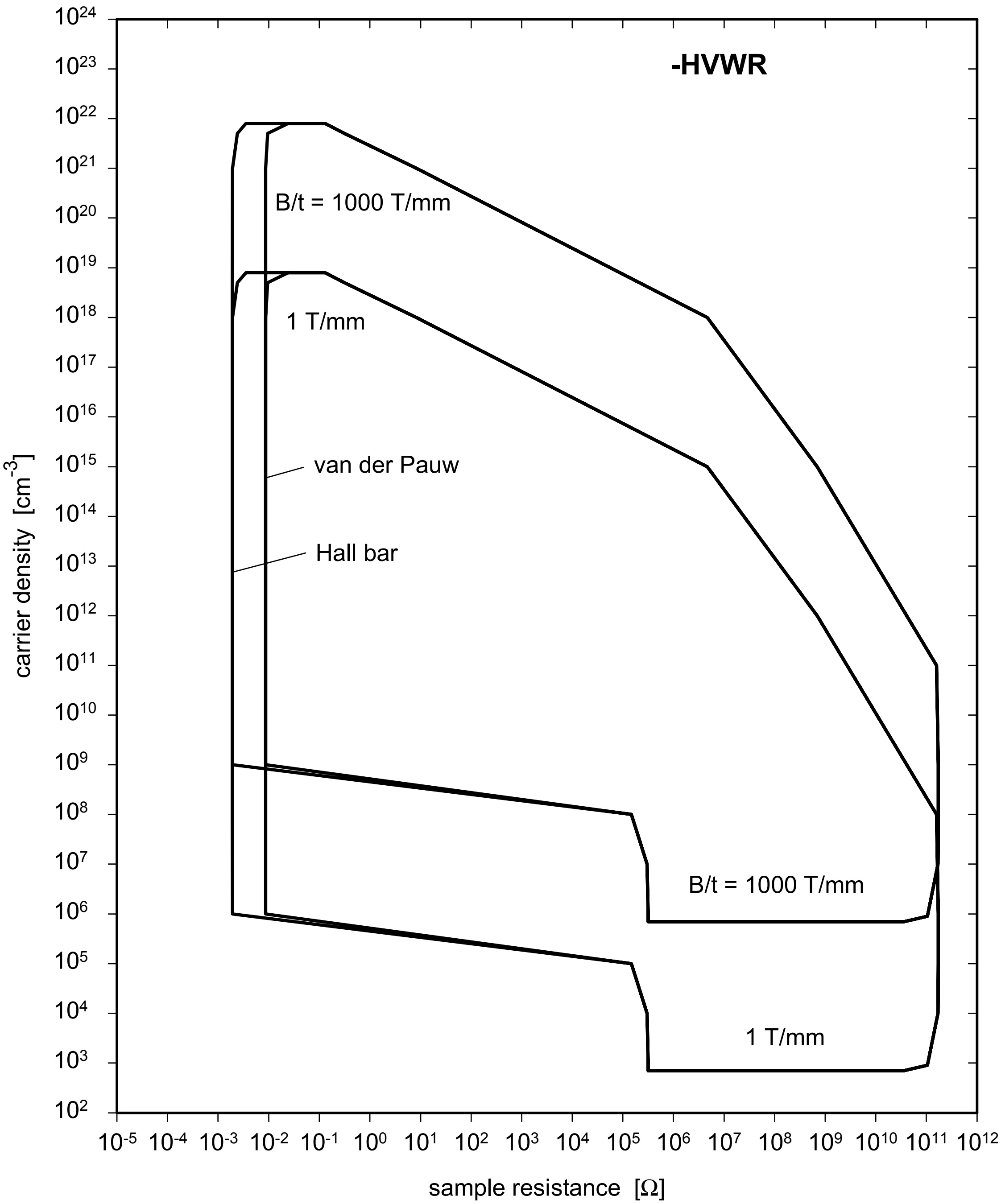


Figure 1-10. Range within which mobility is measured to within an uncertainty of 5% using the -HVWR measurement configuration. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 100 V, 100 mA maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, 25 Ω resistance down each lead wire, assumed sample resistivity measurement voltage efficiencies (V_out/V_in) of 0.1 for van der Pauw or 0.5 for Hall bar structures, zero Hall offset voltage, Hall factor of 1 and magnetic flux density (B) and sample thickness (t) uncertainties of 1% each. Note that the maximum carrier density is roughly proportional to the ratio B/t, so large magnetic flux density and thin samples can improve the measurement range.

1.5.2 -HVWR-HS: High Voltage, Wide Resistance Range, High Sensitivity Measurement Configuration

See section 3.4.2 for wiring instructions. Requires the following minimum Hall effect measurement system: –HVWR-HS — High Voltage, Wide Resistance Range HMS + High Sensitivity option.

Instrumentation summary:

Keithley 7001 Switch System Mainframe
Keithley 7152 4×5 matrix switch cards (2)
Keithley 2182 Nanovoltmeter
Keithley 220 Current Source
Keithley 486 or 487 Picoammeter
Automated switching between Current Meter and Short

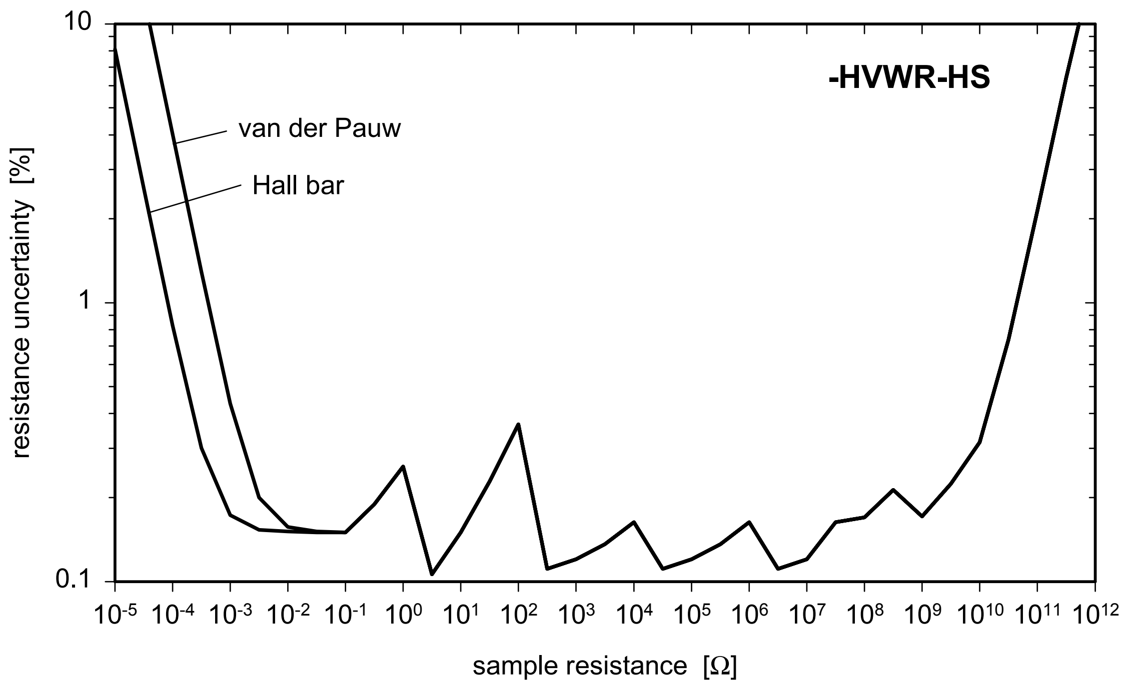


Figure 1-11. Resistance measurement uncertainty using the -HVWR-HS measurement configuration. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 100 V, 100 mA maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, and 25 Ω resistance down each lead wire.

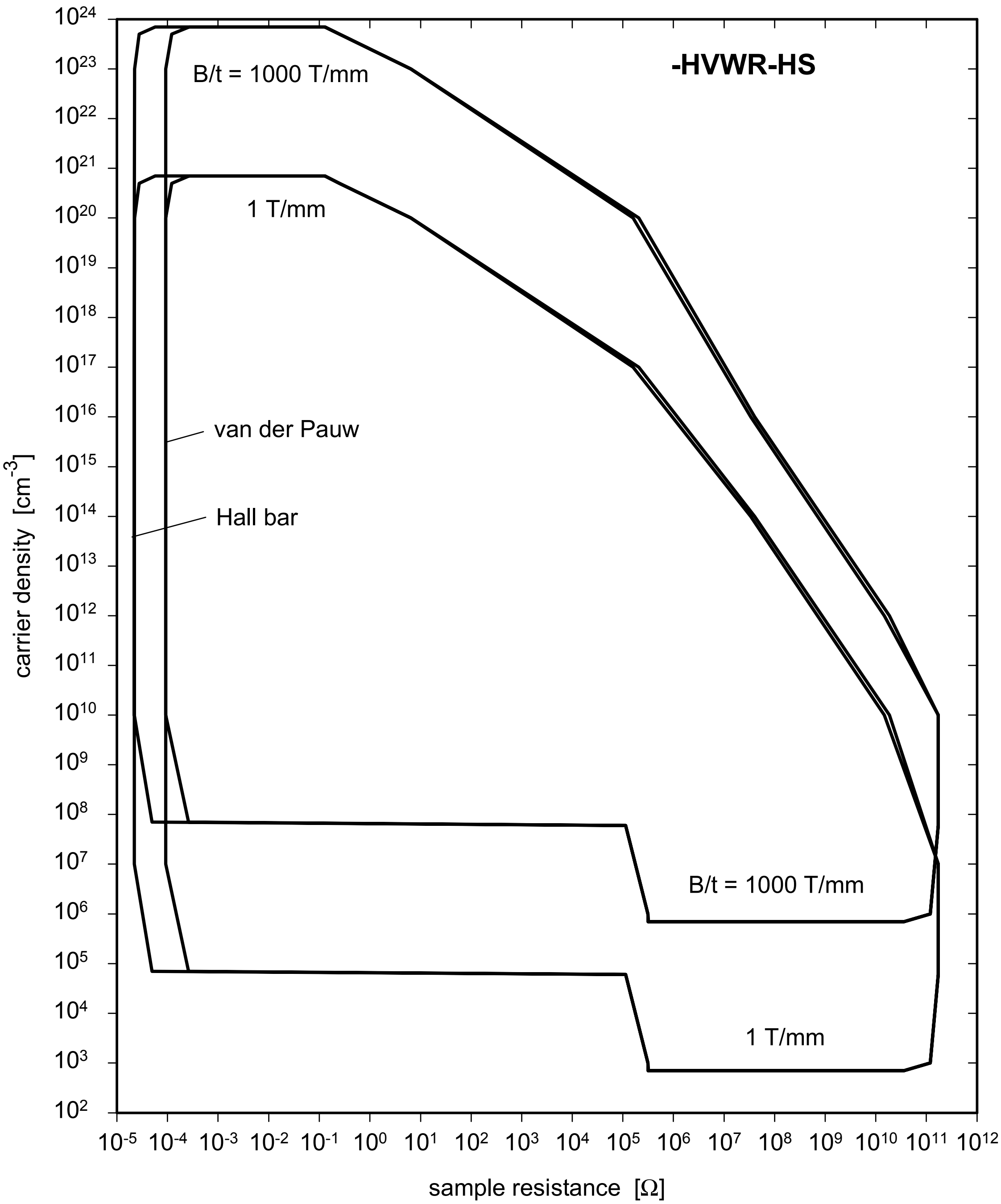


Figure 1-12. Range within which mobility is measured to within an uncertainty of 5% using the -HVWR-HS measurement configuration. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 100 V, 100 mA maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, 25 Ω resistance down each lead wire, assumed sample resistivity measurement voltage efficiencies (V_out/V_in) of 0.1 for van der Pauw or 0.5 for Hall bar structures, zero Hall offset voltage, Hall factor of 1 and magnetic flux density (B) and sample thickness (t) uncertainties of 1% each. Note that the maximum carrier density is roughly proportional to the ratio B/t, so large magnetic flux density and thin samples can improve the measurement range.

1.5.3 -LVWR (vdP): Low Voltage, Wide Resistance Range Measurement Configuration, van der Pauw Structures

See section 3.4.3 for wiring instructions. Manual recabling is required to switch between the 2 or 100 mA maximum current configurations. These configurations require the following minimum Hall effect measurement system:

-LVWR Low Voltage, Wide Resistance Range HMS

and can also be configured from the following systems:

-LVWR-SWT + Fully Automated Switching option

Instrumentation summary:

Keithley 7001 Switch System Mainframe
Keithley 7065 Hall effect matrix switch card with buffer amplifiers (±8 V maximum),
(High resistance mode used for sample resistances > 100,000 ohms)
Keithley 2000 Voltmeter
Keithley 220 Current Source
Keithley 485, 486 or 487 Picoammeter
Return current cable to Current Meter (2 mA maximum)
Return current cable to Short (100 mA maximum)

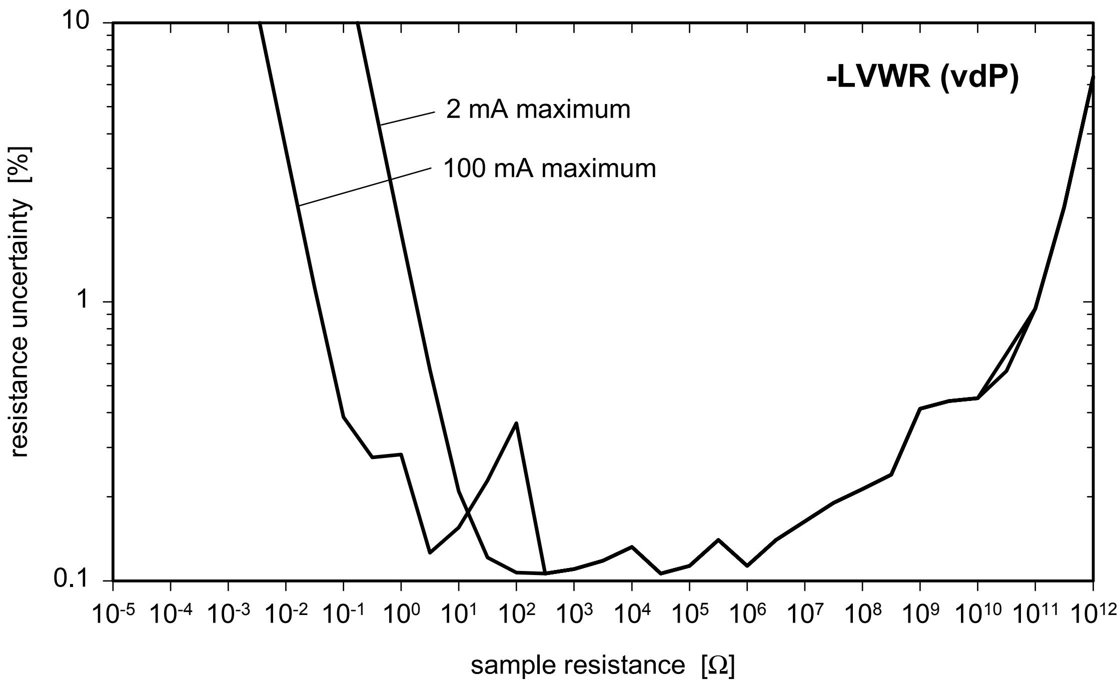


Figure 1-13. Resistance measurement uncertainty using the -LVWR measurement configuration with metered or unmetered current (2 or 100 mA maximum, respectively) and van der Pauw structures. Manual recabling is required to switch between these conditions. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 8 V, indicated maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, and 25 Ω resistance down each lead wire.

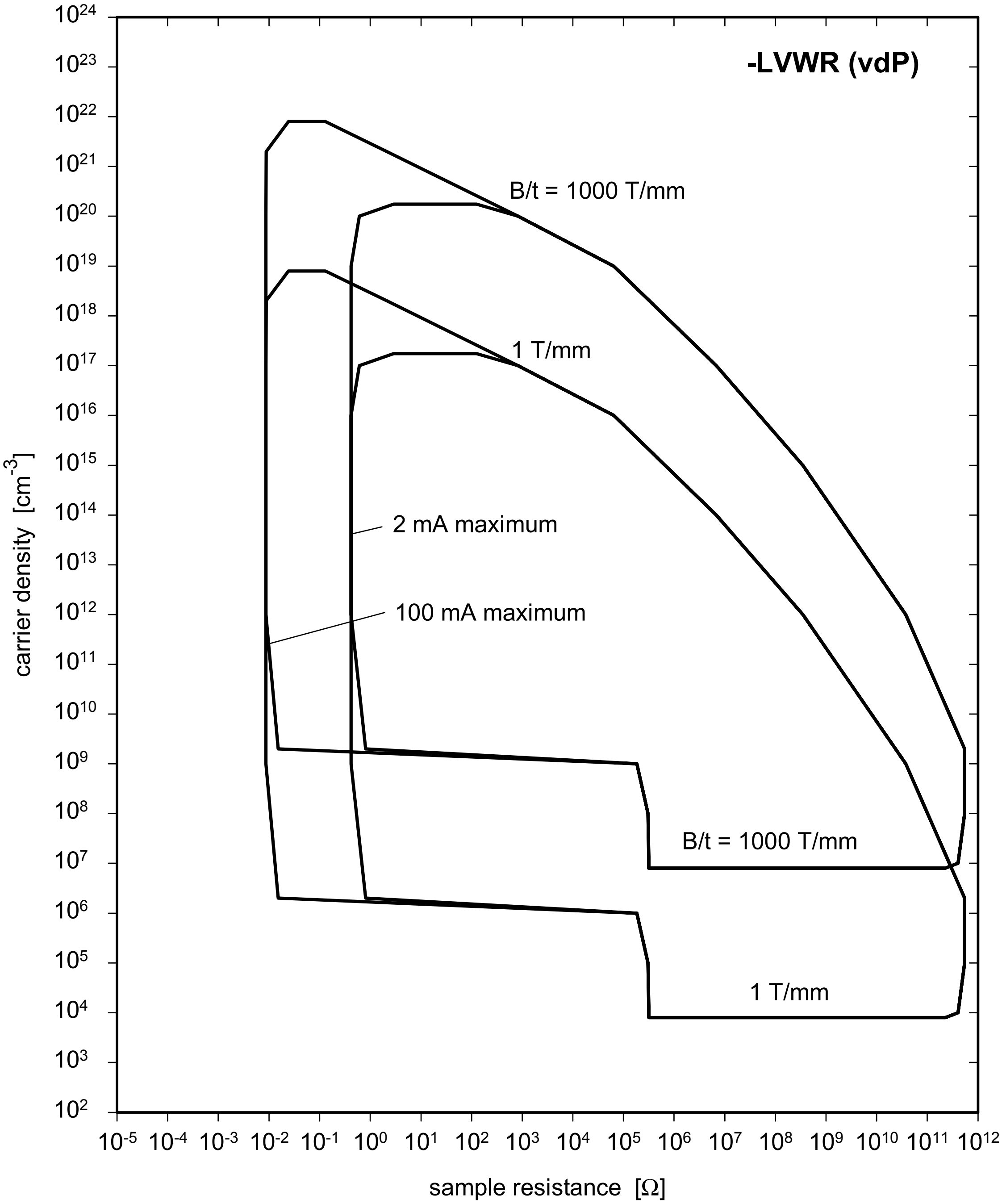


Figure 1-14. Range within which mobility is measured to within an uncertainty of 5% using the -LVWR measurement configuration with metered or unmetered current (2 or 100 mA maximum, respectively) and van der Pauw structures. Manual recabling is required to switch between these conditions. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 8 V, indicated maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, 25 Ω resistance down each lead wire, assumed sample resistivity measurement voltage efficiencies (V_out/V_in) of 0.1 for van der Pauw structures, zero Hall offset voltage, Hall factor of 1 and magnetic flux density (B) and sample thickness (t) uncertainties of 1% each. Note that the maximum carrier density is roughly proportional to the ratio B/t, so large magnetic flux density and thin samples can improve the measurement range.

1.5.4 -LVWR (HB): Low Voltage, Wide Resistance Range Measurement Configuration, Hall Bar Structures

See section 3.4.4 for wiring instructions. The -LVWR measurement configuration comes cabled for van der Pauw (4 contact) samples. Switching between the van der Pauw (vdP) and Hall bar (HB) sample configurations typically takes a few minutes. Manual recabling is also required to switch between the 2 or 100 mA maximum current configurations. These configurations require the following minimum Hall effect measurement system:

-LVWR Low Voltage, Wide Resistance Range HMS

and can also be configured from the following systems:

-LVWR-SWT + Fully Automated Switching option

Note that current-voltage characterization of Hall bars is not possible with the -LVWR measurement configuration without temporary rewiring of the sample. Consider the 750SWT or 750HVLR options if Hall bar contact characterization is required.

Instrumentation summary:

Keithley 7001 Switch System Mainframe
Keithley 7065 Hall effect matrix switch card with buffer amplifiers (±8 V maximum),
(High resistance mode used for sample resistances > 100,000 ohms)
Keithley 2000 Voltmeter
Keithley 220 Current Source
Keithley 485, 486 or 487 Picoammeter
Return current cable to Current Meter (2 mA maximum)
Return current cable to Short (100 mA maximum)

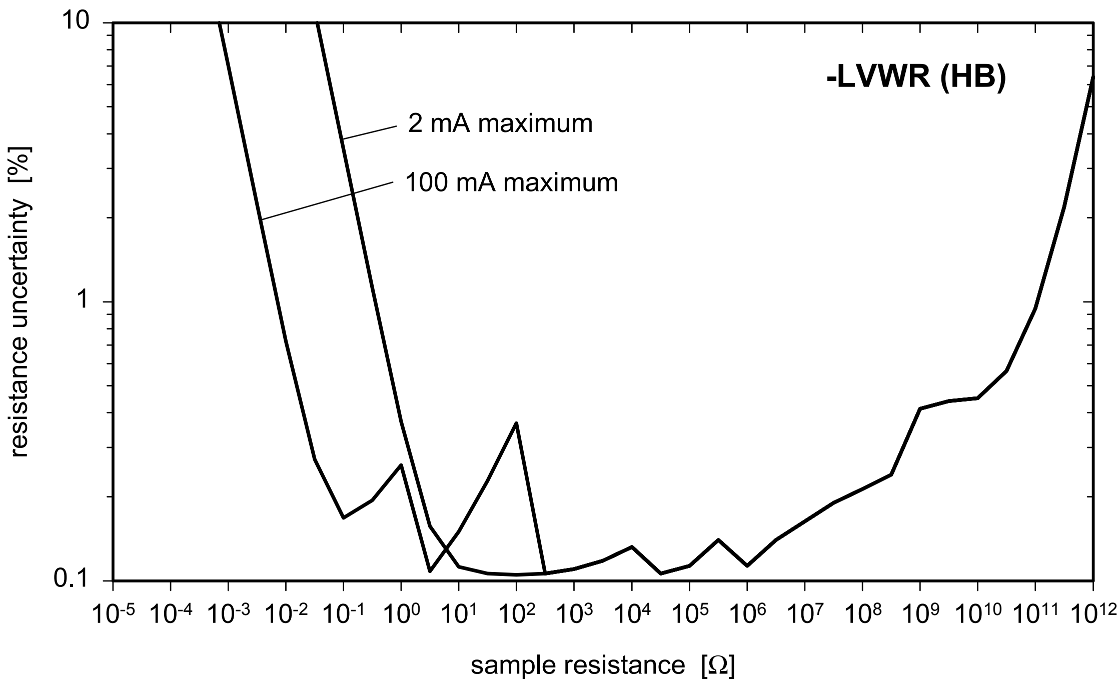


Figure 1-15. Resistance measurement uncertainty using the -LVWR measurement configuration with metered or unmetered current (2 or 100 mA maximum, respectively) and Hall bar structures. Manual recabling is required to switch between these conditions. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 8 V, indicated maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, and 25 Ω resistance down each lead wire.

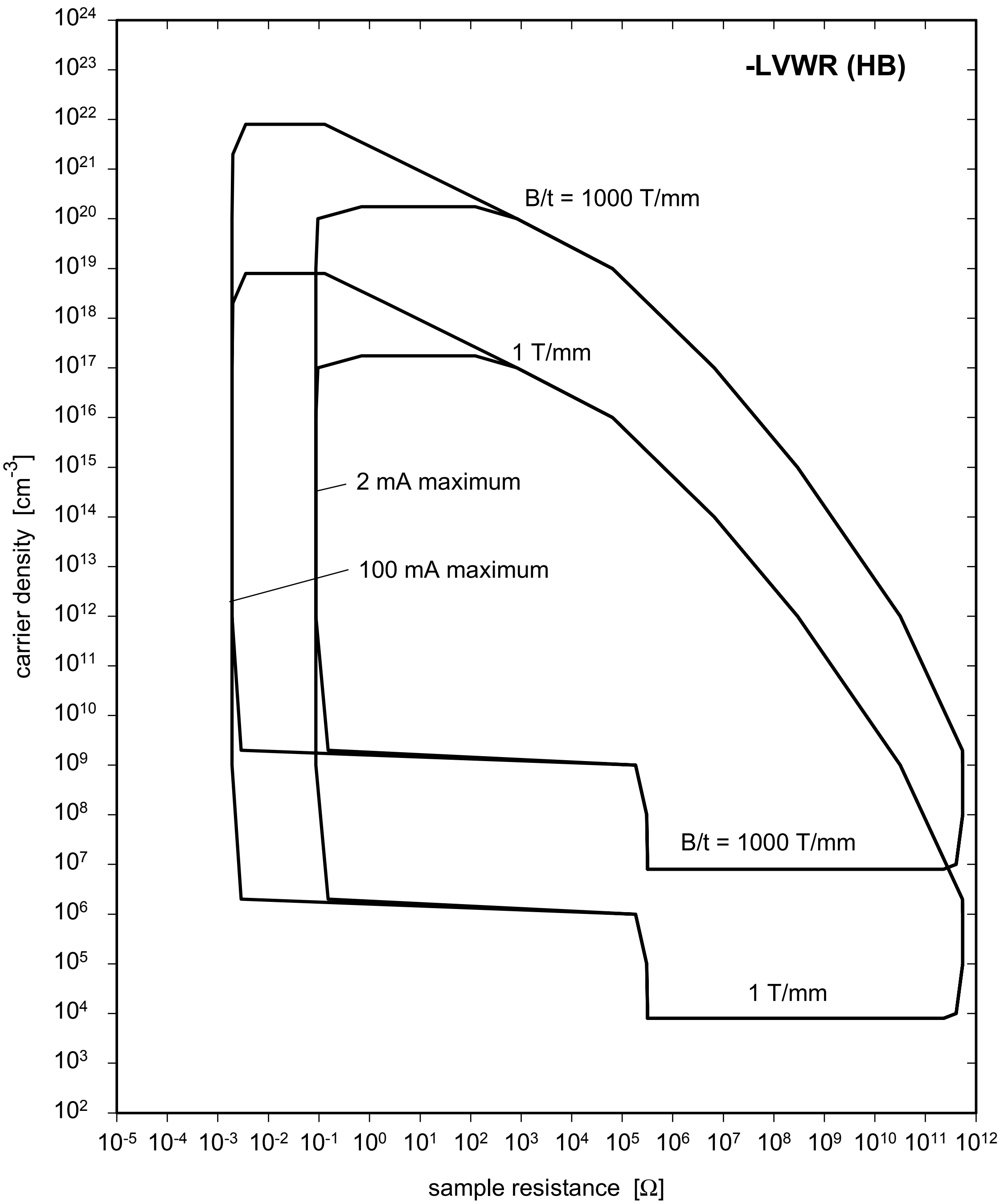


Figure 1-16. Range within which mobility is measured to within an uncertainty of 5% using the -LVWR measurement configuration with metered or unmetered current (2 or 100 mA maximum, respectively) and Hall bar structures. Manual recabling is required to switch between these conditions. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 8 V, indicated maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, 25 Ω resistance down each lead wire, assumed sample resistivity measurement voltage efficiencies (V_out/V_in) of 0.5 for Hall bar structures, zero Hall offset voltage, Hall factor of 1 and magnetic flux density (B) and sample thickness (t) uncertainties of 1% each. Note that the maximum carrier density is roughly proportional to the ratio B/t, so large magnetic flux density and thin samples can improve the measurement range.

1.5.5 -LVWR-HS (vdP): Low Voltage, Wide Resistance Range, High Sensitivity Measurement Configuration, van der Pauw Structures

See section 3.4.5 for wiring instructions. Manual recabling is required to switch between the 2 or 100 mA maximum current configurations. These configurations require the following minimum Hall effect measurement system:

-LVWR-HS Low Voltage, Wide Resistance Range HMS + High Sensistivity option

and can also be configured from the following systems:

-LVWR-HS-SWT + Fully Automated Switching option

Instrumentation summary:

Keithley 7001 Switch System Mainframe
Keithley 7065 Hall effect matrix switch card with buffer amplifiers (±8 V maximum),
(High resistance mode used for sample resistances > 100,000 ohms)
Keithley 182 or 2182 Nanovoltmeter (High Sensitivity option)
Keithley 220 Current Source
Keithley 485, 486 or 487 Picoammeter
Return current cable to Current Meter (2 mA maximum)
Return current cable to Short (100 mA maximum)

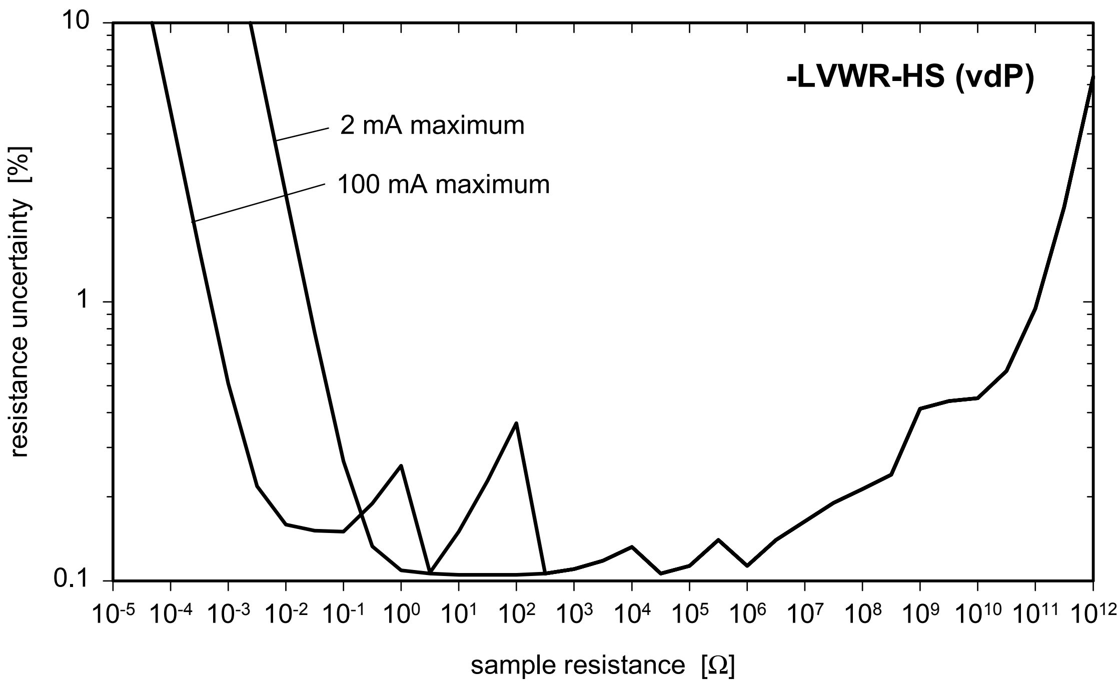


Figure 1-17. Resistance measurement uncertainty using the -LVWR-HS measurement configuration with metered or unmetered current (2 or 100 mA maximum, respectively) and van der Pauw structures. Manual recabling is required to switch between these conditions. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 8 V, indicated maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, and 25 Ω resistance down each lead wire.

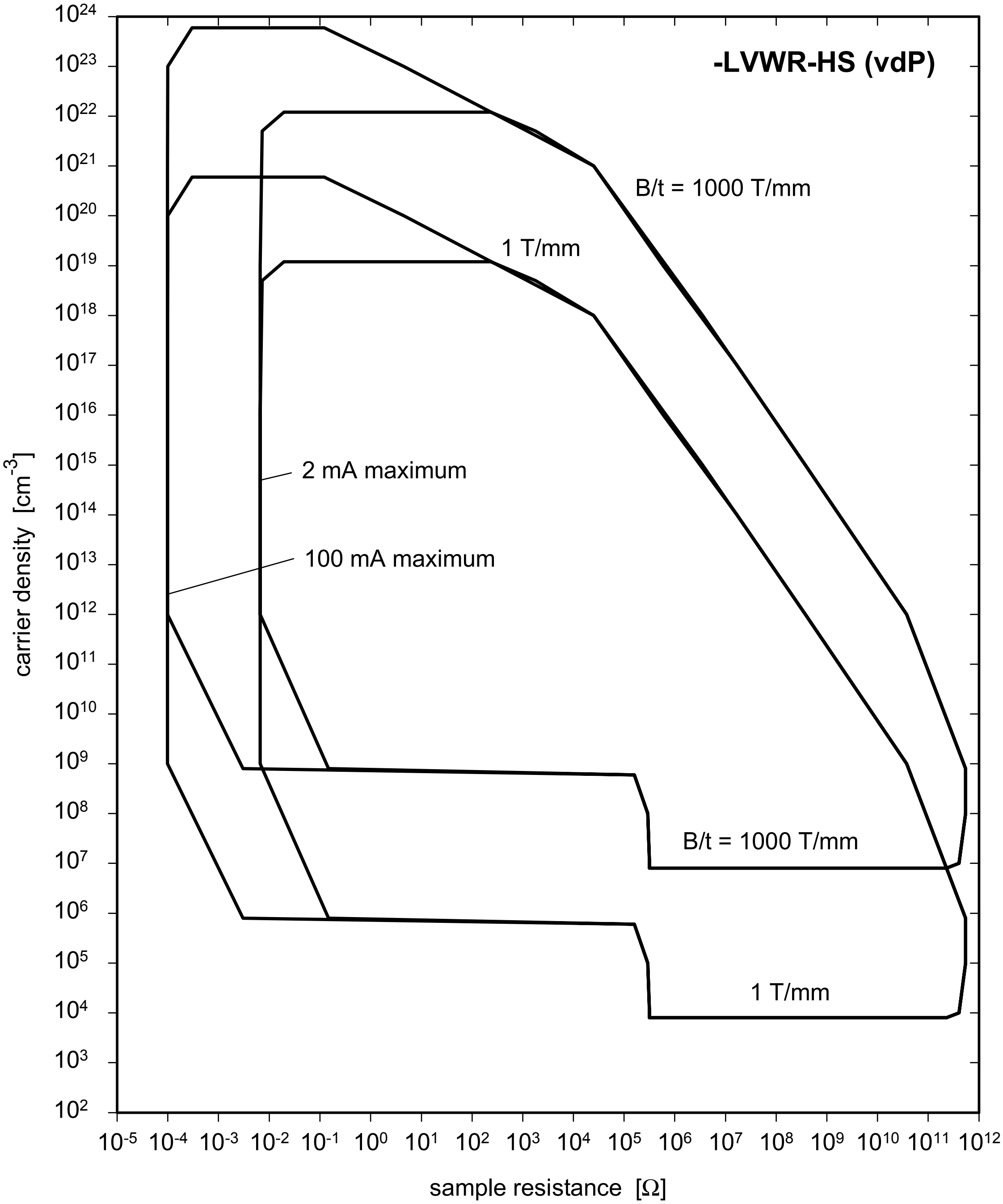


Figure 1-18. Range within which mobility is measured to within an uncertainty of 5% using the -LVWR-HS measurement configuration with metered or unmetered current (2 or 100 mA maximum, respectively) and van der Pauw structures. Manual recabling is required to switch between these conditions. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 8 V, indicated maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, 25 Ω resistance down each lead wire, assumed sample resistivity measurement voltage efficiencies (V_out/V_in) of 0.1 for van der Pauw structures, zero Hall offset voltage, Hall factor of 1 and magnetic flux density (B) and sample thickness (t) uncertainties of 1% each. Note that the maximum carrier density is roughly proportional to the ratio B/t, so large magnetic flux density and thin samples can improve the measurement range.

1.5.6 -LVWR-HS (HB): Low Voltage, Wide Resistance Range, High Sensitivity Measurement Configuration, Hall Bar Structures

See section 3.4.6 for wiring instructions. The -LVWR-HS measurement configuration comes cabled for van der Pauw (4 contact) samples. Switching between the van der Pauw (vdP) and Hall bar (HB) sample configurations typically takes a few minutes. Manual recabling is also required to switch between the 2 or 100 mA maximum current configurations. These configurations require the following minimum Hall effect measurement system:

-LVWR-HS Low Voltage, Wide Resistance Range HMS + High Sensistivity option

and can also be configured from the following systems:

-LVWR-SWT + Fully Automated Switching option

Note that current-voltage characterization of Hall bars is not possible with the -LVWR measurement configuration without temporary rewiring of the sample. Consider the 750SWT or 750HVLR options if Hall bar contact characterization is required.

Instrumentation summary:

Keithley 7001 Switch System Mainframe
Keithley 7065 Hall effect matrix switch card with buffer amplifiers (±8 V maximum),
(High resistance mode used for sample resistances > 100,000 ohms)
Keithley 182 or 2182 Nanovoltmeter (High Sensitivity option)
Keithley 220 Current Source
Keithley 485, 486 or 487 Picoammeter
Return current cable to Current Meter (2 mA maximum)
Return current cable to Short (100 mA maximum)

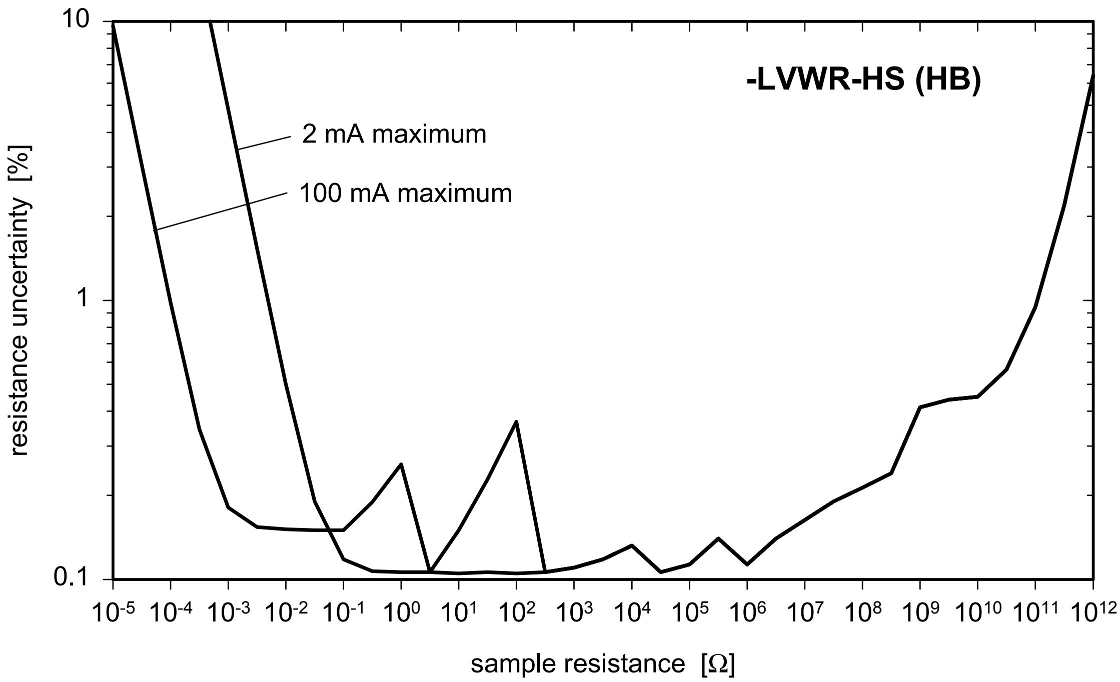


Figure 1-19. Resistance measurement uncertainty using the -LVWR-HS measurement configuration with metered or unmetered current (2 or 100 mA maximum, respectively) and Hall bar structures. Manual recabling is required to switch between these conditions. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 8 V, indicated maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, and 25 Ω resistance down each lead wire.

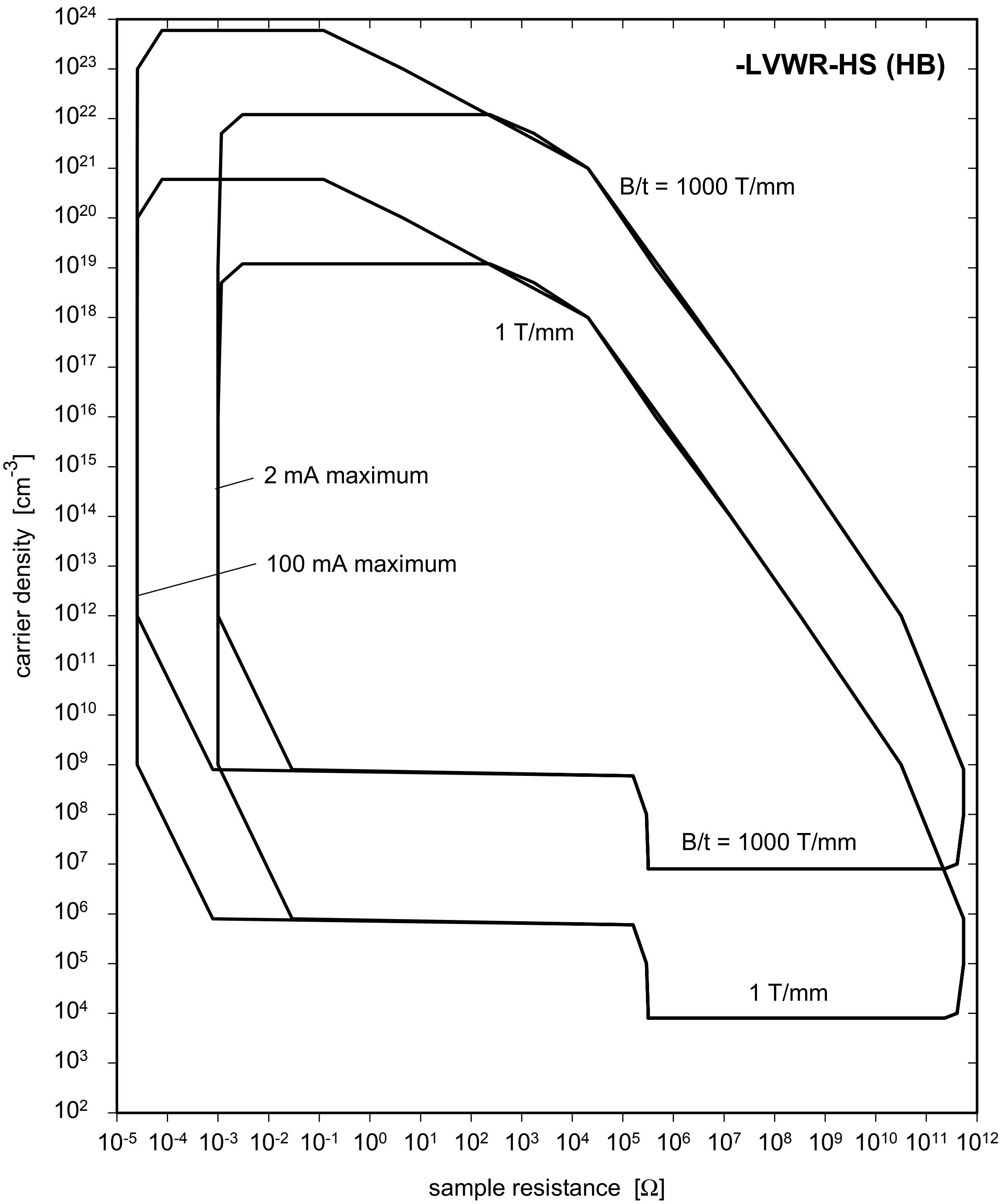


Figure 1-20. Range within which mobility is measured to within an uncertainty of 5% using the -LVWR-HS measurement configuration with metered or unmetered current (2 or 100 mA maximum, respectively) and Hall bar structures. Manual recabling is required to switch between these conditions. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 8 V, indicated maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, 25 Ω resistance down each lead wire, assumed sample resistivity measurement voltage efficiencies (V_out/V_in) of 0.5 for Hall bar structures, zero Hall offset voltage, Hall factor of 1 and magnetic flux density (B) and sample thickness (t) uncertainties of 1% each. Note that the maximum carrier density is roughly proportional to the ratio B/t, so large magnetic flux density and thin samples can improve the measurement range.

1.5.7 -LVWR-SWT: Low Voltage, Wide Resistance Range, Fully Automated Switching Measurement Configuration

See section 3.4.7 for wiring instructions. Requires the following minimum Hall effect measurement system: –LVWR-SWT — Low Voltage, Wide Resistance Range HMS + Fully Automated Switching option.

Instrumentation summary:

Keithley 7001 Switch System Mainframe
Keithley 7065 Hall effect matrix switch card with buffer amplifiers (±8 V maximum),
(High resistance mode used for sample resistances > 100,000 ohms)
Keithley 7152 4×5 matrix switch card
Keithley 2000 Voltmeter
Keithley 220 Current Source
Keithley 485, 486 or 487 Picoammeter
Automated switching between Current Meter and Short

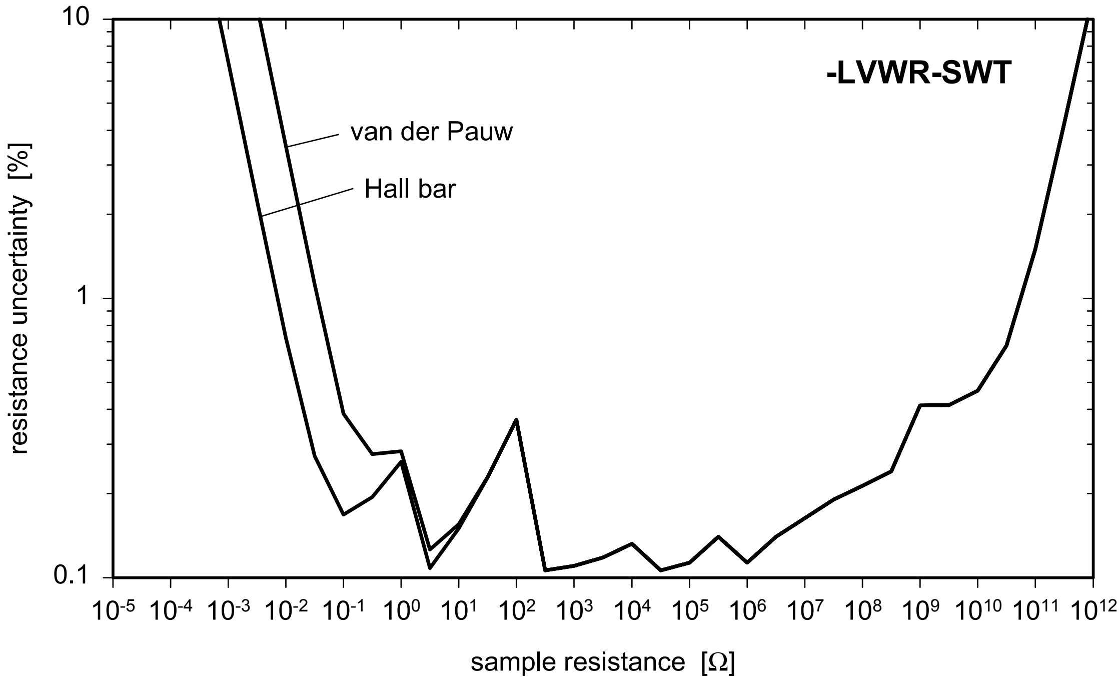


Figure 1-21. Resistance measurement uncertainty using the -LVWR-SWT measurement configuration. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 8 V, 100 mA maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, and 25 Ω resistance down each lead wire.

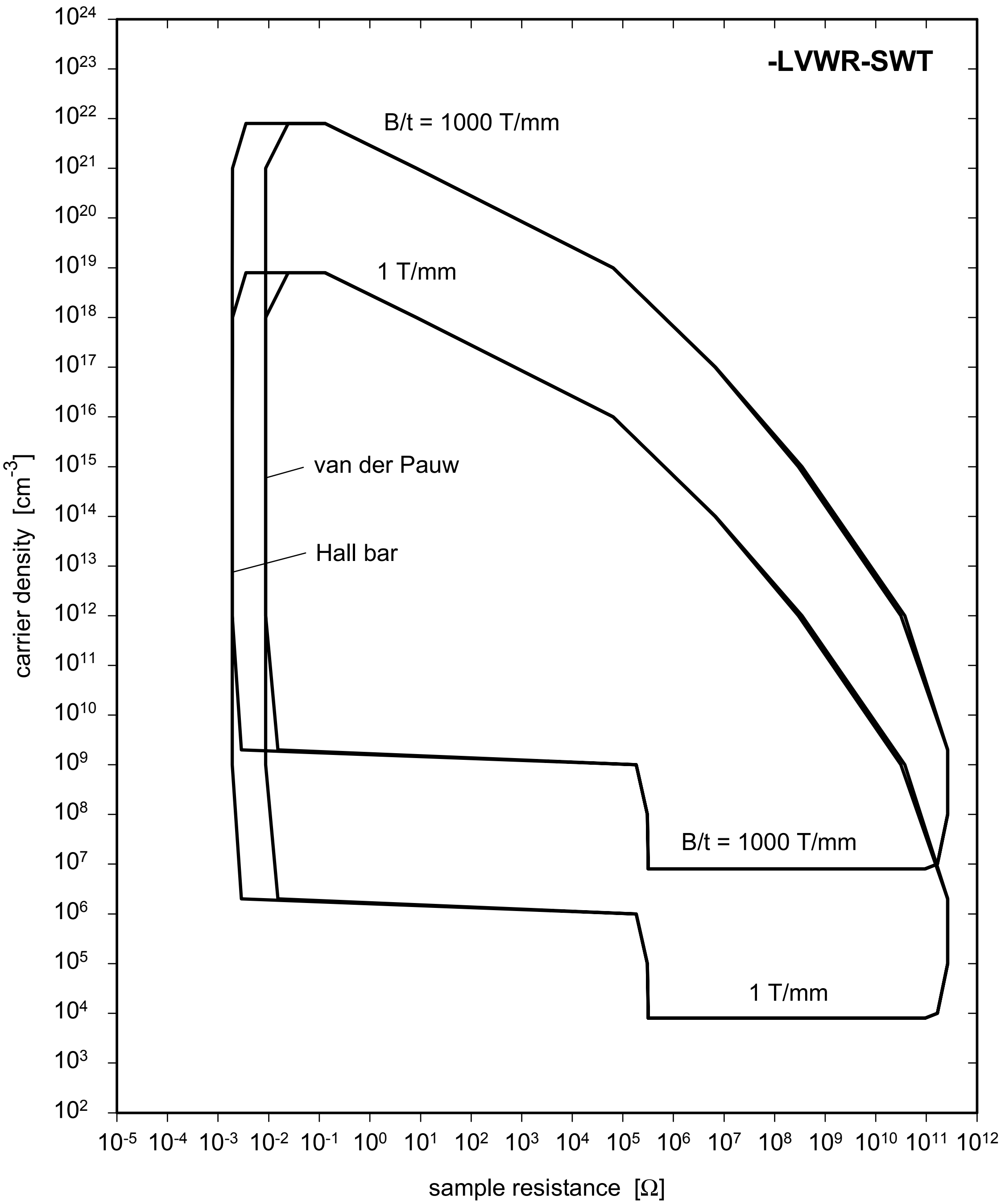


Figure 1-22. Range within which mobility is measured to within an uncertainty of 5% using the -LVWR-SWT measurement configuration. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 8 V, 100 mA maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, 25 Ω resistance down each lead wire, assumed sample resistivity measurement voltage efficiencies (V_out/V_in) of 0.1 for van der Pauw or 0.5 for Hall bar structures, zero Hall offset voltage, Hall factor of 1 and magnetic flux density (B) and sample thickness (t) uncertainties of 1% each. Note that the maximum carrier density is roughly proportional to the ratio B/t, so large magnetic flux density and thin samples can improve the measurement range.

1.5.8 -LVWR-HS-SWT: Low Voltage, Wide Resistance Range, High Sensitivity, Fully Automated Switching Measurement Configuration

See section 3.4.8 for wiring instructions. Requires the following minimum Hall effect measurement system: –LVWR-HS-SWT — Low Voltage, Wide Resistance Range HMS + High Sensitivity + Fully Automated Switching options.

Instrumentation summary:

Keithley 7001 Switch System Mainframe
Keithley 7065 Hall effect matrix switch card with buffer amplifiers (±8 V maximum),
(High resistance mode used for sample resistances > 100,000 ohms)
Keithley 7152 4x5 matrix switch card
Keithley 182 or 2182 Nanovoltmeter (High Sensitivity option)
Keithley 220 Current Source
Keithley 485, 486 or 487 Picoammeter
Automated switching between Current Meter and Short

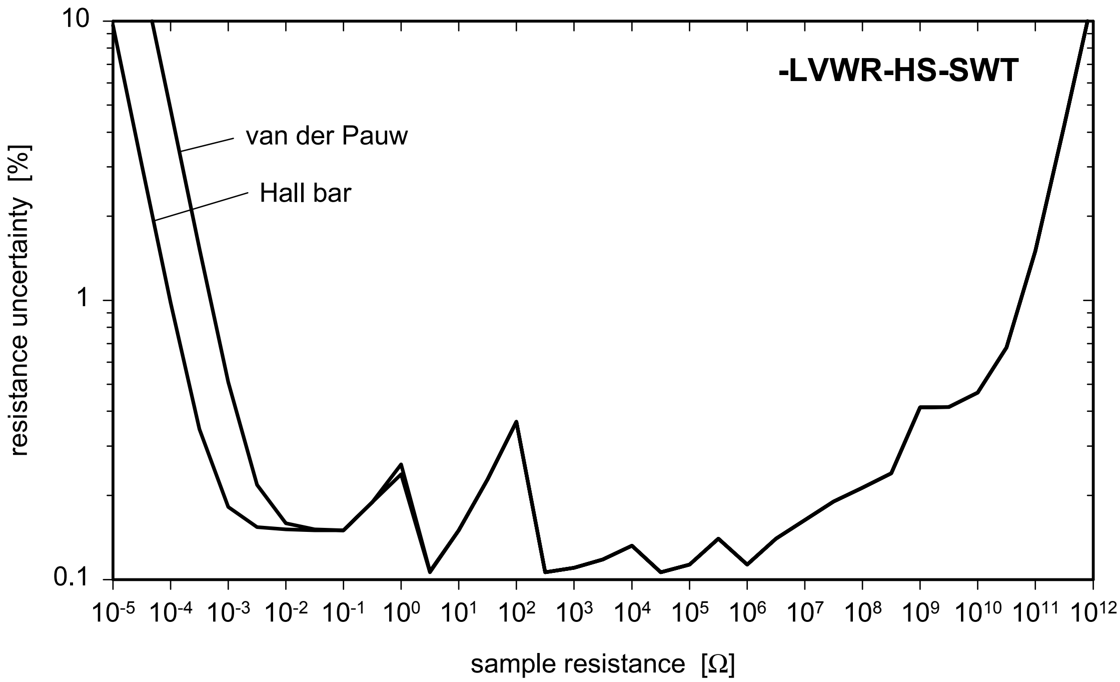


Figure 1-23. Resistance measurement uncertainty using the -LVWR-HS-SWT measurement configuration. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 8 V, 100 mA maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, and 25 Ω resistance down each lead wire.

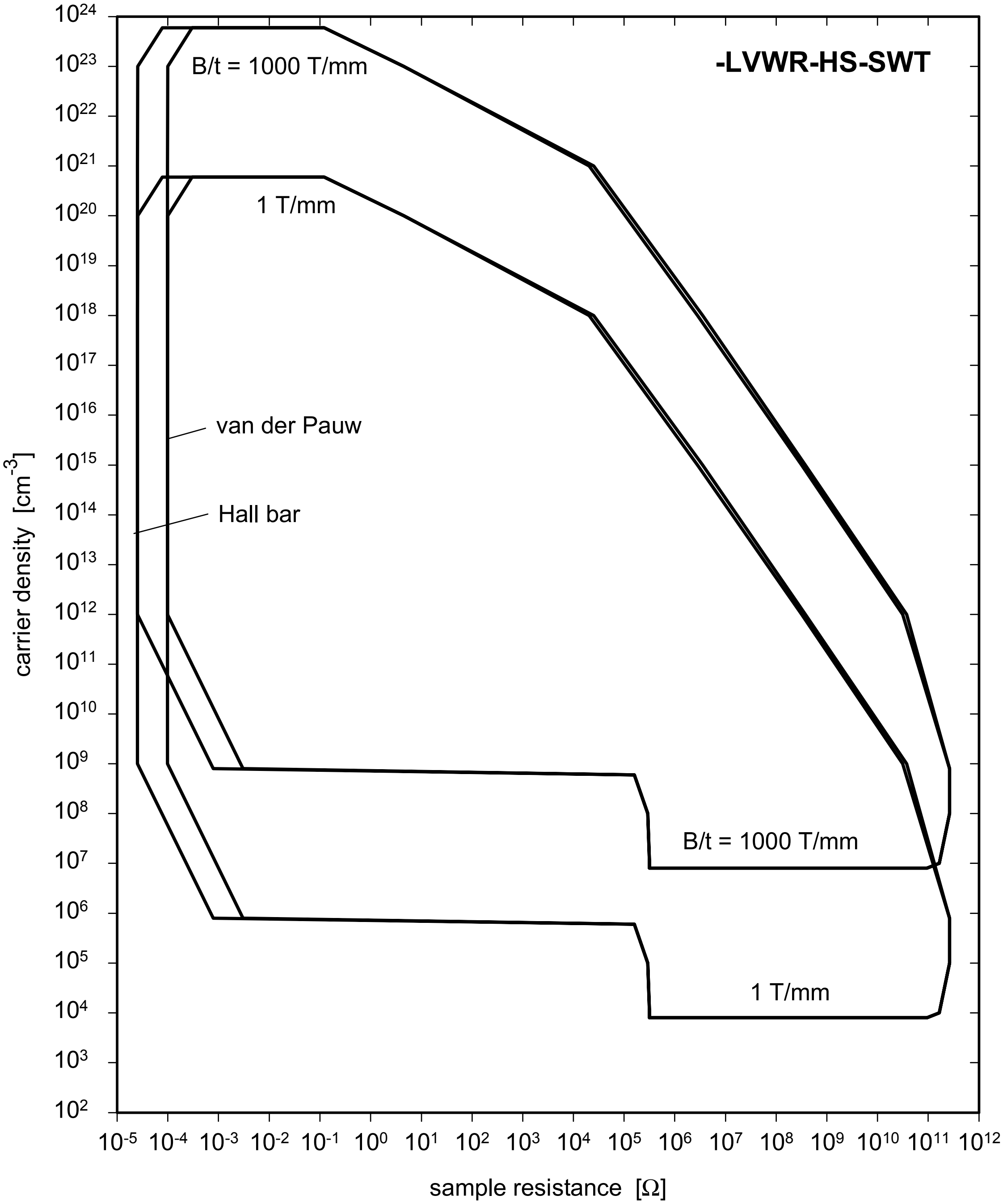


Figure 1-24. Range within which mobility is measured to within an uncertainty of 5% using the -LVWR-HS-SWT measurement configuration. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 8 V, 100 mA maximum current, 295 K sample temperature, no current leakage to sample holder, high resistance mode used for sample resistances > 100,000 Ω, 25 Ω resistance down each lead wire, assumed sample resistivity measurement voltage efficiencies (V_out/V_in) of 0.1 for van der Pauw or 0.5 for Hall bar structures, zero Hall offset voltage, Hall factor of 1 and magnetic flux density (B) and sample thickness (t) uncertainties of 1% each. Note that the maximum carrier density is roughly proportional to the ratio B/t, so large magnetic flux density and thin samples can improve the measurement range.

1.5.9 -HVLR: High Voltage, Low Resistance Range Measurement Configuration

See section 3.4.9 for wiring instructions. Requires the following minimum Hall effect measurement system: –HVLR — High Voltage, Low Resistance Range HMS.

Instrumentation summary:

Keithley 7001 Switch System Mainframe
Keithley 7012-S 4×10 matrix switch card
Keithley 2000 Voltmeter
Keithley 2400 Current Source

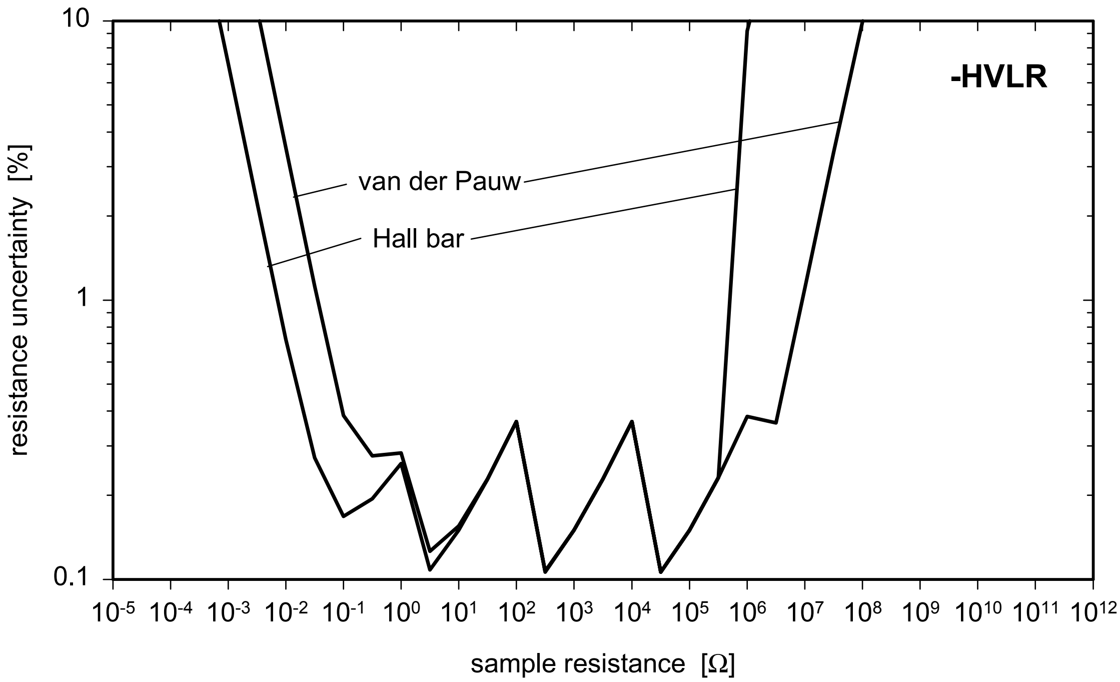


Figure 1-25. Resistance measurement uncertainty using the -HVLR measurement configuration. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 100 V, 100 mA maximum current, 295 K sample temperature, no current leakage to sample holder, and 25 Ω resistance down each lead wire.

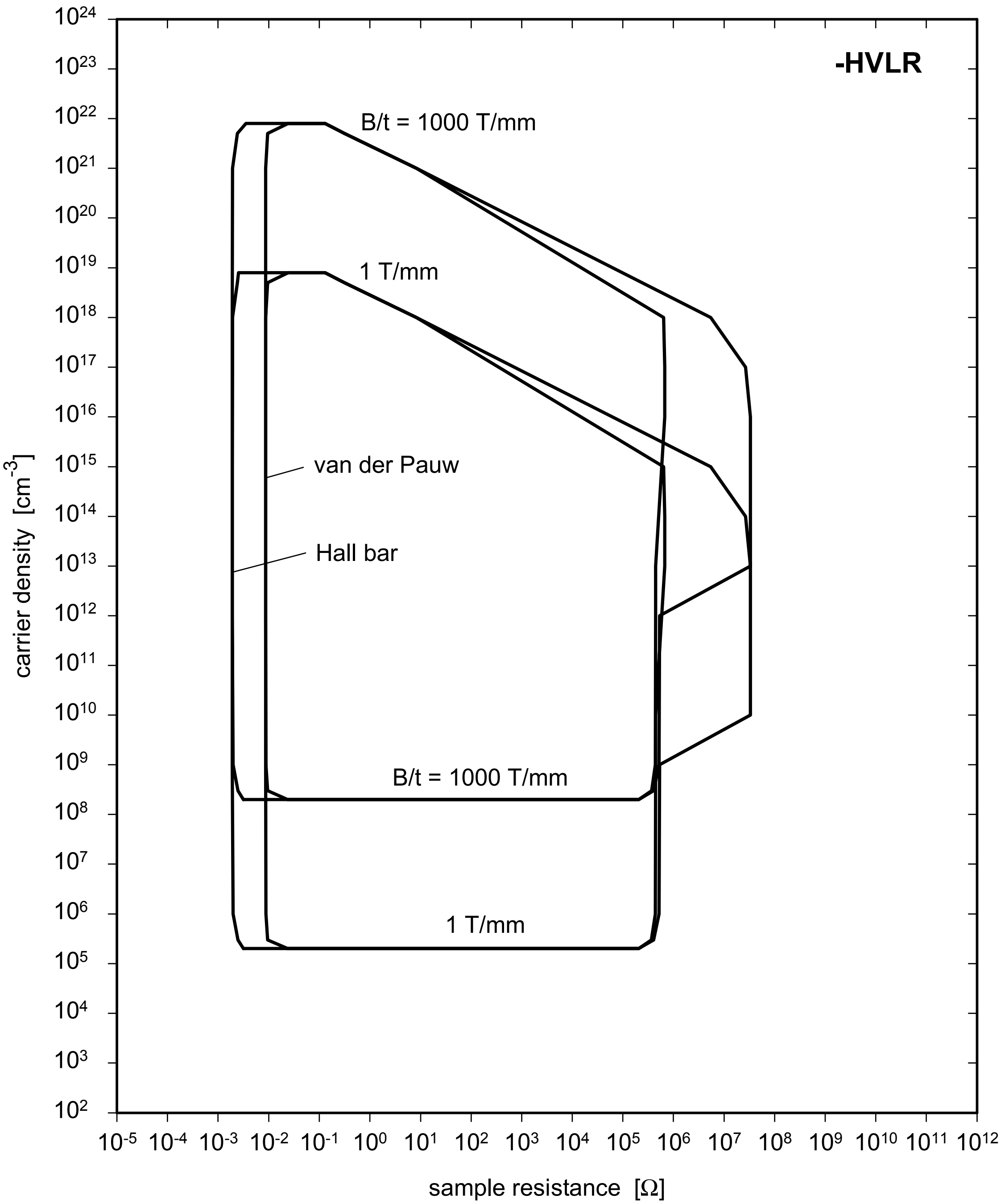


Figure 1-26. Range within which mobility is measured to within an uncertainty of 5% using the -HVLR measurement configuration. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 100 V, 100 mA maximum current, 295 K sample temperature, no current leakage to sample holder, 25 Ω resistance down each lead wire, assumed sample resistivity measurement voltage efficiencies (V_out/V_in) of 0.1 for van der Pauw or 0.5 for Hall bar structures, zero Hall offset voltage, Hall factor of 1 and magnetic flux density (B) and sample thickness (t) uncertainties of 1% each. Note that the maximum carrier density is roughly proportional to the ratio B/t, so large magnetic flux density and thin samples can improve the measurement range.

1.5.10 -HVLR-HS: High Voltage, Low Resistance Range, High Sensitivity Measurement Configuration

See section 3.4.10 for wiring instructions. Requires the following minimum Hall effect measurement system:
–HVLR-HS — High Voltage, Low Resistance Range HMS + High Sensistivity option.

Instrumentation summary:

Keithley 7001 Switch System Mainframe
Keithley 7012-S 4×10 matrix switch card
Keithley 2182 Nanovoltmeter
Keithley 220 Current Source

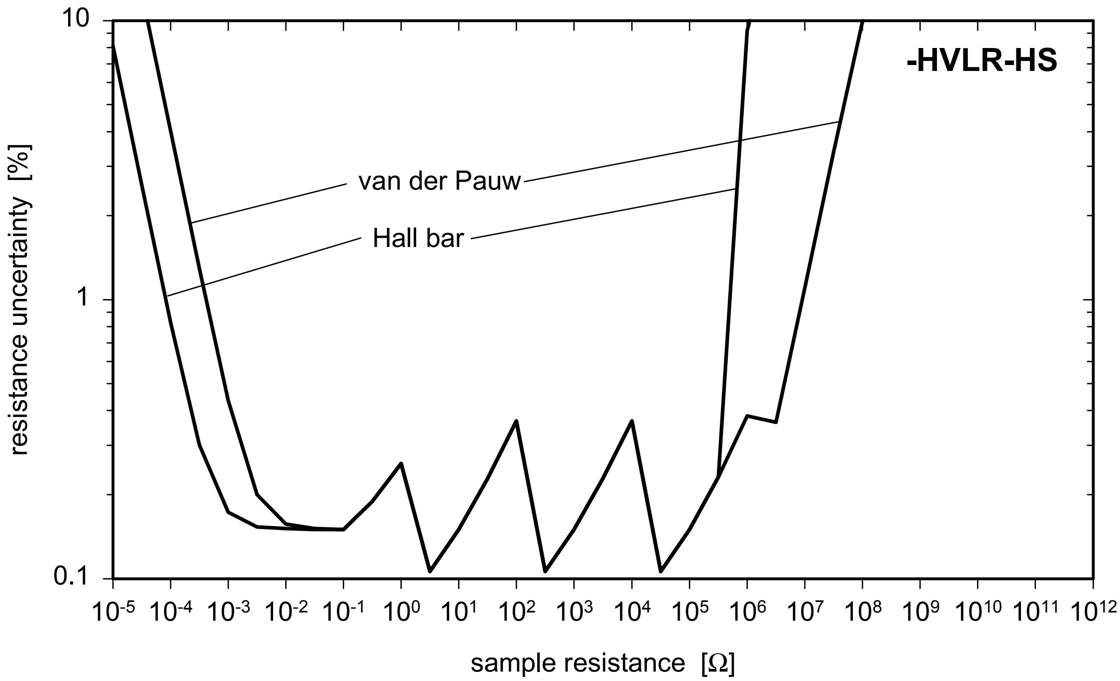


Figure 1-27. Resistance measurement uncertainty using the -HVLR-HS measurement configuration. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 100 V, 100 mA maximum current, 295 K sample temperature, no current leakage to sample holder, and 25 Ω resistance down each lead wire.

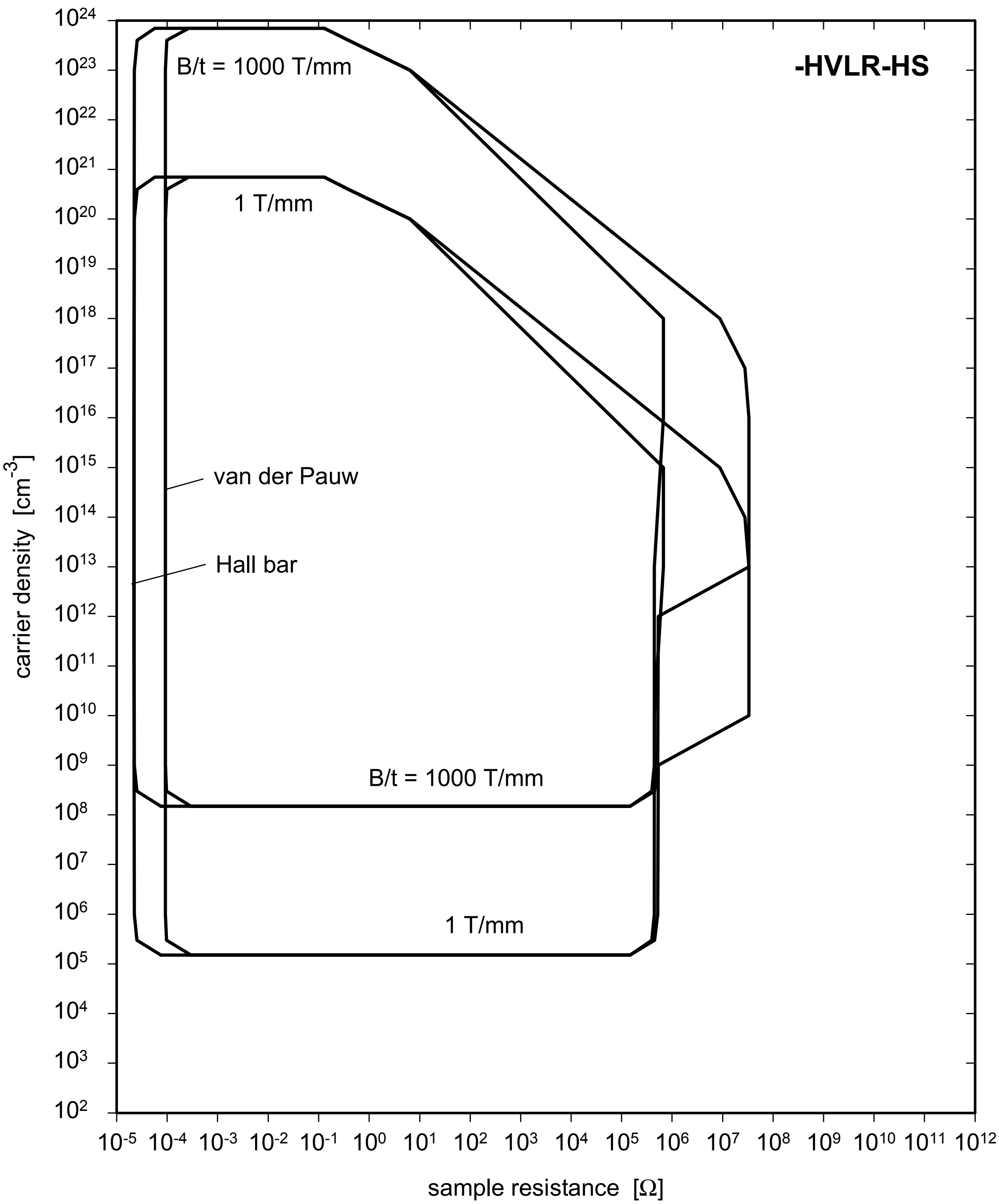


Figure 1-28. Range within which mobility is measured to within an uncertainty of 5% using the -HVLR-HS measurement configuration. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 100 V, 100 mA maximum current, 295 K sample temperature, no current leakage to sample holder, 25 Ω resistance down each lead wire, assumed sample resistivity measurement voltage efficiencies (V_out/V_in) of 0.1 for van der Pauw or 0.5 for Hall bar structures, zero Hall offset voltage, Hall factor of 1 and magnetic flux density (B) and sample thickness (t) uncertainties of 1% each. Note that the maximum carrier density is roughly proportional to the ratio B/t, so large magnetic flux density and thin samples can improve the measurement range.

1.5.11 -LVLR: Low Voltage, Low Resistance Range Measurement Configuration

See section 3.4.11 for wiring instructions. Requires the following minimum Hall effect measurement system: –LVLR — Low Voltage, Low Resistance Range HMS.

Instrumentation summary:

Keithley 7001 Switch System Mainframe
Keithley 7012-S 4x10 matrix switch card
Lake Shore 340 Temperature Controller with resistance card

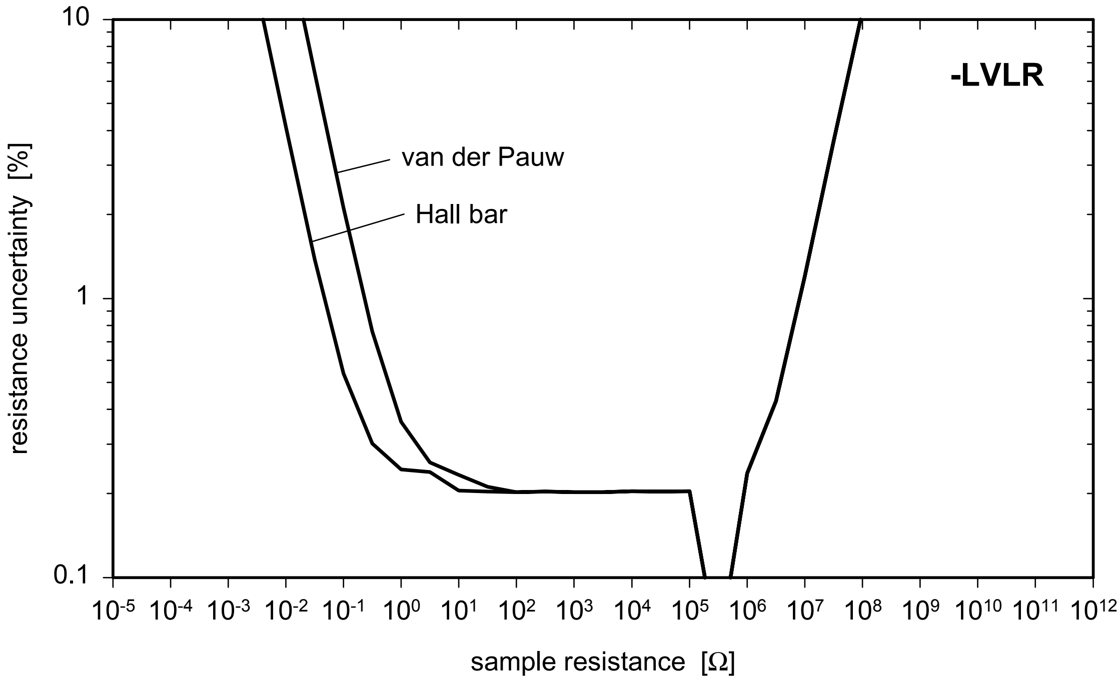


Figure 1-29. Resistance measurement uncertainty using the -LVLR measurement configuration. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 5 V, 1 mA maximum current, 295 K sample temperature, no current leakage to sample holder, and 25 Ω resistance down each lead wire.

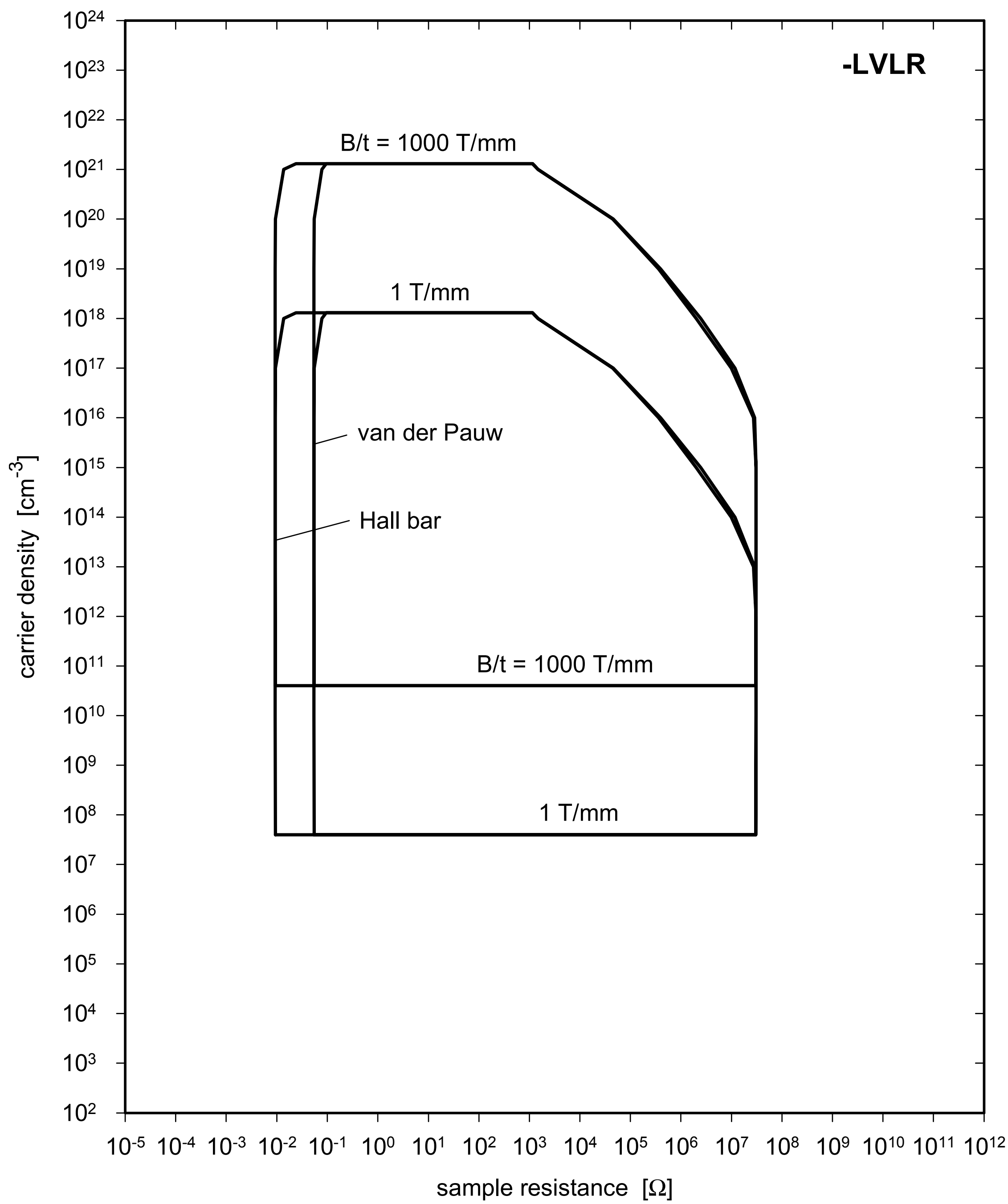


Figure 1-30. Range within which mobility is measured to within an uncertainty of 5% using the -LVLR measurement configuration. Modeled measurement conditions: maximum power dissipation in the sample of 1 mW, maximum excitation or sample output voltage of 5 V, 1 mA maximum current, 295 K sample temperature, no current leakage to sample holder, 25 Ω resistance down each lead wire, assumed sample resistivity measurement voltage efficiencies (V_out/V_in) of 0.1 for van der Pauw or 0.5 for Hall bar structures, zero Hall offset voltage, Hall factor of 1 and magnetic flux density (B) and sample thickness (t) uncertainties of 1% each. Note that the maximum carrier density is roughly proportional to the ratio B/t, so large magnetic flux density and thin samples can improve the measurement range.

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2. PRE-INSTALLATION

Contents:

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2.1 GENERAL

The customer is responsible for site preparation and installation of the 7500/9500 series Hall Measurement System (HMS). This chapter covers preparations to be completed *before* arrival of the system, as well as other safety and environmental considerations.

If the customer has paid for final installation and training, the system must be in its final location with all electrical and cooling water connections complete before arrival of the service engineer.

2.2 SITE REQUIREMENTS

Plan the site layout before the system arrives. Research physical location, environment, cryogenic storage and access, power, ventilation, safety, and local building, electrical, and safety codes. See **Figure 2-1.** and **Figure 2-2.** for physical dimensions of a suggested installation site. After initial screening, evaluate proposed sites according to space, location, power, and structural integrity.

1. **Space:** Adequate for system installation, operation, potential expansion, service, and storage of supplies. Space and layout requirements depend on the system selected. A ceiling height of 2.4 m (8 ft.) is sufficient to allow for operation of the system.
2. **Location:** Convenient for equipment and supply delivery, and handy to related work areas for efficient operation. Place the electromagnet in an area free from major vibration from motors, pumps, forklifts, etc.; it may interfere with measurements. Place the electromagnet as far away as possible from equipment sensitive to stray dc magnetic fields.

   For 9500 Cryogenic Systems only, place the magnet dewar as far away as possible (a minimum of 2 meters or 6 feet), from equipment containing large AC magnetic fields, including the magnet power supply; they can induce signals large enough to overload the magnetometer input amplifiers.
3. **Power:** Adequate for system requirements, potential expansion, and wiring for maximum efficiency and economy of operation.
4. **Structural Integrity:** Level floor strong enough to support anticipated loads and free from extraneous vibrations or magnetic fields. Vibrations transmitted to consoles may degrade system performance.

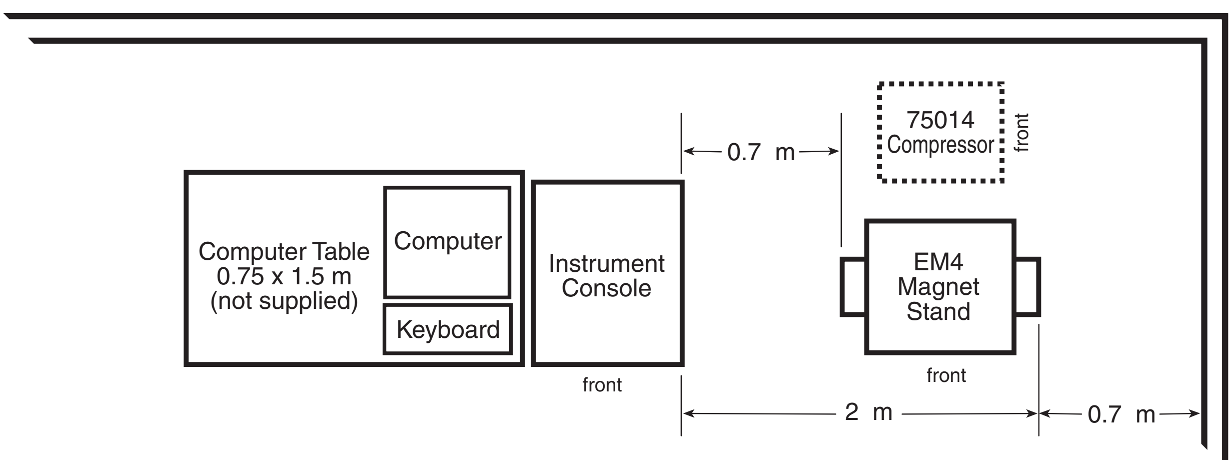


Figure 2-1. Typical Model 7504 HMS Floor Plan and Clearances

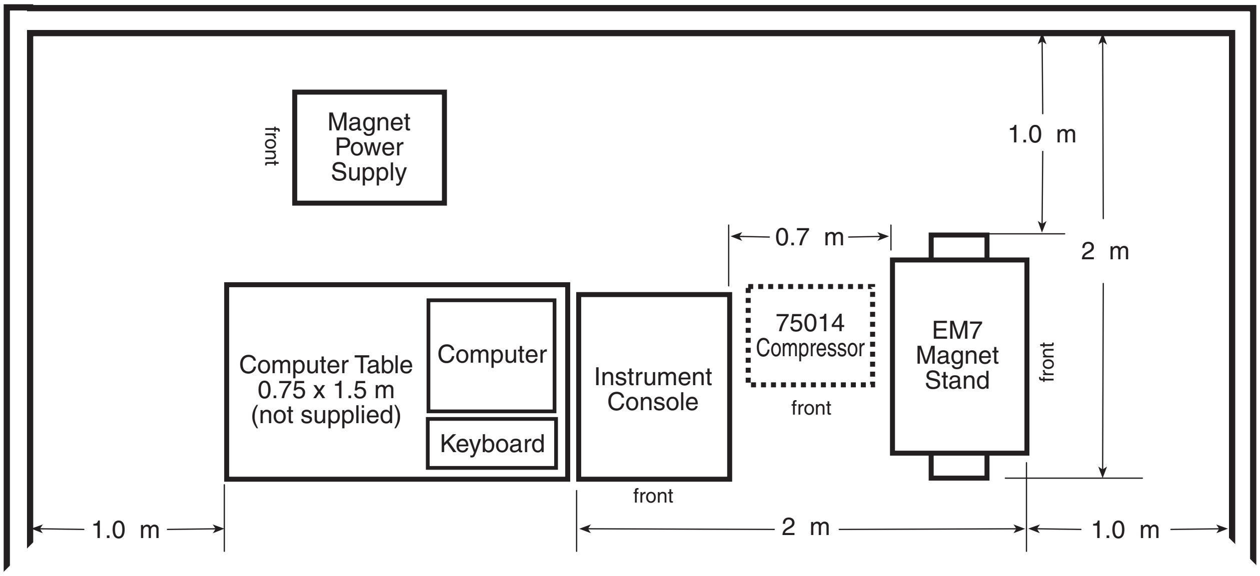


Figure 2-2. Typical Model 7507 HMS Floor Plan and Clearances

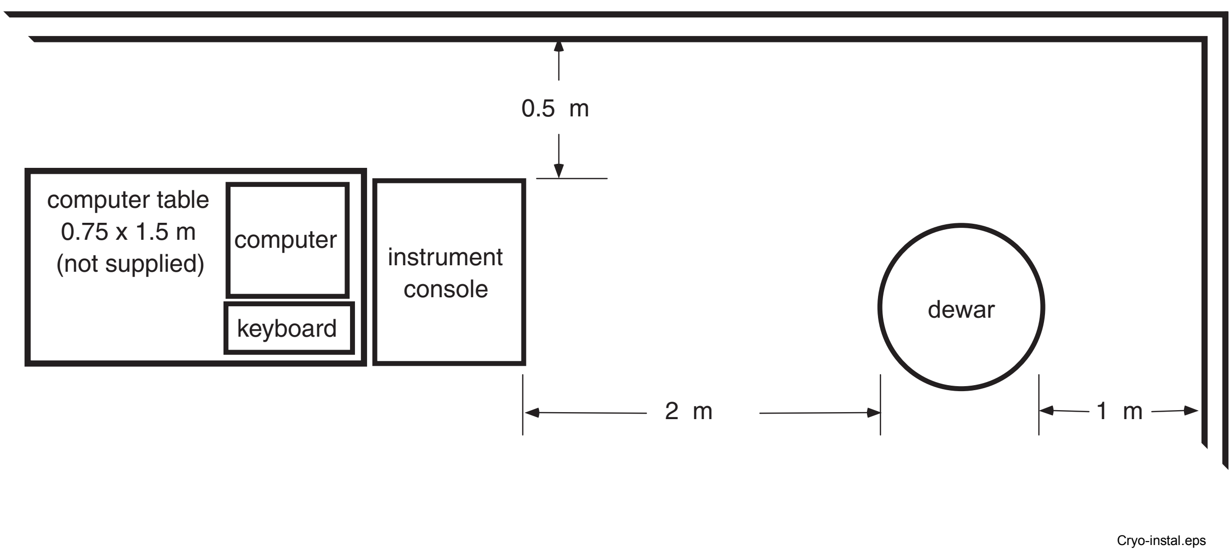


Figure 2-3. Typical 9500 Series Cryogenic HMS Floor Plan and Clearances

2.3 SYSTEM POWER AND GROUND REQUIREMENTS

The AC power source connected to the Model 7500/9500 System 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. In areas where AC voltage is variable, consider a constant voltage transformer. If power outages are a problem, consider an Uninterruptable Power Supply (UPS).

See Table 2-1 for a list of system electrical connections. Fill in the blanks in the table for the equipment for your system, noting that not all equipment is present in all systems. Magnet power supply information is given in section 1.2. The customer must provide an input power cable to the power supply. A plug is provided to mate with the socket on the back of the power supply.

The instrument console is designed for single-phase 3-wire AC power. The Power Strip in the Instrument Console has a three-conductor power input connector which grounds equipment in the Instrument Console when plugged into a 3-wire receptacle. Do not use two-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.

The computer and monitor can be placed on top of the instrument console. First place the instrument console top surface on top to provide more room for the keyboard and mouse. The power cords can be plugged inside the instrument console on models with spare internal outlets, or plugged into nearby wall outlets. Alternately, place the computer and monitor on an adjacent table or work surface within limits of the 3 m (10 ft.) IEEE-488 cable.

Table 2-1. Electrical Connection Requirements (Blanks must be filled in from other sources.)

	Power input	Power cable	Power plug
Magnet power supply		customer provided	
Instrument console	set for 120, 220, 230, or 240 VAC; 1 phase; 50 or 60 Hz; 4-2 A; 480 W maximum	3.8 m (12.5 ft.), rated to 15 A	3-prong U.S. standard male plug
Computer	set for 115 or 230 VAC; 60-50 Hz; 1 phase; 6-3 A; 690 W maximum	1.8 m (6 ft.)	3-prong U.S. standard male plug
Computer monitor	100-240 VAC; 1 phase; 60-50 Hz; 1.8-0.9 A; 180 W maximum	1.8 m (6 ft.)	3-prong U.S. standard male plug
75014 CCRSM compressor (optional)	set for a) 208-230, 60 Hz, or b) 220, 230, 240 VAC, 50 Hz; 1 phase; 15-12.5 A; 3 kW	3.8 m (12.5 ft.), rated to 30 A	NEMA L6-30P (2-pole, 3 wire, 30 A, 250 VAC) male plug
Recirculating chiller (optional)			
Vacuum pump (optional)			

Ground instrument panels and cabinets. The safety ground provides a true ground path for electrical circuitry and, in the event of internal electrical faults such as shorts, 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 instrument:

1. Shows visible damage.
2. Fails to perform the intended measurement.
3. Has been subjected to prolonged storage under unfavorable conditions.
4. Has been subjected to severe transport stresses.

Do not use such apparatus until qualified service personnel verifies its safety.

Electromagnetic interference (EMI) is both a natural and man-made phenomena which may, either directly or indirectly, degrade electronic system performance. Natural EMI includes thunderstorms, solar disturbances, cosmic rays, etc. Man-made EMI includes fixed and mobile transmitters, high voltage power lines, power tools and appliances, florescent lights, and other equipment containing motors, heaters, etcetera. Protect the AC source from EMI. Consider transient surge protectors for lightning protection.

2.4 COOLING WATER REQUIREMENTS

An electromagnet requires cooling water. One supply line and one return line for water must be supplied by the customer. Garden hose fittings are provided along with hose barb adapters for connection to 16 mm (5/8 inch) ID tubing. The electromagnet is provided with a flow switch that will prohibit operation of the power supply if the water flow rate falls below the specification in Table 2-1. A flow meter, not provided, is also useful.

The cooling water should be clean enough to avoid plugging cooling channels with sediment or deposits such as lime. Cooling with deionized water is not recommended as it can cause erosion of the copper windings. A recirculating system should be used in the following cases:

1. The tap water is not of sufficient purity,
2. The loss of cooling water down the drain is too expensive, or
3. Control of the electromagnet temperature is important.

Control of the coolant temperature can be important if the tap water is cold enough to cause water condensation on the surface of the electromagnet poles which are made of expensive and easily corroded soft iron. Lack of cooling water temperature control can also cause sample temperature drift when using the Model 75013 Sample Card Sample Module without the dewar or temperature control. Recirculating chillers are available from Lake Shore or other sources.

Some magnet power supplies are water cooled (CE marked models 665 and 668). Check the sales order to see if one is to be provided with your system. Cooling water requirements are given in section 1.2 and also summarized in **Table 2-3.**.

The optional 75014 CCR Sample Holder Module requires additional cooling water for the compressor. Check appropriate manuals to verify water requirements in **Table 2-4.** and follow any plumbing instructions. The plastic tubing is provided with Swagelok fittings for connection to the compressor. Any fittings required on the inlet or outlet ends must be provided by the customer.

Table 2-2. Electromagnet cooling water requirements for 7500 Series systems

	System Model (Electromagnet Model)		
	7504 HMS (EM4-HV)	**7507 HMS (EM7-HV)**	**7512 HMS (EM12-HF)**
Coil operating temperature, max.	60 °C (140 °F)	60 °C (140 °F)	80 °C (176 °F)
Water purity, min.	Tap water	Tap water	Tap water
Water inlet temperature, max.	32 °C (90 °F)	32 °C (90 °F)	27 °C (81 °F)
Water flow, min.	3.8 liters/min (1 gpm)	11.4 liters/min (3 gpm)	15-23 liters/min (4-6 gpm)
Water chiller cooling capacity	1.8 kW (6,142 BTU/hr)	5 kW (17,060 BTU/hr)	8.5 kW (29,000 BTU/hr)

Table 2-3. Power supply cooling water requirements for 7507 and 7512 HMS systems

NOTE: This does not apply to air-cooled power supplies.

	7507 HMS with water cooled 665 MPS	**7512 HMS with water cooled 668 MPS**
Water inlet temperature	+6 to +25 °C (43 to 77 °F)	
Water outlet temperature, max.	41 °C (105 °F)	
Water inlet pressure	300-600 kPa (45-90 psig)	
Water flow, min.	8 liters/min (2.1 gpm)	8 liters/min (2.1 gpm)
Pressure drop at minimum flow	85 kPa (12 psi)	
Water supply connections	Male F 1/4 for pipe with an internal diameter of 8 mm	
Water chiller cooling capacity	3 kW (10,000 BTU/hr)	3.6 kW (12,000 BTU/hr)

Table 2-4. Compressor cooling water requirements for Model 75014 CCRSM option

	Compressor for 75014 CCR Sample Module (optional)
Room ambient temperature	10 to 38 °C (50 to 100 °F).
Water inlet temperature	4 to 27 °C (40 to 80 °F)
Water outlet temperature, max.	41 °C (105 °F)
Water inlet pressure	240-700 kPa (35-100 psig)
Water flow, min.	2.7 liters/min (0.7 gpm)
Pressure drop at minimum flow	85 kPa (12 psi)
Water supply connections	Plastic tubing (3/8 inch OD x 40 ft. long) provided, Swagelok fittings
Water chiller cooling capacity	3.3 kW (11,000 BTU/hr)

2.5 OTHER SYSTEM REQUIREMENTS

The sample modules available with 7500/9500 series Hall systems may have additional requirements not provided with the measurement system. Check to make sure these are available when the system arrives.

Table 2-5. Other system requirements

75013 SCSM (standard)	Liquid nitrogen, see section 4.1 for quantities.
	Vacuum pump for occasional evacuation of the dewar to a pressure of 100 Pa (0.1 torr) or lower. Rarely required. See full discussion in Chapter 4. Optional valve operator also required for pumpout.
75014 CCRSM (optional)	Helium gas source (standard grade) with delivery pressure of 600-800 kPa (85-115 psig).
	Vacuum pump to evacuate the sample module to a pressure of 100 Pa (0.1 torr) or lower. Intermittant operation is possible. See full discussion in section 4.2. Vacuum hose 3 m (10 ft.) long is provided with KF-25 fittings (KF-16 on older units).
75016 OSM (optional)	Argon gas source (standard grade) with delivery pressure of 600-800 kPa (85-115 psig).
	Vacuum pump with a base pressure of 0.1 Pa (7×10^{-4} torr) or lower. Continuous, oil-free vacuum pumping is required during oven operation. See full discussion in section 4.3. Vacuum hose 1.8 m (6 ft.) long is provided with a KF-25 fitting for connection to the pump.
9500 FCSM (standard)	Electrical power outlet for vacuum pump: 120 or 230 VAC, as specified for system, 50/60 Hz, 375 W.
	Liquid helium transfer line with 9.5 mm (3/8 inch) OD fill tube 760 mm (30 in.) long; Lake Shore model 700TLF or equivalent.
	Liquid helium, see section 4.4 for quantities.

2.6 ENVIRONMENTAL REQUIREMENTS

To meet and maintain specifications, operate the system at an ambient temperature range of 18 to 28 °C (64.4 to 82.4 °F). Operate it within the range of 15 to 35 °C (59 to 95 °F) with less accuracy. The system is intended for laboratory use. Although no specific humidity or altitude specifications exist, relative humidity of 20% to 80% (no condensation) and altitudes from sea level to 2.4 km (8,000 feet) are generally acceptable.

Adequately ventilate the work area to prevent build up of potentially life-threatening concentrations of nitrogen gas (see Paragraph 2.2.1). Oxygen content monitor/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.

2.7 SAFETY

Train personnel in proper emergency measures such as electrical power shut off, fire department notification, fire extinguishing, and personnel and records evacuation. Here is a list of suggested personnel safety considerations:

- Ground Fault Interrupter (GFI) AC circuits.
- Cryogenic Safety Gloves, Apron, Goggles/Faceshield, and Apparel (Paragraph 2.2.1).
- Fire Extinguisher.
- Oxygen Concentration Monitor/Alarm (Paragraph 2.2.1).
- Magnetic Field Warning Signs.
- Fireproof Safe for Data, Original Software and Documentation Storage.
- Emergency Lighting

Locate in the immediate vicinity fire extinguisher(s) that extinguish all three classes of fires: A, B, and C. Class A is ordinary combustibles like wood, paper, rubber, many plastics, and other common materials that burn easily. Class B is flammable liquids like gasoline, oil, and grease. Class C is energized electrical equipment including wiring fuse boxes, circuit breakers, machinery, and appliances. Do not use chemical extinguishers even though they are less expensive and cover all classes of fires. They may damage electronic equipment. Use a Carbon Dioxide or Halon fire extinguisher.

During the planning stage, consult local experts, building authorities, and insurance underwriters on locating and installing sprinkler heads, fire and smoke sensing devices, and other fire extinguishing equipment.

Locate an oxygen concentration monitor and alarm in the system work area near the system. Locate another in the dewar storage area. LHe and LN_2 can rapidly replace the breathing atmosphere in an enclosed area with no warning. Oxygen concentration monitor and alarms are the best way to reduce this potential hazard.

An electromagnet can generate large magnetic fields. Post signs at each entrance to the work area that state: "Warning: High Field Magnets – Fringe fields may be hazardous to pacemakers and other medical devices. Keep magnetic materials clear of area." Paint a yellow magnetic field warning line on the floor 1 meter (3 feet) from the sides of the electromagnets.

Locate a fireproof safe at or near the work site for temporary storage of data and copies of original system software and documentation. Store duplicate copies of vital data well away from the system area, also in a fireproof storage vault or safe.

Even where not required by code, install some type of automatic, battery-operated emergency lighting in case of power failure or fire.

2.7.1 Handling Liquid Helium and Liquid Nitrogen

Helium and Nitrogen are colorless, odorless, and tasteless gases. When properly cooled, the gases liquify. Liquid Helium (LHe) and liquid nitrogen (LN_2) are used with the Model 7500/9500. Although not explosive, there are certain safety considerations in the handling of LHe and LN_2.

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 2-4 shows a typical cryogenic dewar.

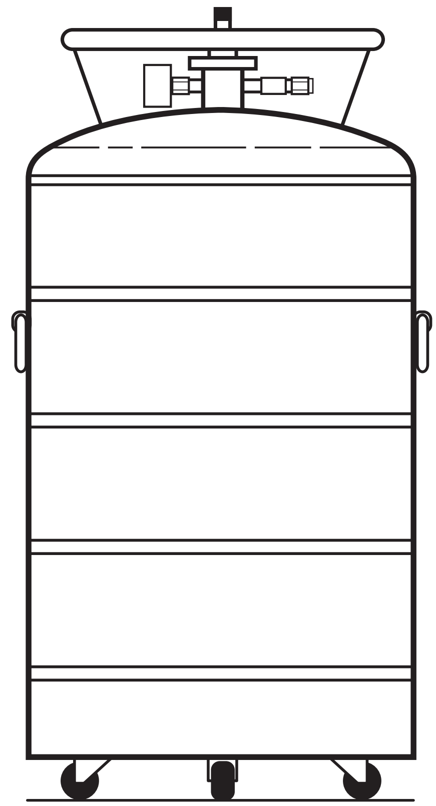


Figure 2-4. Cryogenic Storage Dewar

Transfer LHe and LN_2 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.

WARNING

- **Liquid helium and liquid nitrogen are potential asphyxiants and can cause rapid suffocation without warning. Store and use 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.

2.7.1.1 Recommended First Aid for LHe or LN2 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 minutes. 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.

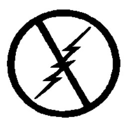
2.7.2 Electrostatic Discharge

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 (ESDS) 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 volts 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 ESDS 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 volts cannot be seen, felt, or heard.

2.7.2.1 Identification of Electrostatic Discharge Sensitive Components

Below are various industry symbols used to label components as ESDS:

2.7.2.2 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:

1. De-energize or disconnect all power and signal sources and loads used with unit.
2. Place unit on a grounded conductive work surface.
3. Ground technician through a conductive wrist strap (or other device) using 1 MΩ series resistor to protect operator.
4. 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.
5. Place ESDS 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.
6. Do not handle ESDS devices unnecessarily or remove from the packages until actually used or tested.

2.7.3 Instrument Safety

Observe these general safety precautions during all phases of instrument operation, service, and repair. Failure to comply with these precautions or with specific warnings elsewhere in this manual violates safety standards of design, manufacture, and intended instrument use. Lake Shore Cryotronics, Inc. assumes no liability for Customer failure to comply with these requirements.

Lake Shore instrumentation protects the operator and surrounding area from electric shock or burn, mechanical hazards, excessive temperature, and spread of fire from the instrument. Environmental conditions outside of the conditions below may pose a hazard to the operator and surrounding area.

- Temperature: 5° to 40° C.
- Maximum relative humidity: 80% for temperature up to 31° C decreasing linearly to 50% at 40° C.
- Power supply voltage fluctuations not to exceed ±10% of the nominal voltage.

Ground Instruments

To minimize shock hazard, connect instrument chassis and cabinet to an electrical ground. Most Lake Shore instruments come with a three-conductor AC power cable. Plug the power cable into an approved 3-contact electrical outlet or use a three-contact adapter with the grounding wire (green) firmly connected to an electrical ground (safety ground) at the power outlet. The power jack and mating plug of the power cable meet Underwriters Laboratories (UL) and International Electrotechnical Commission (IEC) safety standards.

Do Not Operate In An Explosive Atmosphere

Do not operate instruments in the presence of flammable gases or fumes. Operation of any electrical instrument in such an environment constitutes a definite safety hazard.

Keep Away From Live Circuits

Operating personnel must not remove instrument covers. Refer component replacement and internal adjustments to qualified maintenance personnel. Do not replace components with power cable connected. To avoid injuries, always disconnect power and discharge circuits before touching them.

Do Not Substitute Parts Or Modify Instrument

Do not install substitute parts or perform any unauthorized modification to instruments. Return the instruments to an authorized Lake Shore Cryotronics, Inc. representative for service and repair to ensure that safety features are maintained.

2.7.4 Safety Symbols

- Direct current (power line).
- Alternating current (power line).
- Alternating or direct current (power line).
- Three-phase alternating current (power line).
- Earth (ground) terminal.
- Protective conductor terminal.
- Frame or chassis terminal.
- On (supply).
- Off (supply).
- Equipment protected throughout by double insulation or reinforced insulation (equivalent to Class II of IEC 536 - see Annex H).
- Caution: High voltages; danger of electric shock. Background color: Yellow; Symbol and outline: Black.
- Caution or Warning - See instrument documentation. Background color: Yellow; Symbol and outline: Black.
- Fuse.

3. INSTALLATION

Contents:

3.1 GENERAL

The 7500 System was electrically and mechanically inspected and operationally tested prior to shipment. It should be free from mechanical damage upon receipt. This chapter covers installation and connection of the electromagnet, power supply, and instrument console. Chapter 4 covers sample module setup. Chapter 5 covers system operation. Study chapters 4 and 5 before attempting to run the system.

If the customer has paid for final installation and training, the system must be in its final location with all electrical and cooling water connections complete before arrival of the service engineer.

3.2 UNPACKING AND INSPECTING

Set pallets on level surface. Inspect shipping containers for external damage. Make all claims for damage (apparent or concealed) or partial loss of shipment in writing to Lake Shore within five (5) days from receipt of goods. If damage or loss is apparent, notify shipping agent immediately.

Carton Shockwatch® indicators aid in judging the condition of received goods (see **Figure 3-1.**). A Shockwatch® sticker is also on the pallet under the units. Please accept shipment even if Shockwatch® is red. Note it on the bill of lading and inspect for damage immediately.

Figure 3-1. Shockwatch Indicator

Cut off strapping, lift off lid, and locate the packing list included with the system. Use the packing list to check receipt of all components, cables, accessories, and manuals as the system is unpacked. Inspect for damage. Inventory all components supplied before discarding any shipping materials.

Remove the box from the top of the Instrument Console. Use four people to lift the Instrument Console from the pallet. Do not lift the console at the top; always lift from the bottom.

Note how the console was supported on the pallet for future reference. Foam blocks between the instruments support their weight during shipment; remove them, or simply leave them in place. To transport the unit, first insert the foam blocks.

The second pallet contains the electromagnet. For Model 7500 with 7 inch electromagnets, a third pallet contains the magnet power supply. Verify receipt of all manuals. If any manuals are missing, contact Lake Shore immediately. **Be sure to fill out and send instrument warranty cards.**

If there is instrument freight damage, file claims promptly with the carrier and insurance company, and advise Lake Shore Cryotronics of such filings. Advise Lake Shore immediately of missing parts. Lake Shore cannot be responsible for any missing parts unless notified within 60 days of shipment. The standard Lake Shore Cryotronics, Inc. Warranty appears on the A Page (immediately behind the title page) of this manual.

3.3 HARDWARE INSTALLATION

Place the electromagnet, system console, and computer in their planned locations. See **Figures 2-1** and **2-2** in Chapter 2 for suggested floorplans.

3.3.1 System Connection Overview

Components of the Model 7504, 7507, or 7512 systems connect schematically as shown in **Figure 3-1** or **Figure 3-2**. The differences between the systems are the electromagnet size (4, 7, or 12 inch diameter poles) and power supply location (in the instrument console or separate unit). A typical 9500 Series System is shown schematically in Figure 3-4.

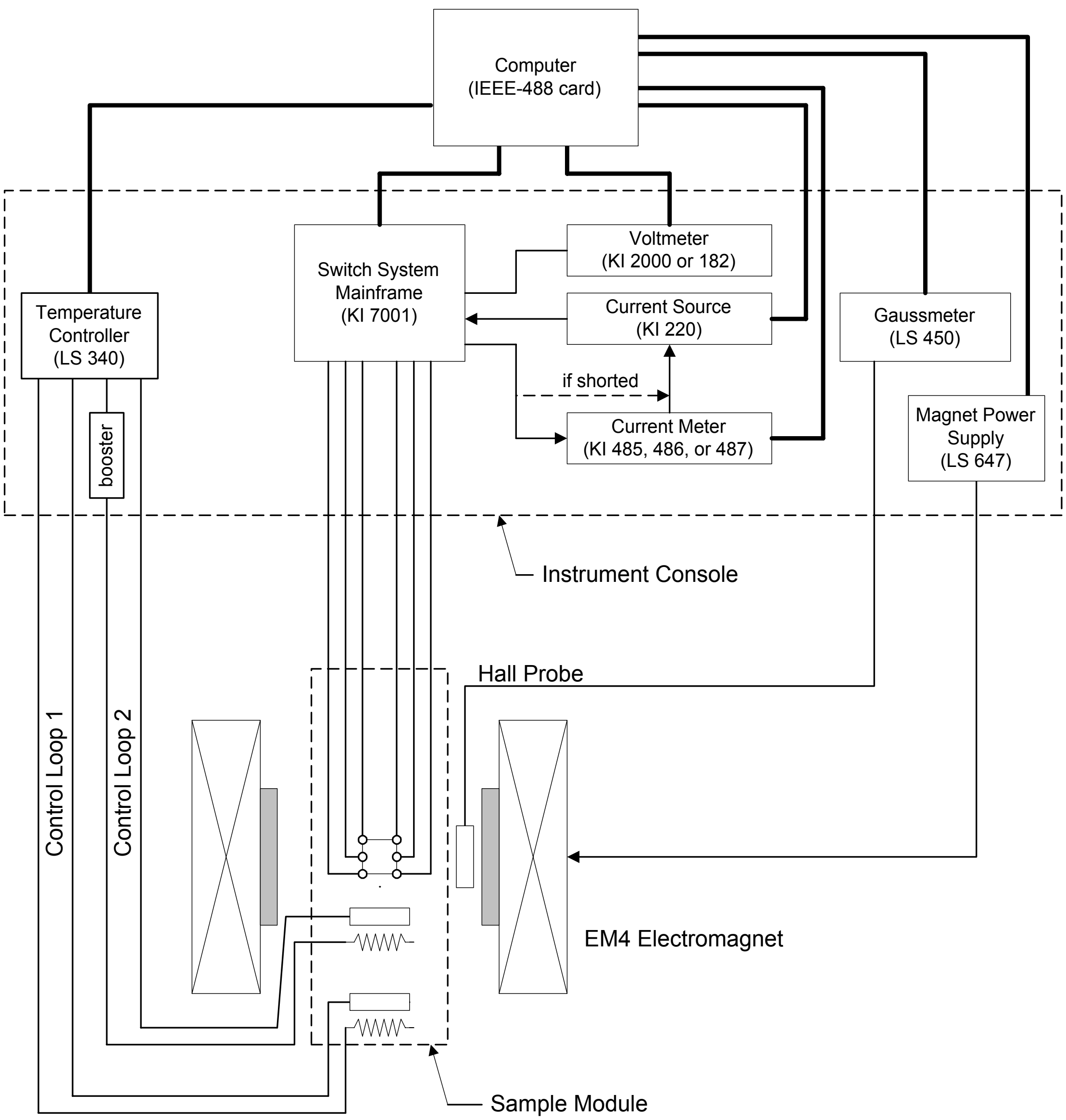


Figure 3-1 Model 7504 HMS Block Diagram. Some components such as the temperature controller are optional.

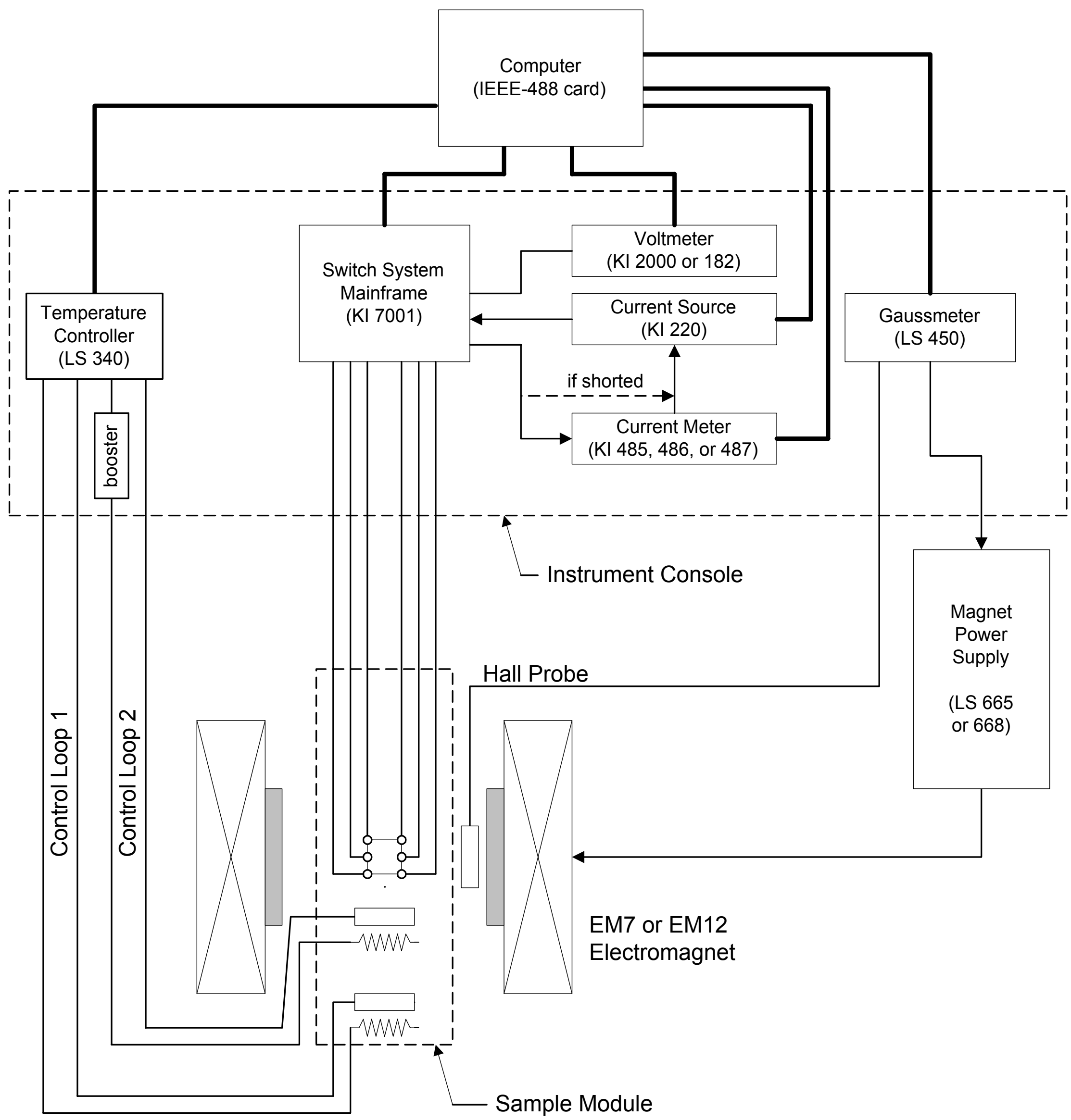


Figure 3-2 Model 7507 or 7512 HMS Block Diagram. Some components such as the temperature controller are optional.

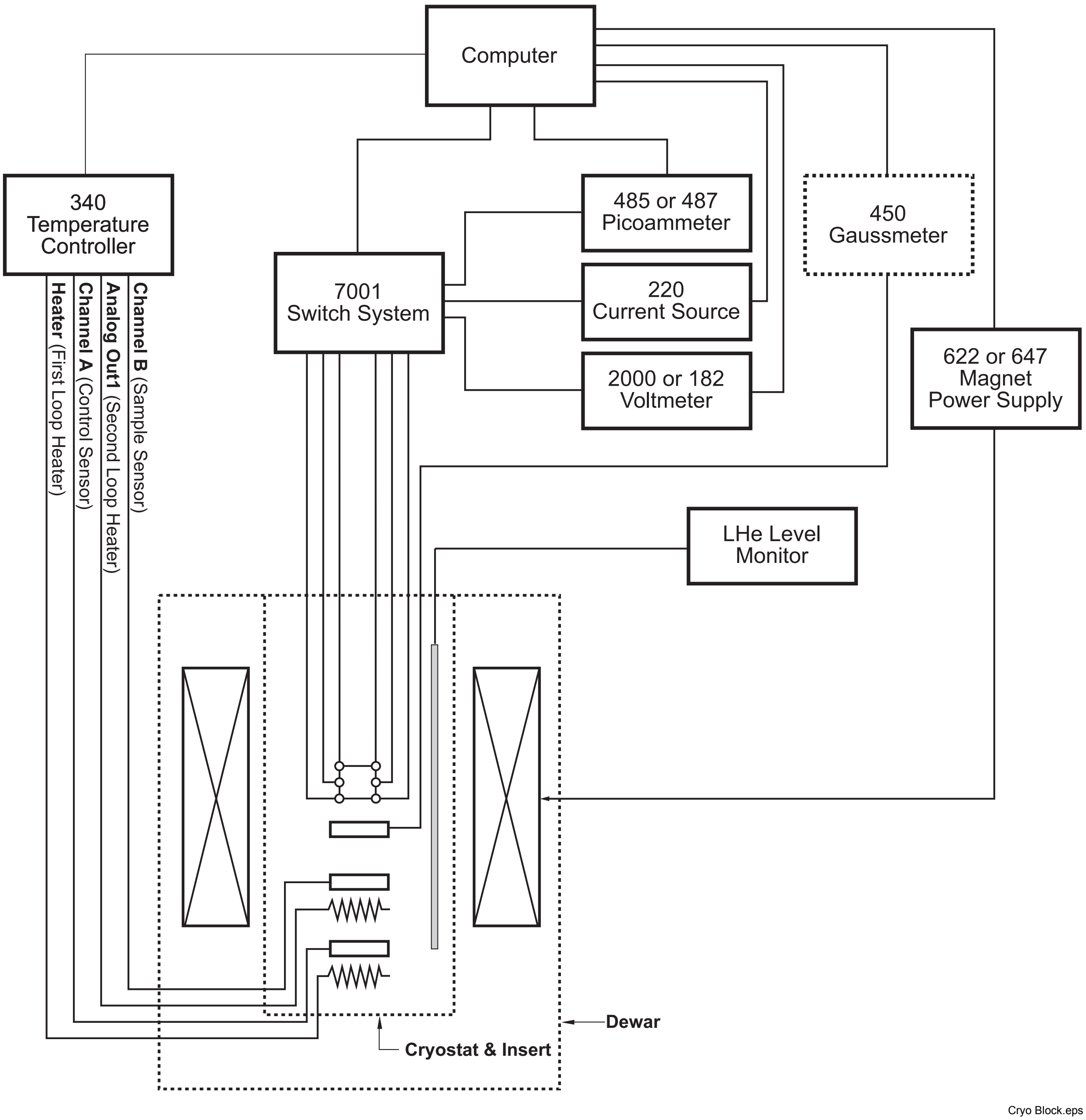


Figure 3-3. Typical 9500 Series System Block Diagram. Some components are optional.

3.3.2 Electromagnet Installation (7500 Series Only)

Model EM4, EM7 and EM12 electromagnets are used with Hall effect measurement systems. The models are designated by their 4, 7 and 12 inch diameter poles. Note that the pole diameter is measured before any necking down at the pole face. Determine the model of the electromagnet to be installed and follow the installation instructions in the appropriate section.

CAUTION: Treat the electromagnet pole caps carefully; they are easily damaged. See section 3.3 Pole Caps in the electromagnet manual. Deep dents or scratches on pole caps can impair magnetic field homogeneity. Wipe pole caps clean with a soft, clean, lint-free cloth lightly oiled with a high quality light oil. The iron in the pole caps is soft and rusts easily if not protected from moisture with a coat of oil.

3.3.2.1 Model EM4 Electromagnet Installation (7504, 4 inch poles)

See installation instructions in Chapter 2 of the User's Manual for EM4 Series & EM7 Electromagnets for clarification and additional information if any of the following instructions are unclear.

The Model EM4 electromagnet ships with a stand (see **Figure 3-5**). Move the stand with electromagnet attached to its final location. Electrical and coolant connections require rear access.

Verify bolted joints did not loosen during shipment. Adjust the screw feet to level the top of the stand.

The Model EM4 normally ships with one set of pole caps with 4 inch diameter pole faces. Pole caps necked down to smaller diameter pole faces can produce higher magnetic fields, but with smaller region of uniform field. If more than one set of pole caps was purchased, use the set with the largest diameter pole faces for initial operation. Leave pole caps backed out for sample module installation (Chapter 4).

3.3.2.2 Model EM7 Electromagnet Installation (7407, 7 inch poles)

Refer to the installation instructions in Chapter 2 of the User's Manual for EM4 Series & EM7 Electromagnets for clarification and additional information if any of the following instructions are unclear.

The Model EM7 electromagnet ships with a pedestal stand under the magnet frame (see **Figure 3-6**). Move the electromagnet assembly to its final location. Electrical and coolant connections require rear access.

Verify bolted joints did not loosen during shipment. The top saddle plate should be level and the entire electromagnet assembly should be solid. Bolt the pedestal stand to the floor.

The Model EM7 normally ships with two sets of pole caps with 3 and 6 inch diameter pole faces. Pole caps necked down to smaller diameter pole faces can produce higher magnetic fields, but with smaller region of uniform field. The EM7 electromagnet normally ships with the 3 inch pole face caps installed. Use these for initial operation unless the larger pole faces are required immediately. Instructions for changing the pole caps are given in the User's Manual for EM4 Series & EM7 Electromagnets. **WARNING: the pole caps are heavy and easily dented - handle with care!** Leave pole caps backed out for sample module installation (Chapter 4).

3.3.2.3 Model EM12 Electromagnet Installation (7512, 12 inch poles)

See installation instructions in the User's Manual for EM12 Series Electromagnets for clarification and additional information if any of the following instructions are unclear.

The Model EM7 electromagnet ships with a stand under the magnet frame (see User's Manual). Move the electromagnet assembly to its final location. Electrical and coolant connections require rear access.

Verify bolted joints did not loosen during shipment. The top saddle plate should be level and the entire electromagnet assembly should be solid. Bolt the magnet stand to the floor.

The Model EM12 normally ships with one or two sets of pole caps with customer specified pole face diameters. Pole caps necked down to smaller diameter pole faces can produce higher magnetic fields, but with smaller region of uniform field. The EM12 electromagnet normally ships with pole caps installed as specified by the customer. Use these for initial operation. Instructions for changing the pole caps are given in the User's Manual for EM12 Series Electromagnets. **WARNING: the pole caps are very heavy and easily dented - handle with care!**

3.3.3 Magnet Power Supply (MPS) Installation (7500 Series Only)

Different magnet power supplies power the Model EM4, EM7 and EM12 electromagnets. Follow installation instructions in the appropriate section.

3.3.3.1 Model 647 MPS Connections for Model EM4 Electromagnets (7504, 4 inch poles)

1. Connect water supply to magnet inlet hose. Connect flow switch to magnet outlet hose.

2. Connect water outlet to flow switch.

3. Bolt Terminal Cables to MPS output terminals. Black connects to negative, Red connects to positive. The other ends of the Terminal Cables connect to the electromagnet terminals.

4. Connect Flow Switch wires to Model 647 rear panel connectors #1 and #2. Red connects to #1 (+), Black connects to #2 (-).

WARNING: Do not operate the power supply without a Flow Switch connected or the electromagnet may be damaged due to insufficient water flow. The Model 647 operates even if wires to the flow switch are broken or removed from the rear connector - you must be careful that this does not occur!

5. Ground the electromagnet iron frame to the chasis of the power supply. The grounding wire should be at least 14 AWG (2 mm^2).

6. A plug to connect to the power cable should be plugged into the socket on the back of the MPS or with the instrumentation accessories. Connect a properly rated power cable to the plug and connect to the AC power source. See Chapter 2 or the Model 647 User's Manual for power cable specifications.

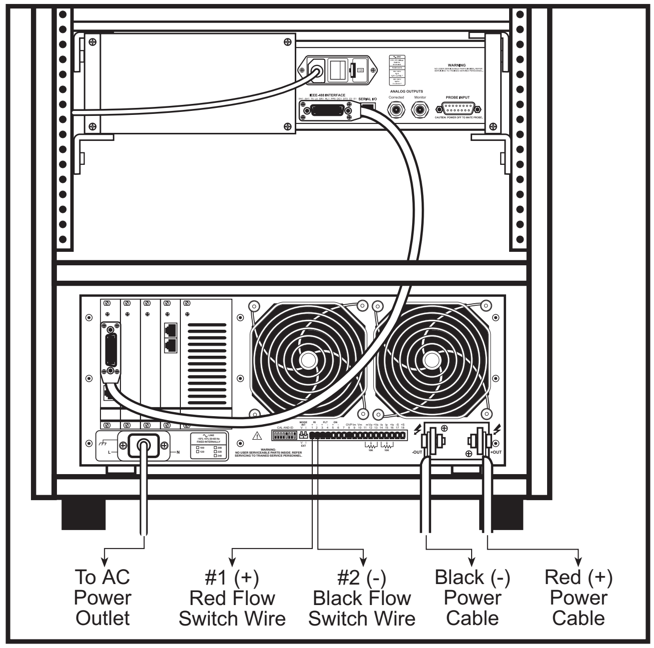


Figure 3-4 Model 647 Magnet Power Supply Connections.

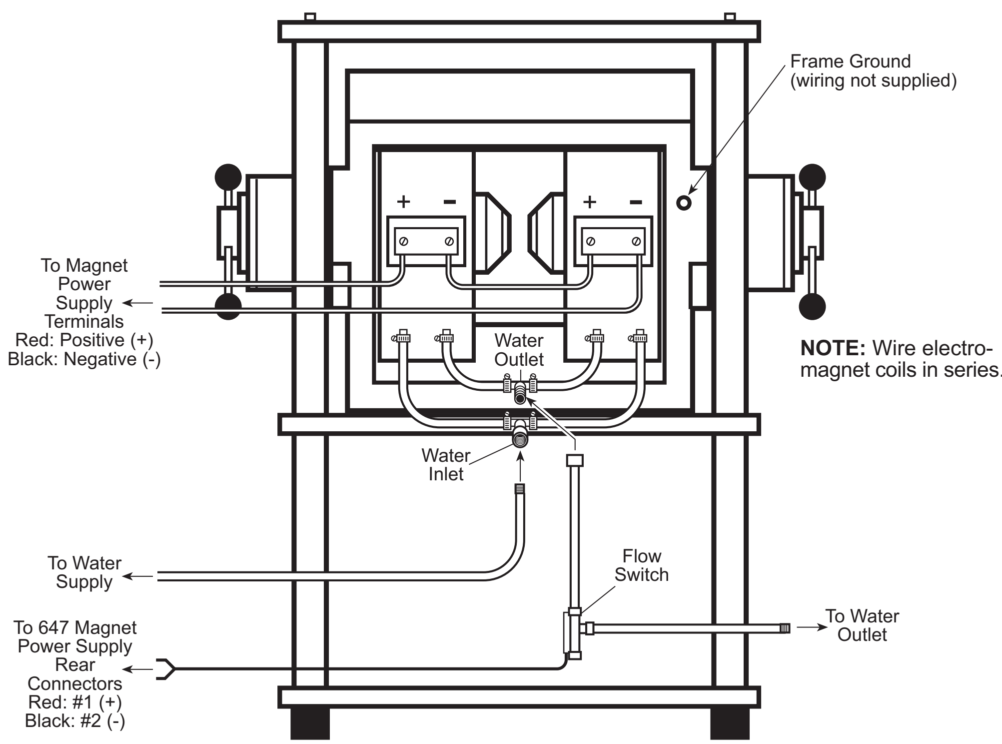


Figure 3-5 EM4 Electromagnet Power and Water Connections.

3.3.3.2 Model 665 or 668 MPS Connections for Model EM7 or EM12 Electromagnets (7507 or 7512)

See **Figure 3-6** while making the following connections.

1. Connect water supply to upper magnet inlet hoses.
2. Connect water outlet to Flow Switch.
3. Plug Flow Switch into Model 665/668 MPS rear panel port labeled **Remote Control/Status**. **NOTE:** The Power Supply will not function without a Flow Switch connected.
4. Connect power cables to Model 665/668 MPS power terminals. Red connects to Positive (+), Black connects to Negative (-).
5. Ground the electromagnet iron frame to the chasis of the power supply. The grounding wire should be at least 14 AWG (2 mm^2).
6. Locate the long coaxial cable with BNC connectors, typical length 3-6 meters (10-20 feet). It normally ships coiled inside the instrument console with one end connected to the **Corrected Analog Output** on the rear of the Model 450 Gaussmeter. The other end connects to the **Remote Reference** on the back of the 665/668 MPS.
7. A plug to connect to the power cable should be plugged into the socket on the back of the MPS or with the instrumentation accessories. Connect a properly rated power cable to the plug and connect to the AC power source. See Chapter 2 or the Model 647 User's Manual for power cable specifications.

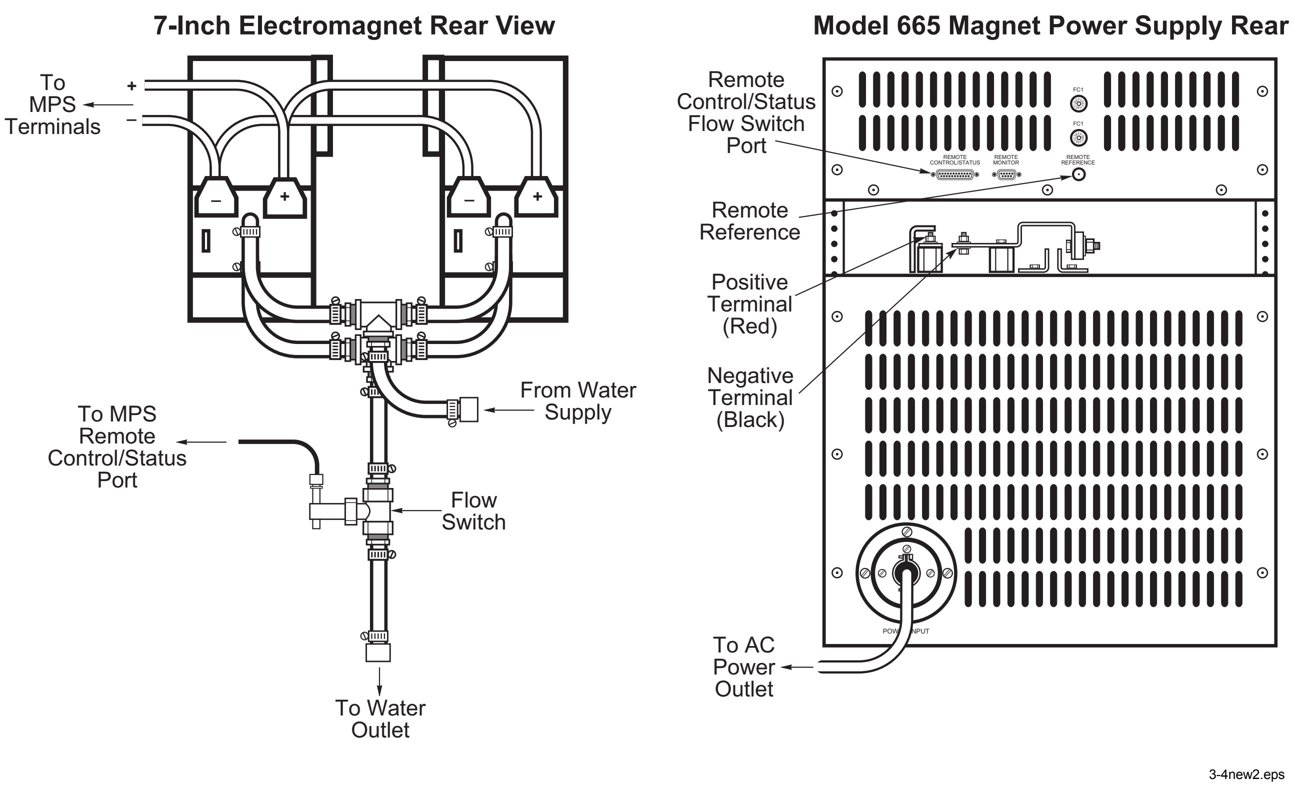


Figure 3-6 EM7 Electromagnet Power and Water Connections.

3.3.4 Model 241 Liquid Helium Level Monitor Connections (9500 Series Only)

1. Locate the cable with a 4-Pin connector on one end and a DB-9 connector on the other end. Plug the DB-9 connector into the Model 241 DB-9 port (Figure 3-8). Plug the 4-Pin connector into the 4-Pin output on the superconducting magnet dewar (see Figure 3-11).

2. Plug the power adapter cable into an AC outlet. Plug the other end into the Model 241 12 VDC power port (Figure 3-8).

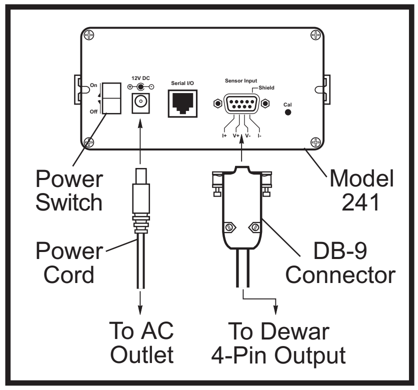


Figure 3-7. Model 241 Connections

3.3.5 Cryogenic Equipment Setup (9500 Series Only)

1. Remove the vacuum pump from its shipping box. If not already installed, clamp the Foreline Trap to the pump with a 25 mm clamp. Clamp the pump hose to the Foreline Trap with a 25 mm clamp. See Figure 3-9.

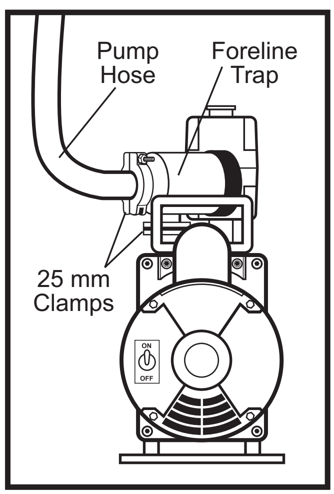


Figure 3-8. **Vacuum Pump Connections**

2. Remove the cryostat from its shipping crate and carefully lay it on its side, or place it in a probe stand (recommended). Clamp the pump Solenoid Valve Assembly to the cryostat Sample Space Access Pipe with a 16 mm clamp. See Figure 3-10.

3. Push the end of the Solenoid Valve Assembly Flush Hose onto the ribbed inlet of the Vent Manifold. See Figures 3-10 and 3-11.

4. Check the dewar O-Ring for cracks and proper seating. **Optional:** To pre-cool the dewar, pour 5 liters of liquid nitrogen into it. Liquid nitrogen is considerably less expensive than liquid helium.

5. Open the cryostat Vent Valve (Figure 3-10) and with two people, lift the cryostat and carefully slide it into the dewar. If pre-cooling, the liquid nitrogen will boil vigorously upon cryostat insertion. Tighten the eight cryostat flange bolts, complete Steps 6 thru 11, then tighten again.

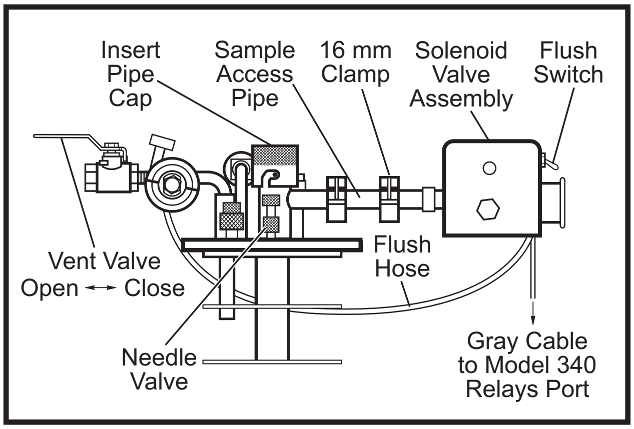


Figure 3-9. **Cryostat Connections**

6. Clamp pump hose to Solenoid Valve Assembly with 25 mm clamp (Figure 3-10). Plug in pump and turn it **On**.

7. If pre-cooling with liquid nitrogen, after the boil-off dies down, shut Vent Valve and open Needle Valve one full turn (Figure 3-10).

8. Connect the Magnet Power Supply Terminal Cables to the cryostat MPS terminals (Figure 3-11). Red = positive, Black = negative.

9. Push Flush Switch back to **FLUSH** (Figure 3-10).

10. Remove the Insert Pipe Cap (Figure 3-10) and slide the Hall Insert into the Insert Pipe. Align the Insert Cap Slot with the Insert Pipe Locking Nub and turn the Hall Insert clockwise to lock in place.

11. Push Flush Switch forward away from **FLUSH**.

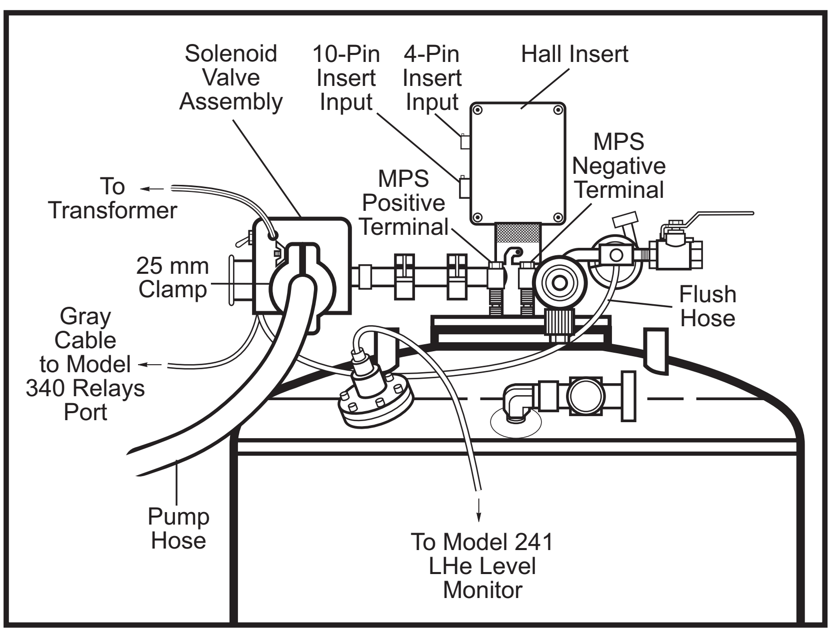


Figure 3-10. **Cryostat and Dewar Connections**

12. Plug cable from Model 340 Analog Out 2 port into 4-pin Hall Insert Input (Figure 3-11).

13. Plug Model 340 tri-cable into 10-pin Hall Insert input (Figure 3-11).

14. Plug male end of the Solenoid Valve Assembly Transformer Cord into the Solenoid Valve assembly (Figure 3-11). Plug other end into Transformer. Plug the Transformer 3-contact plug into a power strip.

15. Plug gray cable from Solenoid Valve Assembly into rear Model 340 Relays outputs (Figures 3-10 and 3-11).

16. Turn On Model 340. Turn On computer.

17. After the computer boots up, open the Model 340 IDEAS driver. The main screen appears. Under the **Utilities** menu bar option, select **Relay Setting**. Turn the Lo Relay **On**, then click **OK**. The Solenoid Valve Assembly clicks and the pump evacuates air from the sample space.

CAUTION: Evacuate the sample space as soon as possible to avoid water freezing in the sample space.

18. It takes several hours for the liquid nitrogen to boil off. The Model 340 monitors the temperature as it drops. Set the IDEAS 340 Chart Recorder to graph the temperature every 120 seconds; an increase in temperature indicates complete liquid nitrogen boil off; the dewar is ready for liquid helium transfer.

3.3.6 Instrument Console Installation

The instrument console is on casters and moves easily on flat surfaces. If a table top was provided, set it on top of the instrument console. Position instrument console for easy rear access until installation is complete.

3.3.6.1 Instrument Connection Point Identification

Figure 3-11 and **Figure 3-12** and **Table 3-1** identify connection points on all instruments in the instrument console. Refer to these when making connections during installation.

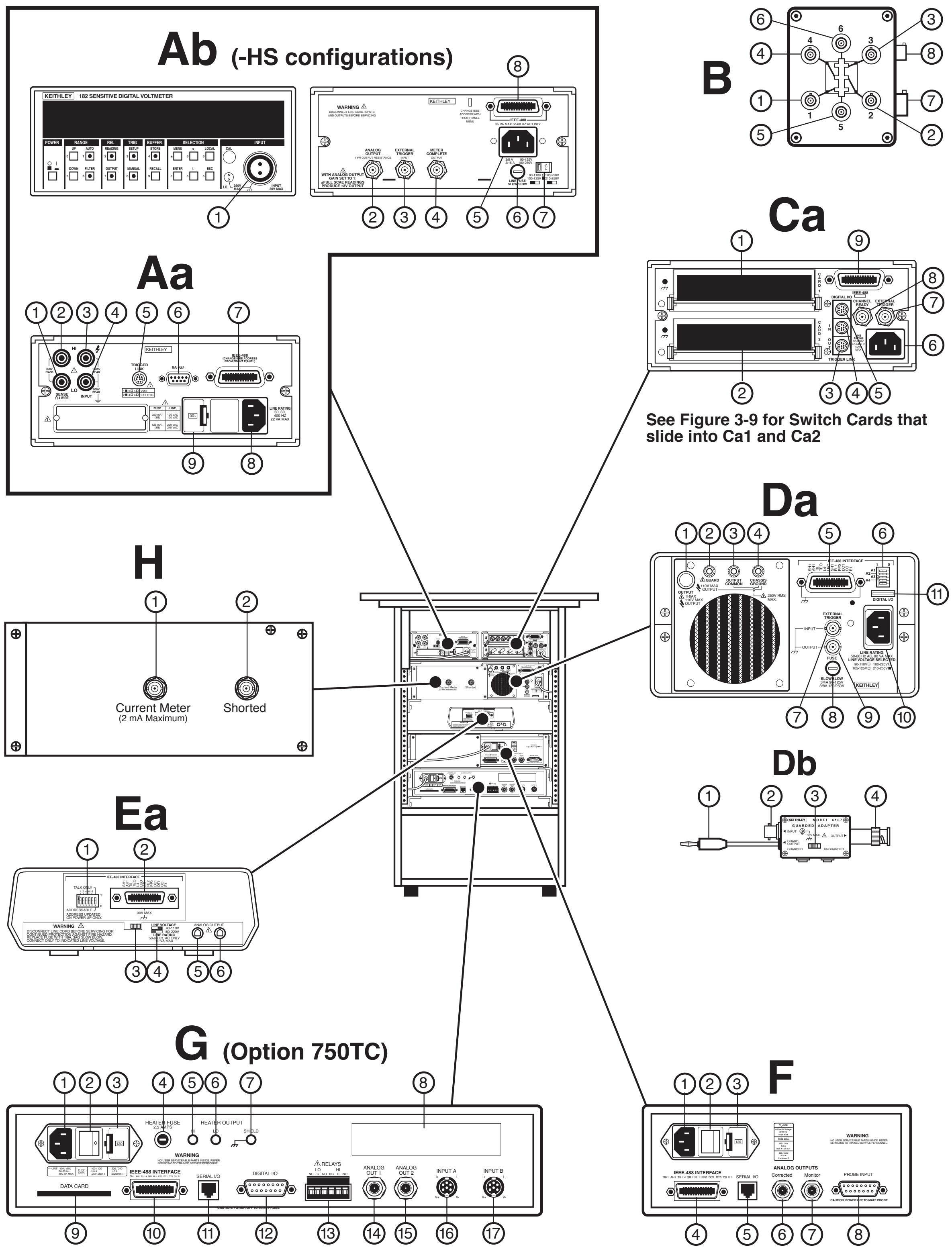


Figure 3-11 Instrumentation Console and connection points for all measurement configurations except -HVWR.

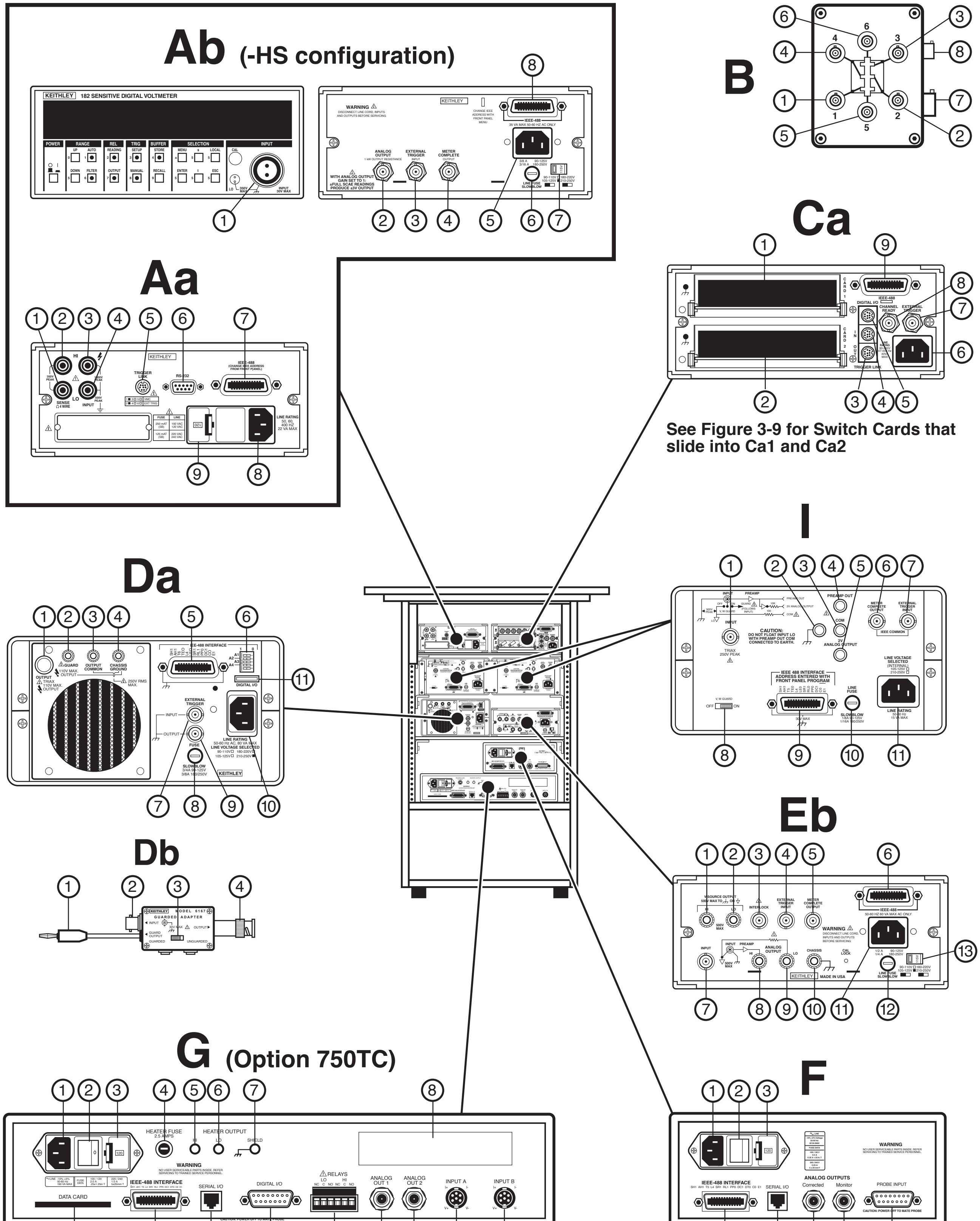


Figure 3-12 Instrumentation Console and connection points for -HVWR High Voltage, Wide Resistance range measurement configurations.

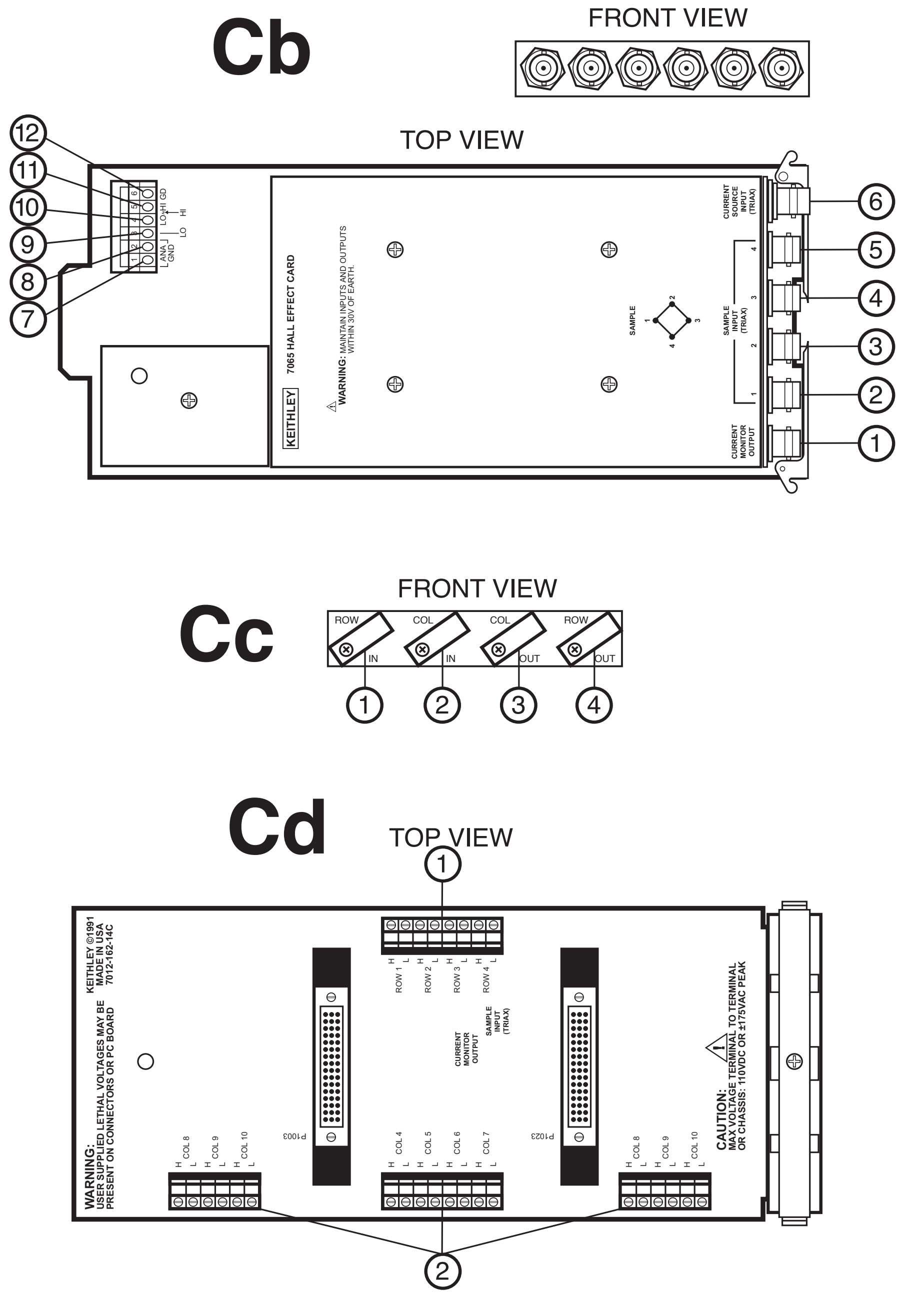


Figure 3-13 Switch card connection points.

Table 3-1 Hall Measurement System Instrumentation Connection Point Designations. The locations of the connections listed below are shown in **Figure 3-11** and **Figure 3-12**. Items in **bold face** are used to make a connection in at least one Series 7500 instrumentation configuration.

Aa	**Keithley Model 2000 Multimeter**
1	Sense Ω 4-wire Lo
2	Sense Ω 4-wire Hi
3	Input Hi
4	Input Lo
5	Trigger Link
6	RS-232 Interface
7	IEEE-488 Interface
8	Power Input
9	Line Input Voltage Selector Switch and Fuse Block
Ab	**Keithley Model 182 Sensitive Digital Voltmeter**
1	Input on front panel
2	Analog Output
3	External Trigger
4	Meter Complete
5	Power Input
6	Line Power Fuse
7	Line Input Voltage Selector Switch
8	IEEE-488 Interface
B	**Sample Holder Junction Box**
1	Output #1, 3-lug triaxial BNC
2	Output #2, 3-lug triaxial BNC
3	Output #3, 3-lug triaxial BNC
4	Output #4, 3-lug triaxial BNC
5	Output #5, 3-lug triaxial BNC
6	Output #6, 3-lug triaxial BNC
7	10-Pin circular connector
8	4-Pin circular connector
Ca	**Keithley Model 7001 Switch System Mainframe**
1	Switch Card Slot #1
2	Switch Card Slot #2
3	Trigger Link OUT
4	Trigger Link IN
5	Digital I/O
6	Power Input
7	External Trigger
8	Channel Ready
9	IEEE-488 Interface

Cb	**Keithley Model 7065 Hall Effect Switch Card**
1	Output to current meter, coaxial BNC
2	Sample connection #1, 2-lug triaxial BNC
3	Sample connection #2, 2-lug triaxial BNC
4	Sample connection #3, 2-lug triaxial BNC
5	Sample connection #4, 2-lug triaxial BNC
6	Input from current source, 2-lug triax BNC
7	Internal terminal block, Analog ground
8	Internal terminal block, Analog ground
9	Internal terminal block, Lo
10	Internal terminal block, Hi (Lo)
11	Internal terminal block, Hi (Hi)
12	Internal terminal block, GD
Cc	**Keithley Model 7152 4x5 Low Current Matrix Switch Card**
1	ROW IN, M-series block connector to 5 triaxial cables
2	COL IN, M-series block connector to 5 triaxial cables
3	COL OUT, M-series block connector to 5 triaxial cables
4	ROW OUT, M-series block connector to 5 triaxial cables
Cd	**Keithley Model 7012-S 4x10 Matrix Switch Card**
1	ROW, Screw terminal block, 4 rows x 2 conductors per row (Hi and Lo)
2	COL, Screw terminal block, 10 columns x 2 conductors per column (Hi and Lo)
Da	**Keithley Model 220 Programmable Current Source**
1	Output (Hi, Lo, Shield), 2-lug triaxial BNC
2	Guard Output
3	Output Common
4	Chassis Ground
5	IEEE-488 Interface
6	IEEE-488 Address DIP Switch
7	External Trigger Input
8	Line Power Fuse
9	External Trigger Output
10	Power Input
11	Digital I/O

Db	**Keithley Model 6167 Guarded Input Adapter**
1	Output (Hi, Guard, shield), 2-lug triaxial BNC
2	Guard Input
3	Guarded/Unguarded Selection Switch
4	Input (Hi, Lo, Shield), 2-lug triaxial BNC
Ea	**Keithley Model 485 Autoranging Picoammeter**
1	IEEE-488 Address DIP Switch
2	IEEE-488 Interface
3	Line Input Voltage Selector Switch
4	Analog Output Hi
5	Analog Output Lo
6	Input, coaxial BNC on front panel
Eb	**Keithley Model 486 Picoammeter OR Model 487 Picoammeter/Voltage Source**
1	Input (Hi, Lo, Shield), 3-lug triaxial BNC
2	Analog Output Hi
3	Analog Output Lo
4	Common (chassis ground)
5	Power Input
6	Line Power Fuse
7	Line Input Voltage Selector Switch
8	IEEE-488 Interface
9	Meter Complete
10	External Trigger
11	Interlock (487 ONLY)
12	Voltage Output Lo (487 ONLY)
13	Voltage Output Hi (487 ONLY)
F	**Keithley Model 450 Gaussmeter**
1	Power Input
2	Power Switch
3	Line Power Fuse
4	IEEE-488 Interface
5	Serial Interface
6	Corrected Analog Output
7	Monitor Analog Output
8	Hall Probe Input

G	**Lake Shore Model 340 Temperature Controller**
1	Power Input
2	Power Switch
3	Line Power Fuse
4	Heater Fuse
5	Heater HI Output
6	Heater LO Output
7	Shield
8	Option Card Blank
9	Data Card Slot
10	IEEE-488 Interface
11	Serial Interface
12	Digital I/O
13	Relay Input
14	Analog Out 1
15	Analog Out 2
16	Input Channel A
17	Input Channel B
H	**7500 Rear Bulkhead Panel**
1	Current Meter (2 mA maximum), coaxial BNC
2	Shorted, coaxial BNC (unmetered: current returns directly to the current source)
I	**Keithley Model 6512 Programmable Electrometer**
1	Input (Hi, Guard, Shield), 3-lug triaxial BNC
2	Chassis Ground
3	Preamp Out Common
4	Preamp Out Hi
5	Analog Output Hi
6	Meter Complete Output
7	External Trigger Input
8	Guarded/Unguarded Selection Switch
9	IEEE-488 Interface
10	Line Power Fuse
11	Power Input

3.3.6.2 IEEE-488 Computer Interface Cable Connections

The instrument console normally ships with all IEEE-488 cables installed. The IEEE-488 cable to the computer is coiled inside the rear of the instrument console. IEEE-488 cables can be damaged or loosened during shipment and might require tightening if a communication problem is encountered. The IEEE-488 cables normally connect in a daisy-chain arrangement, but this is not required. **Table 3-2** gives a typical sequence of connections. Instruments not present in a system are skipped.

Table 3-2 Typical IEEE-488 computer interface cable connection sequence & addresses.

Mfr/Model	Instrument	IEEE-488 Address
-	Computer	**0**
KI 182	Sensitive Digital Voltmeter	**7** (default)
KI 220	Programmable Current Source	**21** (default = 12)
KI 485/486/487	Picoammeter	**22** (default)
KI 2000	Digital Voltmeter	**16** (default)
KI 2182	Nanovoltmeter	**7** (default)
KI 7001	Switch System Mainframe	**6** (default = 7)
KI 6512	Programmable Electrometer	not used
LS 330/340	Temperature Controller	**14** (default = 12)
LS 450	Gaussmeter	**8** (default = 12)
LS 620/622/647	Magnet Power Supply	**12** (default)

3.3.6.3 Keithley Model 182 Sensitive Digital Voltmeter (750HS option)

The Keithley Model 182 Sensitive Digital Voltmeter (SDVM; 750HS option only) ships installed in the Instrument Console.

The input cable connector requires connection to the front panel input. The other end of the cable ships already routed to the rear of the Instrument Console and connected to the Keithley 7065 Hall effect switch card.

3.3.6.4 Voltmeter Connections to the 7065 Hall Effect Switch Card

The connections to the Keithley 7065 Hall effect switch card may loosen either during shipment or by pulling on the cables. If necessary, remove the 7065 Hall card from the 7001 Switch System Mainframe by following the instructions that came with the 7065 Hall card.

Reconnect the wires to the 7065 Hall card terminal block positions shown in **Figure 3-14**. The terminal block has spring loaded knife edges for contacting an inserted wire. Push down on a contact lever with a small screwdriver to release the spring contacts, insert the wire, and release the lever. Gently pull on the wire to make sure it is held firmly.

Measurement systems requiring more than one wire per position in this terminal block (750SWT Fully Automated Switching option) require special care. Handle the bare wire ends carefully to keep them clean. Twist the two wires around each other so they are mechanically locked, but still able to fit into the terminal block holes. Remove a few wire strands if necessary. Do not solder the wires together if the system includes a Keithley Model 182 or 2182 Sensitive Digital Voltmeter; thermoelectric voltages could be generated in the connection. After insertion into the terminal block, gently pull on the wires to make sure they are held firmly. After inserting the switch card into the Keithley Model 7001 Switch System Mainframe, secure the cables so they can not be pulled from the terminal block accidentally.

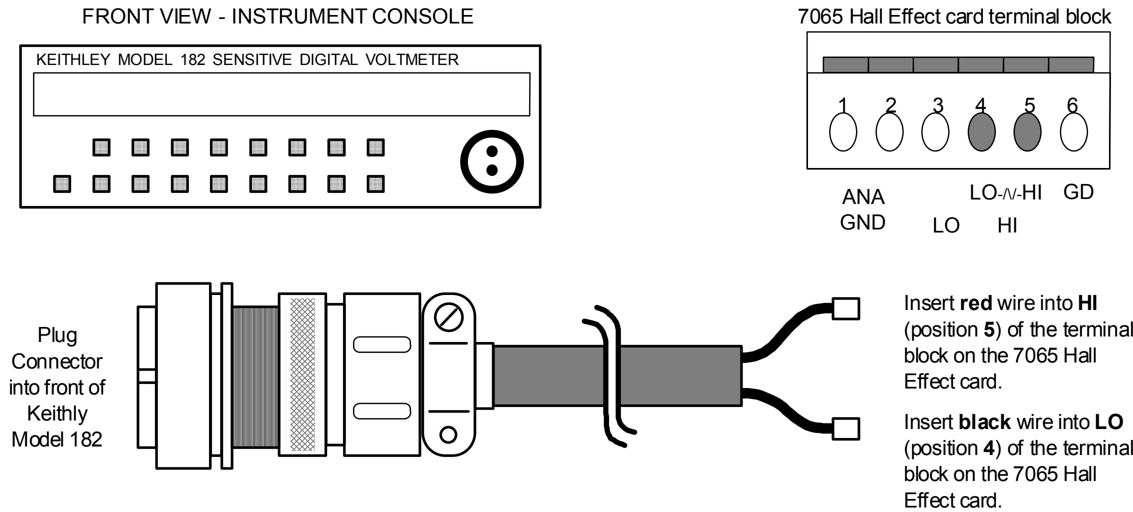


Figure 3-14 Typical Keithley 182 SDVM Cable Installation

3.3.6.5 Model 450 Gaussmeter Connections

The Hall probe ships in a foam-lined box. Leave the Hall probe in its protective plastic tube until it is mounted between the electromagnet poles (see Chapter 4). With instrument power OFF, plug the Hall Probe into the Model 450 rear DB-15 port labeled **Probe Input**. Attach the Hall probe to the instrument before turning on the power.

CAUTION: The Hall probe is delicate and easily damaged by rough handling.

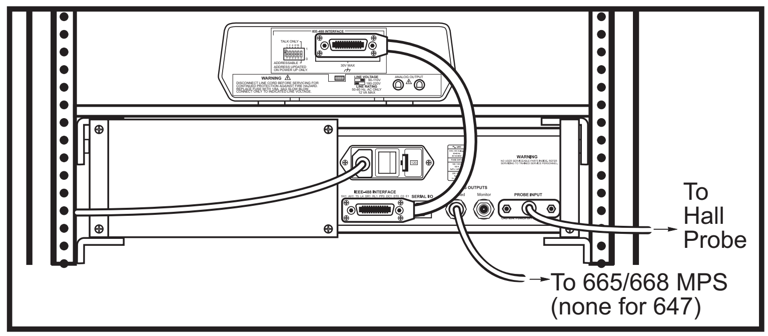


Figure 3-15 Model 450 Gaussmeter Connections.

Systems with a power supply controlled by the corrected output of the 450 Gaussmeter should already have a coaxial cable connected between the Gaussmeter and magnet power supply (MPS). If not, then do the following: locate the long coaxial cable with BNC connectors, typical length 3-6 meters (10-20 feet), normally shipped coiled inside the instrument console with one end connected to the **Corrected Analog Output** on the rear of the Model 450 Gaussmeter. The other end connects to the **Remote Reference** on the back of the 665/668 or similar MPS.

3.3.6.6 750TC Temperature Control Option

The Model 750TC Option adds a Model 340 Temperature Controller to a Model 7500 HMS. To add this option:

1. Remove a blank panel (or panels) to create a 3.5 inch high space in the instrument console. Attach the rack mounts to the 340 Temperature Controller and mount in the rack.
2. Connect the power cord and IEEE-488 communications cable. Refer to **Figure 3-16** for typical connections.
3. Cable connections to specific sample modules are covered in Chapter 4.

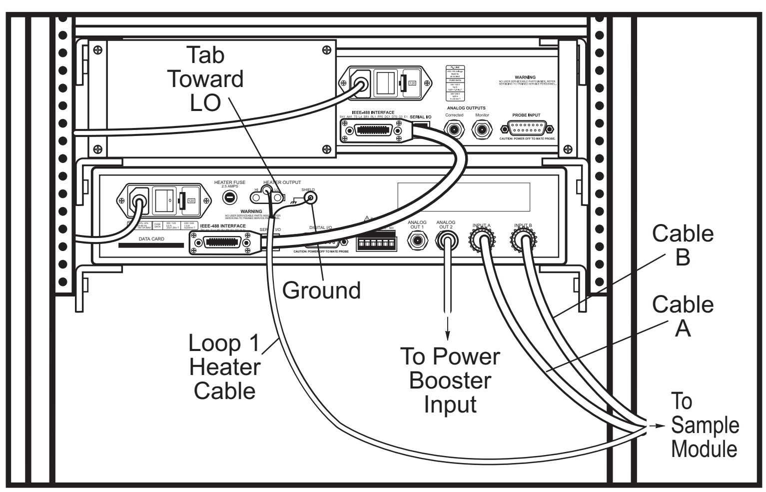


Figure 3-16 Typical 340 temperature controller connections.

3.3.7 Computer Installation

3.3.7.1 Computer Hardware Connection

The computer connects the same way regardless of system instrumentation (see **Figure 3-17**).

1. Plug the mouse into the rear computer port with a mouse icon beneath it.
2. Plug the keyboard into the rear computer port with a keyboard icon beneath it.
3. Plug the Monitor into the rear computer port with a monitor icon beneath it.
4. Connect the IEEE-488 cable to the IEEE-488 port on the back of the computer. A typical connection is shown in **Figure 3-17**.
5. Plug the monitor power cord into the back of the monitor.
6. Plug the computer power cord into the back of the computer.
7. Plug the other ends of the monitor and computer power cords into electrical outlets. If the computer is placed on top of the instrument console, plugging into a power strip inside the instrument console is convenient, if there is room.

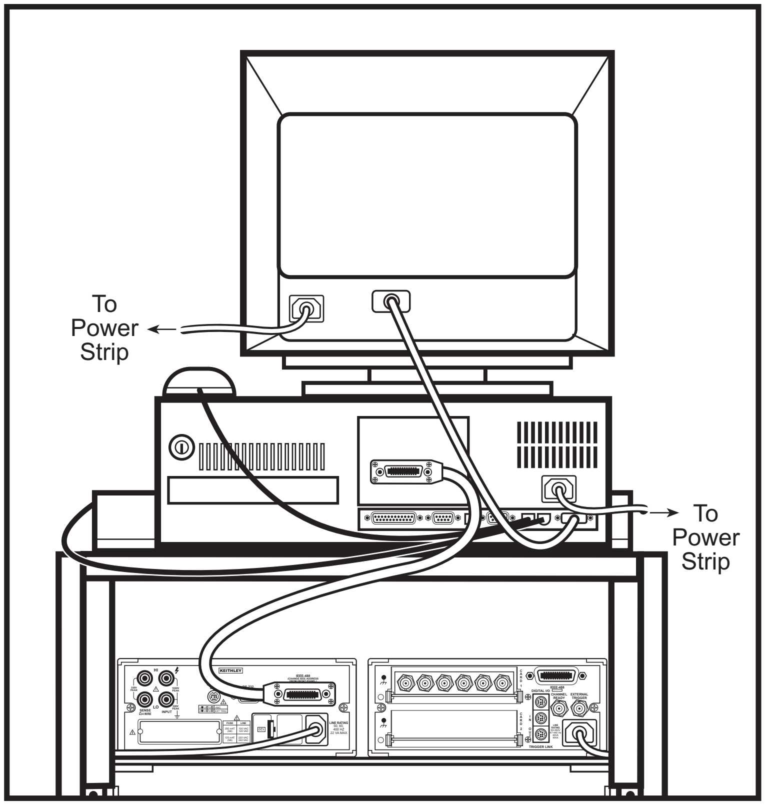


Figure 3-17 Computer Connections

3.3.7.2 Monitor Configuration

Lake Shore normally performs monitor configuration prior to shipment; it is not required during a typical system installation. This section is included only for reference to set up a different computer or monitor to operate the 7500 HMS.

The following procedures are for the Windows 95 operating system. Other operating system versions might require different sequences or settings.

1. Right click on the desktop background screen to bring up the screen's contextual menu and select **Properties** -> **Settings** tab -> **Advanced Properties** button -> **Monitor** tab.
2. At the Monitor tab, check the items according to the first section in **Table 3-3**.

   For Plug and Play monitors: Check the Plug and Play box. Click the **Apply** button. Click on the **Change** button to check which monitor was selected. Click **OK** to return to the **Monitor** tab.

   For other monitors: Leave the Plug and Play box unchecked -> **Change** button -> **Show all devices** -> select Hewlett-Packard (or actual manufacturer of the monitor) in the left hand menu -> select actual monitor model from the list in the right hand menu, and click **OK** to return to the **Monitor** tab.
3. Click **OK** to return to the **Settings** tab. Select the Resolution, Colors, Refresh rate, and Font size recommended in the table.
4. Click **OK** and select the **Screen Saver** tab. Verify **None** is selected. This is required to avoid interference with the Hall System Software.
5. Click **OK** until a dialog box appears stating that the computer must be restarted for the changes to take effect. Restart the computer.

Table 3-3 Monitor settings for use with Hall System Software.

	Monitor size (measured diagonally)		
Property	**14 inch** (12.9 viewable)	**15 inch** (13.7 viewable)	**17 inch** (15.8 viewable)
Energy Star compliant	Yes	Yes	Yes
Plug and Play capable	No	Yes	Yes
Reset display on suspend/resume	Yes	Yes	Yes
Resolution (pixels) (Note 1)	1024 x 768	1024 x 768	1024 x 768
Colors	256	256	256
Refresh rate (Note 2)	75 Hz	75 Hz	75 Hz
Font size	Large Fonts	Large Fonts	Large Fonts
Screen saver (Note 3)	None	None	None

Note 1: Lower resolution makes objects on the screen appear larger, but at the expense of showing less on the screen at a time. Using Small Fonts can increase the information shown on the screen.
Note 2: Or select monitor default setting.
Note 3: Disable the screen saver; it interferes with Hall System Software operation.

3.3.7.3 Installing an IEEE-488 Communications Card

The computer provided with the 7500 HMS already contains an IEEE-488 card. The information in this section is provided only in case another card must be installed in another computer or to replace a defective card. The Hall System Software is designed to work with a National Instruments (NI) IEEE-488 communications card. Consult Lake Shore before attempting to use any other communications card.

1. Shut down computer.
2. Remove computer cover. Consult computer users manual if cover removal is not clear. Install the National Instruments IEEE-488 card into one of the computer slots, being careful not to damage the connections. Install the card in Slot 2 of an HP Vectra computer to avoid interference between the IEEE-488 cable to be connected externally and the computer case. Save the removed slot cover with the manuals. Replace the computer cover. Do NOT attach the external IEEE-488 cable.
3. Start the Computer. Install the NI-488 software using the Windows setup disks provided by National instruments. Perform a FULL installation. Refer to the NI-488 manual if required.
   Configure the NI-488 software. Follow the path: **Start** -> **Settings** -> **Control Panel** -> **GPIB** -> select **GPIB0**, and click the **Configure** button. Set the following:
   Base I/O Address = 0x2b8 (typical; use whatever appears)
   Interrupt Level = None (sometimes must change)
   DMA Channel = None (must change)
   Bus Timing = 500 nsec (typical; use whatever appears)
4. Locate the NI-488 GPIB directory on the computer. Run the Software Diagnostic Test program. Follow the instructions and run the test. If the result is "**Test on GPIB0 Completed Successfully**" then **Exit** the program and continue. Otherwise, fix the problem and rerun the test.
5. Run the Hardware Diagnostic Test program. Follow the instructions. Some notes:
   A PC2 (AKA PCII) board is typically used, but check to make sure.
   Address requested is default.
   DMA channel is None.
   Interrupt level is None.
   Run the test. If the hardware passes the test then **Exit** the program and continue. Otherwise, fix the problem and rerun the test.
6. Shut down the computer.

3.3.8 Electrical Power Connection

Lake Shore builds each Model 7500 HMS according to the input power specified on the Sales Order. The electromagnet power supply, instrument console, and optional equipment (compressors, chillers, etc.) can have different power requirements.

3.3.8.1 Line Voltage and Fuse Verification

Lake Shore presets electrical component power requirements for proper operation upon receipt. Before applying power to the main input power cable, verify input power settings for each instrument are correct for the power source voltage.

CAUTION: Do not attempt to apply electrical power to the system until all instruments have been checked for proper input power settings and fuse/circuit breaker ratings.

If the input power does not match the instrument settings, either 1) contact Lake Shore for further instructions, or 2) refer to the manuals for the individual instruments and change their settings.

CAUTION: For continued protection against fire hazard, replace only with the same fuse type and rating specified.

3.3.8.2 System Electrical Grounding

Ground instrument panels and cabinets. The safety ground provides a true ground path for electrical circuitry and, in the event of internal electrical faults such as shorts, carries the entire fault current to ground to protect users from electrical shock. The Power Strip in the Instrument Console has a three-conductor power input connector which grounds equipment in the Instrument Console when plugged into a 3-wire receptacle.

Check the ground between the electromagnet iron frame and the chasis of the power supply. This should have been done as part of the electromagnet and power supply installation.

When the earth ground connection is impaired, render the Model 7500 inoperative and secure it against any unintended operation. The connection is likely impaired if the instrument:

1. Shows visible damage.
2. Fails to perform the intended measurement.
3. Has been subjected to prolonged storage under unfavorable conditions.
4. Has been subjected to severe transport stresses.

Do not use such apparatus until qualified service personnel verifies its safety.

3.3.8.3 Power Cords

Lake Shore instrumentation includes a three-conductor power cord with a U.S. standard three-prong plug. Single phase line voltage appears between the outer two flat prongs. The round center conductor is a safety ground and connects to the instrument metal chassis when the power cord attaches to the power connector. For safety, plug the cord into an appropriate *grounded* receptacle.

For installation in other receptacles, cut off the power plug and replace with an appropriate, grounded plug.

3.4 MODEL 7500 MEASUREMENT CONFIGURATIONS

The other instruments in the console connect differently depending on measurement configuration. See **Figure 3-11** and **Figure 3-12** for illustrations and **Table 3-1** for a list of all instrumentation and connection points. Some systems can be configured to meet varying measurement needs. Below is a list of possible system configurations and the corresponding paragraph reference. Lake Shore's Configurations for options are detailed below. For additional information on available options, see Chapter 1.

-HVWR High Voltage, Wide Resistance range measurement configuration: Built around two 7152 Matrix Switch Cards and two 6512 Electrometers, allowing voltage measurements of ±100 V and sample excitations up to ±100 V and ±100 mA. This measurement configuration is useful for highly resistive samples or for producing high electric fields in a sample. Automated switching between sample types allows measurement of either 4-wire (van der Pauw) or 6-wire (Hall bar) samples.

-LVWR Low Voltage, Wide Resistance range measurement configuration: Built around a Keithley 7065 Hall switch card (contains buffer amplifiers for measurements on high resistance samples, limited to 8 V between any two inputs). Wired for van der Pauw or 4-wire samples only. This configuration is able to measure samples with the highest electrical resistances.

The standard system comes cabled for 4-lead van der Pauw structures (4 contacts). To make 6-contact Hall bar measurements (-HB configurations), change cabling within the instrument console (cables provided). Switching between the two configurations typically takes much less than one hour. Current-voltage characterization of Hall bars is not possible with the -HB configuration option unless the -SWT Fully Automated Switching option is also present.

-HVLR High Voltage, Low Resistance range measurement configuration: Built around a Keithley 7012-S 4x10 matrix switch card with a Keithley 220 Current Source and 2000 DVM. Capable of operation to 100 V and 1 A, but with a sample resistance upper limit of a few tens of megohms. Automated switching between sample types allows measurement of either 4-wire (van der Pauw) or 6-wire (Hall bar) samples.

-LVLR Low Voltage, Low Resistance range measurement configuration: Built around a Keithley 7012-S 4x10 matrix switch card with a Lake Shore Model 340 Temperature Controller to source currents and measure voltages. Excitation currents are limited and the sample resistance upper limit is a few megohms. Automated switching between sample types allows measurement of either 4-wire (van der Pauw) or 6-wire (Hall bar) samples.

Model 750HS High Sensitivity Option (-HS): A sensitive digital nanovoltmeter (Keithley Model 182 or 2182) and special input cabling provide much greater voltage sensitivity and accuracy - useful for measuring heavily doped, low mobility, and low resistance samples.

Model 750SWT Fully Automated Switching Option (-SWT): Adds a Keithley 7152 Low Current Switch Card with cabling and software to allow automated switching between sample types. Allows measurement of either 4-wire (van der Pauw) or 6-wire (Hall bar) samples. The current meter (2 mA maximum) also switches in and out automatically for operation from 500 fA to 100 mA without recabling. A larger current range can be especially important for samples whose properties vary widely with temperature. The additional switch card and cabling slightly reduces maximum measurable sample resistances.

Table 3-4 Measurement Configuration Table. See the listed section for configuration instructions and schematics.

Measurement Configuration Purchased	Possible Configurations	Configuration Description	Section
-HVWR	-HVWR	**High Voltage, Wide Resistance Range**	3.4.1
-HVWR-HS	-HVWR-HS	+ High Sensitivity	3.4.2
-LVWR		**Low Voltage, Wide Resistance Range**	
	-LVWR (vdP)	(for van der Pauw structures)	3.4.3
	-LVWR (HB)	(for Hall bar structures)	3.4.4
-LVWR-HS	-LVWR-HS (vdP)	+ High Sensitivity (for van der Pauw structures)	3.4.5
	-LVWR-HS (HB)	+ High Sensitivity (for Hall bar structures)	3.4.6
-LVWR-SWT	-LVWR-SWT	+ Fully Automated Switching	3.4.7
	-LVWR (vdP)	(for van der Pauw structures)	3.4.3
	-LVWR (HB)	(for Hall bar structures)	3.4.4
-LVWR-HS-SWT	-LVWR-HS-SWT	+ High Sensitivity, Auto Switch	3.4.8
	-LVWR-HS (vdP)	+ High Sensitivity (for van der Pauw structures)	3.4.5
	-LVWR-HS (HB)	+ High Sensitivity (for Hall bar structures)	3.4.6
-HVLR	-HVLR	**High Voltage, Low Resistance Range**	3.4.9
-HVLR-HS	-HVLR-HS	+ High Sensitivity	3.4.10
-LVLR	-LVLR	**Low Voltage, Low Resistance Range**	3.4.11

3.4.1 -HVWR: High Voltage, Wide Resistance Range Measurement Configuration

High resistance measurement capability using two Keithley 7152 4x5 Low Current Matrix Switch Cards and two Keithley 6512 Electrometers. The electrometers can be bypassed for low resistance measurements.

Operation to ±100 V, ±100 mA.

Computer controlled switching between sample geometries and metered or unmetered sample currents.

Sample geometries: van der Pauw, 4-wire, Hall bar or 6-wire.

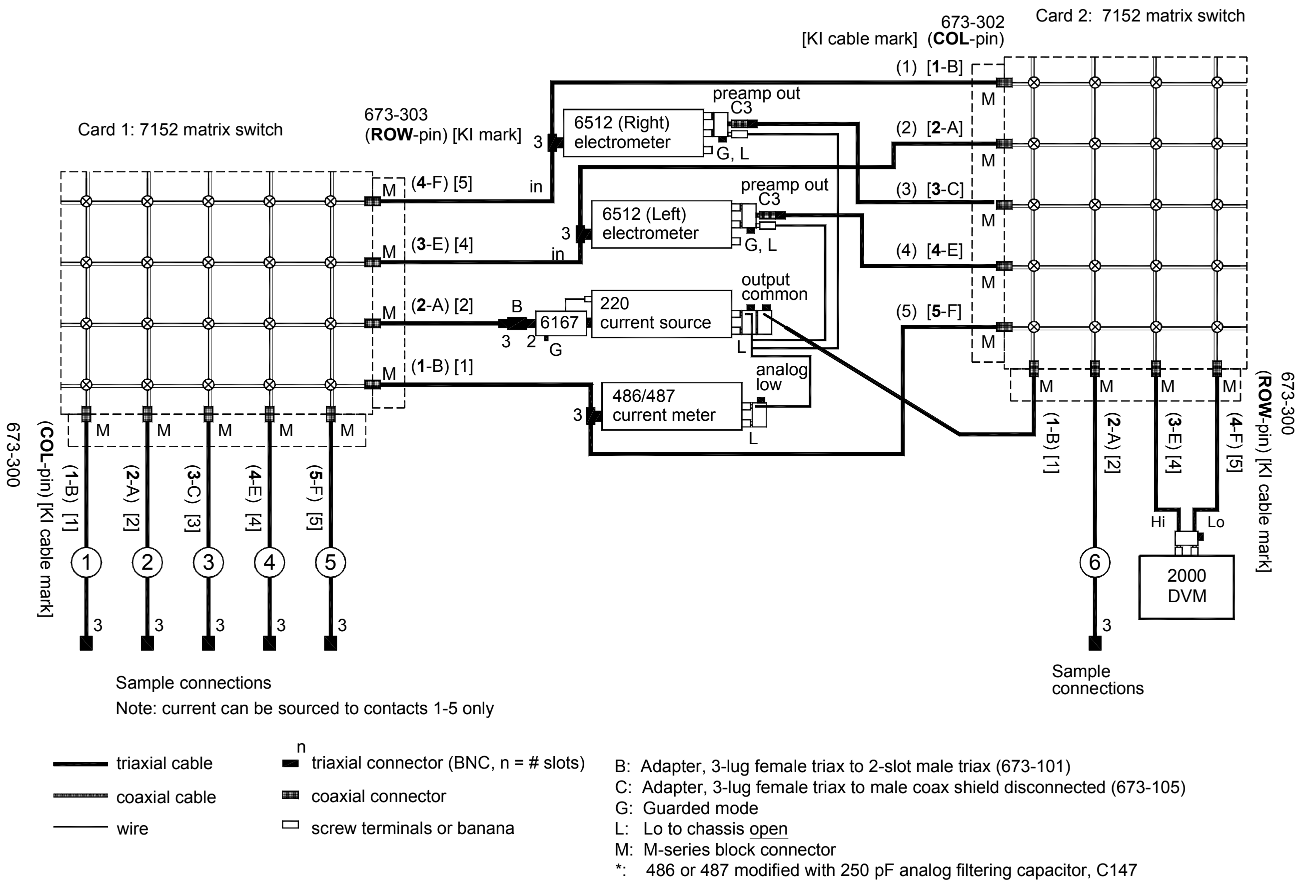


Figure 3-18 -HVWR measurement configuration schematic (dwg. 109-97-00 rev. D). Left and right electrometer designations are as viewed from the front of the instrument console.

Table 3-5 -HVWR measurement configuration connection list. High voltage configuration.

#	CONNECTION	FROM	TO
1	Keithley 7152 4x5 Low current matrix switch card		(**Ca1**) Slot #1 in the 7001 switch system mainframe
2	Keithley 7152 4x5 Low current matrix switch card		(**Ca2**) Slot #2 in the 7001 switch system mainframe
3	6167 Guarded adapter for 220 current source (set **Db3** for guarded operation)	(**Db4**) Input on 6167 (**Db1**) single banana plug on 6167	(**Da1**) Output on back of 220 current source (**Da2**) Guard output on back of 220
4	673-101, Adapter, triaxial 2-slot to 3-lug	(**Db2**) Current output on 6167 guarded adapter	(to be completed by connection #10.2)
5	673-103, Triaxial tees, (1) 3-slot to (2) 3-lug **Note:** The electrometers typically need two tees stacked on each input to connect both cables.	(**Right I1**) Input of right 6512 electrometer, and (**Left I1**) Input of left 6512 electrometer, and (**Eb1**) Input of 486/7 I meter	(to be completed by connections #8.1, 10.5) (to be completed by connections #8.2, 10.4) (to be completed by connections #8.5, 10.1)
6	2 of: dual banana plug with coaxial BNC with 673-105 Adapter, BNC to 3-lug triax, triax shield isolated, guard to coax shield	(**Right I3-4**) Right 6512 electrometer preamp out, GND tab to COM; and (**Left I3-4**) Left 6512 electrometer preamp out, GND tab to COM	(to be completed by connection #8.3) (to be completed by connection #8.4)
7	673-404, 750HV return current cable assembly	(**Da3-4**) 2-banana, 3-cable end, GND to output common of 220	(**Eb2-3**) 2-banana, 1-cable, GND to analog low of 486/7, (**Left I3**) 1-banana to COM of left 6512 electrometer, and (**Right I3**) 1-banana to COM of right 6512 electrometer
8	673-303, Cable assembly, M-series connector to (5) 3-slot triax, 1 m long	(**Ca2, Cc2**) Column input on lower 7152 switch card, (tape marker #**1**) trx3 (tape marker #**2**) trx3 (tape marker #**3**) trx3 (tape marker #**4**) trx3 (tape marker #**5**) trx3	(**Right I1**) Right 6512 input T (**Left I1**) Left 6512 input tee (**Right I3-4**) Right 6512 P-out (**Left I3-4**) Left 6512 Pre-out (**Eb1**) 486/7 meter input tee
9	673-304, Cable assembly, M-series connector to (1) dual banana to single triax cable, (2) 3-slot triax 3 m long, (1) dual banana to two triax, 1 m long	(**Ca2, Cc4**) Row output on lower 7152 switch card, (tape marker #**1**) dual banana (tape marker #**2**) trx3 (tape marker #**3**) trx3 (tape marker #**4-5**) 2-banana	(**Da3-4**) GND to 220 out COM (**B6**) Sample connection #6 ( ) not used (**Aa3-4**) Input on 2000 DVM, GND tab to Lo
10	673-303, Cable assembly, M-series connector to (5) 3-slot triax, 1 m long	(**Ca1, Cc4**) Row output on upper 7152 switch card, (tape marker #**1**) trx3 (tape marker #**2**) trx3 (tape marker #**3**) trx3 (tape marker #**4**) trx3 (tape marker #**5**) trx3	(**Eb1**) 486/7 meter input tee (**Db2**) 6167 output adapter ( ) not used (**Left I1**) Left 6512 input tee (**Right I1**) Right 6512 input T
11	673-300, Cable assembly, M-series connector to (5) 3-slot triax, 3 m long	(**Ca1, Cc2**) Column input on upper 7152 switch card, (Sample cable #**1**) trx3 (Sample cable #**2**) trx3 (Sample cable #**3**) trx3 (Sample cable #**4**) trx3 (Sample cable #**5**) trx3	(**B1**) Sample connection #1 (**B2**) Sample connection #2 (**B3**) Sample connection #3 (**B4**) Sample connection #4 (**B5**) Sample connection #5

3.4.2 -HVWR-HS: High Voltage, Wide Resistance Range, High Sensitivity Measurement Configuration

High resistance measurement capability using two Keithley 7152 4x5 Low Current Matrix Switch Cards and two Keithley 6512 Electrometers. The electrometers can be bypassed for low resistance measurements.

Operation to ±100 V, ±100 mA.

Computer controlled switching between sample geometries and metered or unmetered sample currents.

Sample geometries: van der Pauw, 4-wire, Hall bar or 6-wire.

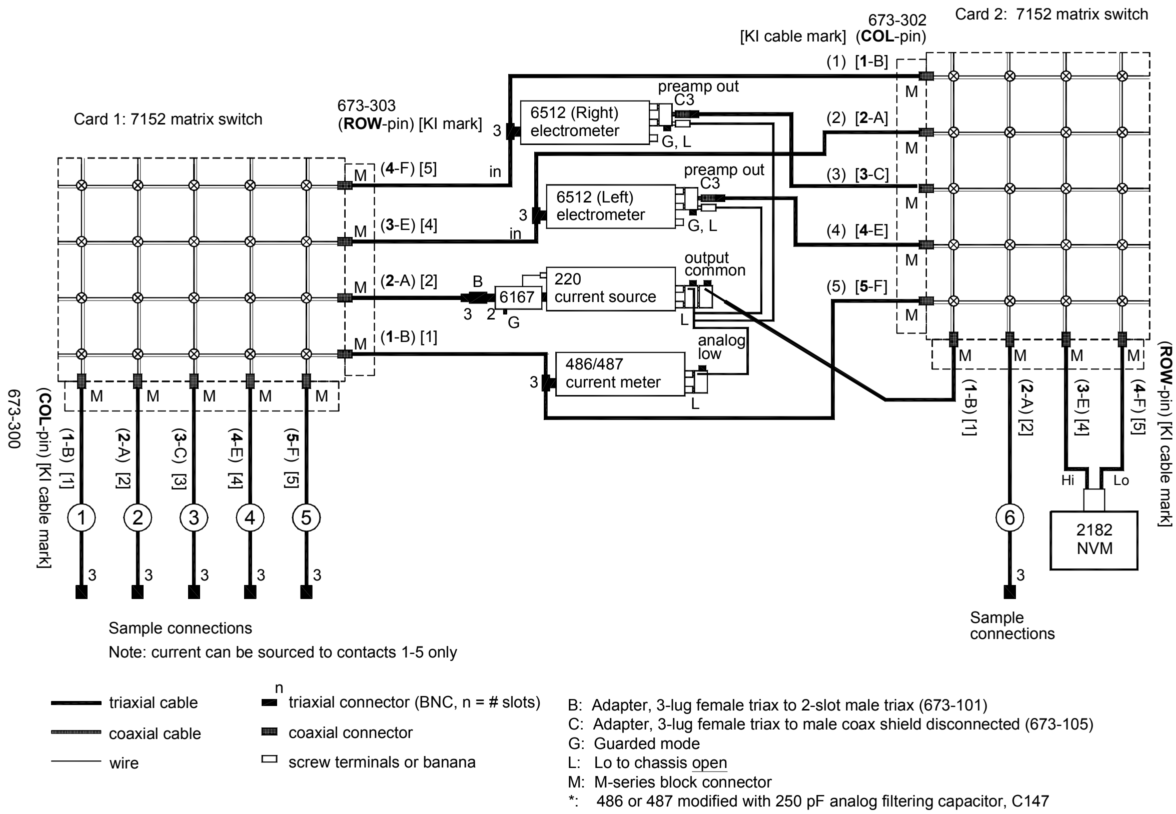


Figure 3-19 -HVWR-HS measurement configuration schematic (dwg. Xxx-xx-00 rev. -). Left and right electrometer designations are as viewed from the front of the instrument console.

Table 3-6 -HVWR-HS measurement configuration connection list.

#	CONNECTION	FROM	TO
1	Keithley 7152 4x5 Low current matrix switch card		(**Ca1**) Slot #1 in the 7001 switch system mainframe
2	Keithley 7152 4x5 Low current matrix switch card		(**Ca2**) Slot #2 in the 7001 switch system mainframe
3	6167 Guarded adapter for 220 current source (set **Db3** for guarded operation)	(**Db4**) Input on 6167 (**Db1**) single banana plug on 6167	(**Da1**) Output on back of 220 current source (**Da2**) Guard output on back of 220
4	673-101, Adapter, triaxial 2-slot to 3-lug	(**Db2**) Current output on 6167 guarded adapter	(to be completed by connection #10.2)
5	673-103, Triaxial tees, (1) 3-slot to (2) 3-lug **Note:** The electrometers typically need two tees stacked on each input to connect both cables.	(**Right I1**) Input of right 6512 electrometer, and (**Left I1**) Input of left 6512 electrometer, and (**Eb1**) Input of 486/7 I meter	(to be completed by connections #8.1, 10.5) (to be completed by connections #8.2, 10.4) (to be completed by connections #8.5, 10.1)
6	2 of: dual banana plug with coaxial BNC with 673-105 Adapter, BNC to 3-lug triax, triax shield isolated, guard to coax shield	(**Right I3-4**) Right 6512 electrometer preamp out, GND tab to COM; and (**Left I3-4**) Left 6512 electrometer preamp out, GND tab to COM	(to be completed by connection #8.3) (to be completed by connection #8.4)
7	673-404, 750HV return current cable assembly	(**Da3-4**) 2-banana, 3-cable end, GND to output common of 220	(**Eb2-3**) 2-banana, 1-cable, GND to analog low of 486/7, (**Left I3**) 1-banana to COM of left 6512 electrometer, and (**Right I3**) 1-banana to COM of right 6512 electrometer
8	673-303, Cable assembly, M-series connector to (5) 3-slot triax, 1 m long	(**Ca2, Cc2**) Column input on lower 7152 switch card, (tape marker #**1**) trx3 (tape marker #**2**) trx3 (tape marker #**3**) trx3 (tape marker #**4**) trx3 (tape marker #**5**) trx3	 (**Right I1**) Right 6512 input T (**Left I1**) Left 6512 input tee (**Right I3-4**) Right 6512 P-out (**Left I3-4**) Left 6512 Pre-out (**Eb1**) 486/7 meter input tee
9	673-304, Cable assembly, M-series connector to (1) dual banana to single triax cable, (2) 3-slot triax 3 m long, (1) dual banana to two triax, 1 m long	(**Ca2, Cc4**) Row output on lower 7152 switch card, (tape marker #**1**) dual banana (tape marker #**2**) trx3 (tape marker #**3**) trx3 (tape marker #**4-5**) 2-banana	 (**Da3-4**) GND to 220 out COM (**B6**) Sample connection #6 ( ) not used (**Aa3-4**) Input on front of 2182 NVM
10	673-303, Cable assembly, M-series connector to (5) 3-slot triax, 1 m long	(**Ca1, Cc4**) Row output on upper 7152 switch card, (tape marker #**1**) trx3 (tape marker #**2**) trx3 (tape marker #**3**) trx3 (tape marker #**4**) trx3 (tape marker #**5**) trx3	 (**Eb1**) 486/7 meter input tee (**Db2**) 6167 output adapter ( ) not used (**Left I1**) Left 6512 input tee (**Right I1**) Right 6512 input T
11	673-300, Cable assembly, M-series connector to (5) 3-slot triax, 3 m long	(**Ca1, Cc2**) Column input on upper 7152 switch card, (Sample cable #**1**) trx3 (Sample cable #**2**) trx3 (Sample cable #**3**) trx3 (Sample cable #**4**) trx3 (Sample cable #**5**) trx3	 (**B1**) Sample connection #1 (**B2**) Sample connection #2 (**B3**) Sample connection #3 (**B4**) Sample connection #4 (**B5**) Sample connection #5

3.4.3 -LVWR (vdP): Low Voltage, Wide Resistance Range Measurement Configuration, van der Pauw Stuctures

Highest resistance measurement capability using the Keithley 7065 Hall effect switch card. The buffer amplifiers on the 7065 Hall effect switch card can be bypassed for low resistance measurements.

Operation to ±8 V, ±2 mA (±100 mA with manual recabling).

Sample geometries: van der Pauw or 4-wire ONLY.

For metered operation with sample currents less than 2 mA: connect coaxial cable 673-011 from connection point Cb1 to H1 (Current Meter, **I** < 2 mA) and make sure current meter is on.

For unmetered operation allowing sample currents greater than 2 mA: connect coaxial cable 673-011 from connection point Cb1 to H2 (Shorted) and specify an sample current of 2 mA or larger. For unmetered operation over a range of currents, also do the following: make sure the Hall System Software is closed, shut off power to the current meter, and restart the Hall software.

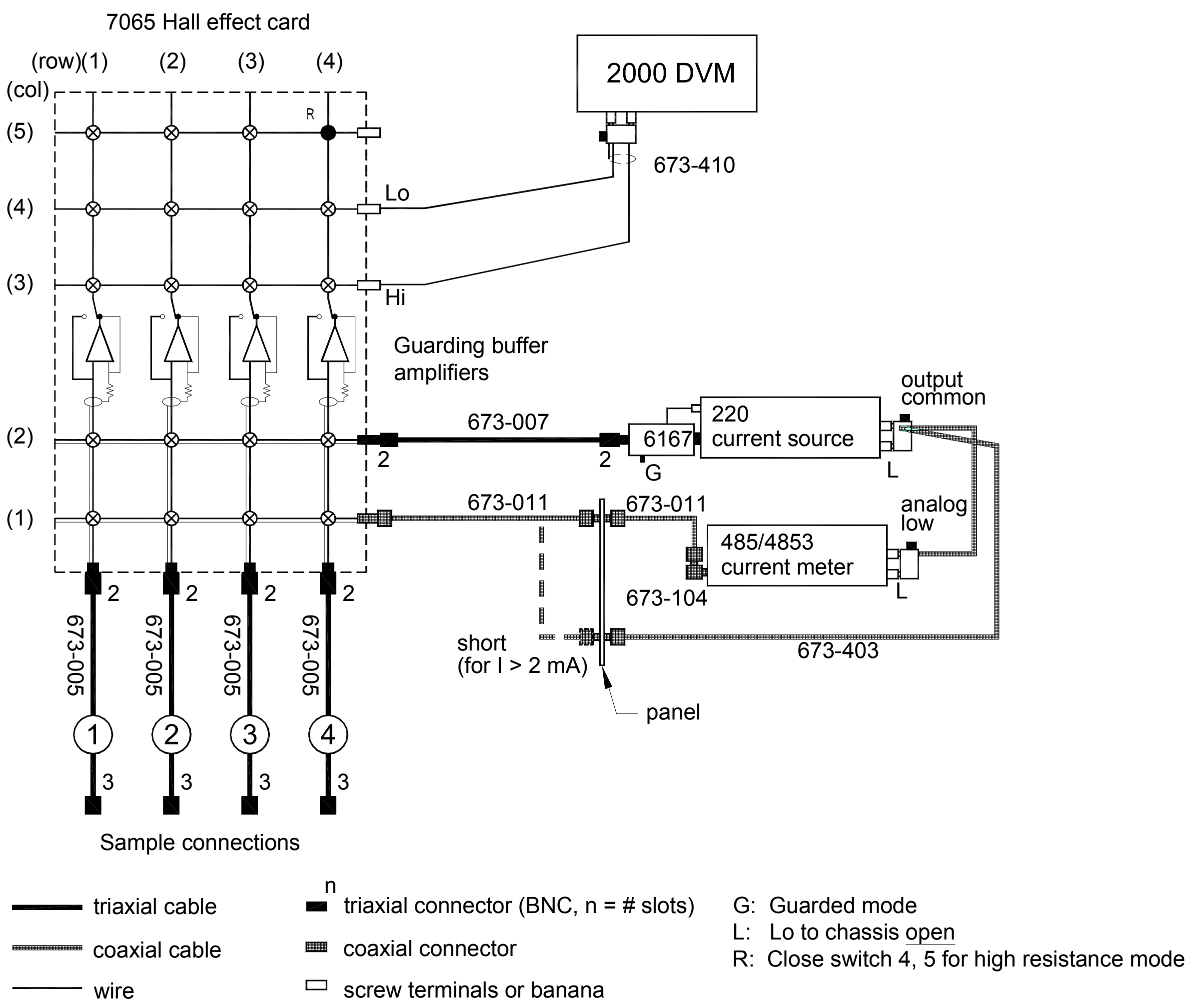


Figure 3-20 -LVWR measurement configuration schematic (dwg. 103-97-00 rev. B).

Table 3-7 -LVWR measurement configuration connection list.

#	CONNECTION	FROM	TO
1	673-410, Banana to twisted pair, bare wire ends	(**Aa3-4**) Input on 2000 DVM, GND tab to Lo	(**Cb10-11**) Terminal block on 7065 Hall card
2	Keithley 7065 Hall effect card		(**Ca1**) Slot #1 in the 7001 switch system mainframe
3	6167 Guarded adapter for 220 current source (set **Db3** for guarded operation)	(**Db4**) Input on 6167 (**Db1**) single banana plug on 6167	(**Da1**) Output on back of 220 current source (**Da2**) Guard output on back of 220
4	673-011, coaxial low noise cable, 1.2 m long	(**Ea6**) Front of 485 current meter, coaxial BNC	(**H1-inside**) Current meter bulkhead BNC
5	673-011, coaxial low noise cable, 1.2 m long	(**Cb1**) Current output on 7065 Hall card	(**H1**) Current meter coaxial BNC bulkhead, **OR** (**H2**) Shorted BNC bulkhead for I>2 mA
6	673-403, 7500 return current cable assembly	(**Da3-4**) Double cable end banana, GND to output common	(**H2-inside**) Shorted coaxial BNC bulkhead, and (**Ea4-5**) single cable end banana, GND to analog low
7	673-007, Triaxial cable, 2-slot, 0.9 m long	(**Cb6**) Current input on 7065 Hall card	(**Db2**) Output of 6167 on back of 220
8	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (1)	(**Cb2**) Sample input #1 on 7065 Hall card	(**B1**) Junction box of sample holder module
9	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (2)	(**Cb3**) Sample input #2 on 7065 Hall card	(**B2**) Junction box of sample holder module
10	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (3)	(**Cb4**) Sample input #3 on 7065 Hall card	(**B3**) Junction box of sample holder module
11	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (4)	(**Cb5**) Sample input #4 on 7065 Hall card	(**B4**) Junction box of sample holder module

3.4.4 -LVWR (HB): Low Voltage, Wide Resistance Range Measurement Configuration, Hall Bar Stuctures

Highest resistance measurement capability using the Keithley 7065 Hall effect switch card. The buffer amplifiers on the 7065 Hall effect switch card can be bypassed for low resistance measurements.

Operation to ±8 V, ±2 mA (±100 mA with manual recabling).

Sample geometries: Hall bar or 6-wire ONLY.

For metered operation with sample currents less than 2 mA: connect triaxial cable 673-006 and Adapter to connection point H1 (Current Meter, **I** < 2 mA) and make sure current meter is on.

For unmetered operation allowing sample currents greater than 2 mA: connect triaxial cable 673-006 and Adapter to connection point H2 (Shorted) and specify an sample current of 2 mA or larger. For unmetered operation over a range of currents, also do the following: make sure the Hall System Software is closed, shut off power to the current meter, and restart the Hall software.

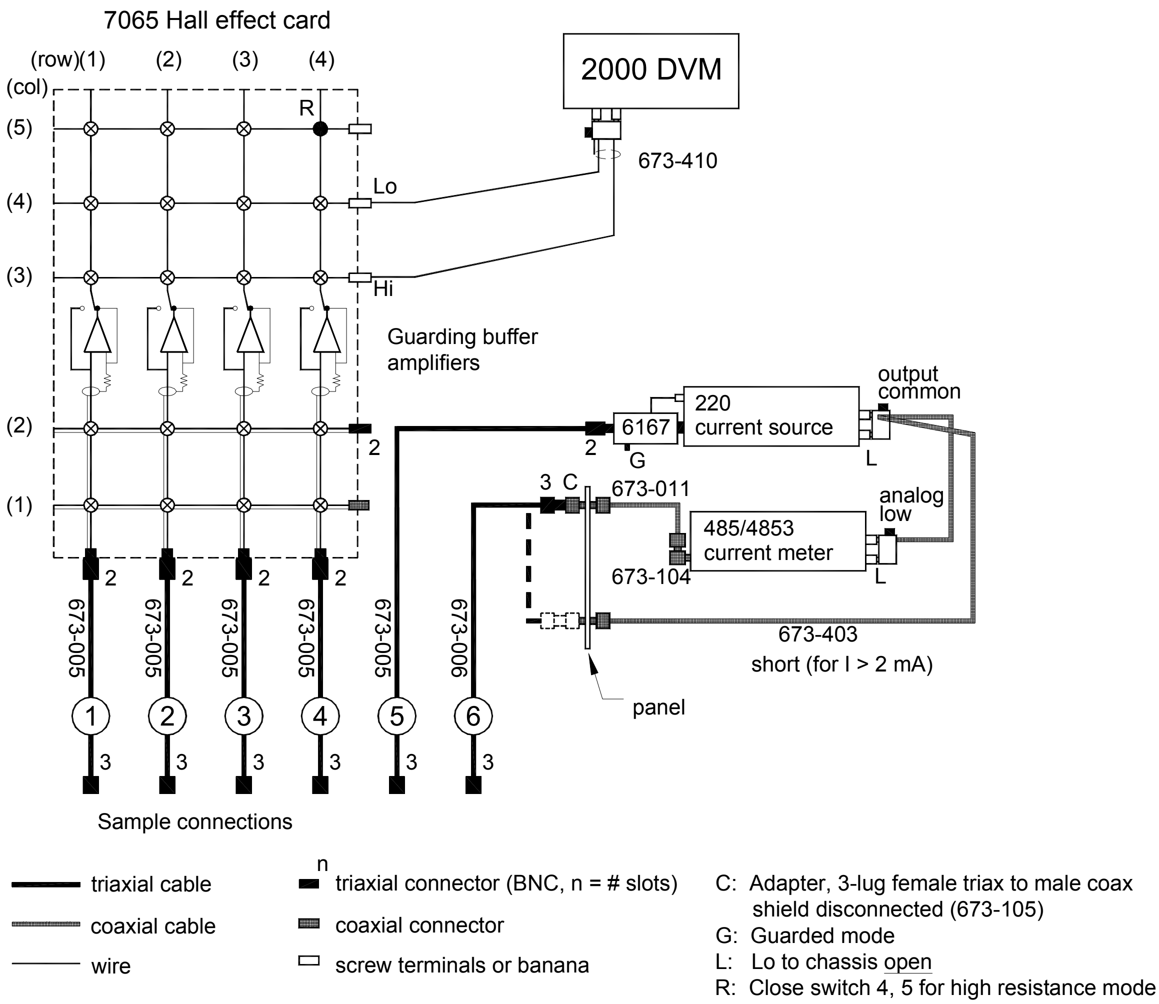


Figure 3-21 -LVWR-HB measurement configuration schematic (dwg. 105-97-00 rev. B).

Table 3-8 -LVWR-HB measurement configuration connection list.

#	CONNECTION	FROM	TO
1	673-410, Banana to twisted pair, bare wire ends	(**Aa3-4**) Input on 2000 DVM, GND tab to Lo	(**Cb10-11**) Terminal block on 7065 Hall card
2	Keithley 7065 Hall effect card		(**Ca1**) Slot #1 in the 7001 switch system mainframe
3	6167 Guarded adapter for 220 current source (set **Db3** for guarded operation)	(**Db4**) Input on 6167 (**Db1**) single banana plug on 6167	(**Da1**) Output on back of 220 current source (**Da2**) Guard output on back of 220
4	673-011, coaxial low noise cable, 1.2 m long	(**Ea6**) Front of 485 current meter, coaxial BNC	(**H1-inside**) Current meter bulkhead BNC
5	673-403, 7500 return current cable assembly	(**Da3-4**) Double cable end banana, GND to output common	(**H2-inside**) Shorted coaxial BNC bulkhead, and (**Ea4-5**) single cable end banana, GND to analog low
6	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (1)	(**Cb2**) Sample input #1 on 7065 Hall card	(**B1**) Junction box of sample holder module
7	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (2)	(**Cb3**) Sample input #2 on 7065 Hall card	(**B2**) Junction box of sample holder module
8	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (3)	(**Cb4**) Sample input #3 on 7065 Hall card	(**B3**) Junction box of sample holder module
9	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (4)	(**Cb5**) Sample input #4 on 7065 Hall card	(**B4**) Junction box of sample holder module
10	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (5)	(**Cb6**) Current input on 7065 Hall card	(**B5**) Junction box of sample holder module
11	673-105, Adapter, coax to 3-lug triax, triax shield isolated, guard to coax shield	(**H1**) Current meter bulkhead BNC for I < 2 mA, **OR** (**H2**) Shorted bulkhead BNC	(to be completed by connection # 12)
12	673-006, Triaxial cable, 3-slot, 3 m long, marked (6)	(see connection # 11) triax end of adapter	(**B6**) Junction box of sample holder module

3.4.5 -LVWR-HS (vdP): Low Voltage, Wide Resistance Range, High Sensitivity Measurement Configuration, van der Pauw Stuctures

Highest resistance measurement capability using the Keithley 7065 Hall effect switch card. The buffer amplifiers on the 7065 Hall effect switch card can be bypassed for low resistance measurements.

Operation to ±8 V, ±2 mA (±100 mA with manual recabling).

High sensitivity option (750HS) for improved measurement of low voltages.

Sample geometries: van der Pauw or 4-wire ONLY.

For metered operation with sample currents less than 2 mA: connect coaxial cable 673-011 from connection point Cb1 to H1 (Current Meter, I < 2 mA) and make sure current meter is on.

For unmetered operation allowing sample currents greater than 2 mA: connect coaxial cable 673-011 from connection point Cb1 to H2 (Shorted) and specify an sample current of 2 mA or larger. For unmetered operation over a range of currents, also do the following: make sure the Hall System Software is closed, shut off power to the current meter, and restart the Hall software.

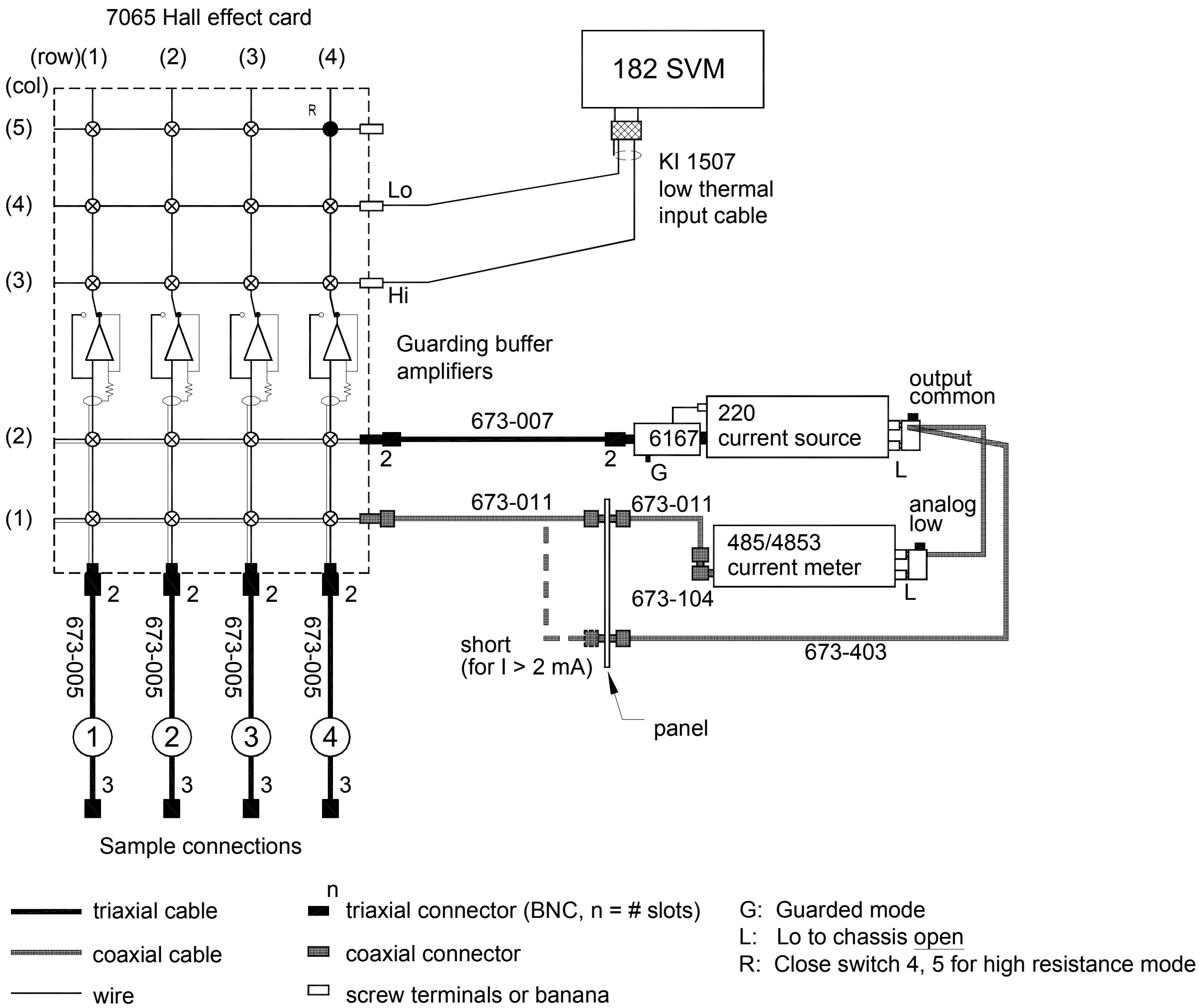


Figure 3-22 -LVWR-HS measurement configuration schematic (dwg. 104-97-00 rev. B).

Table 3-9 -LVWR-HS measurement configuration connection list.

#	CONNECTION	FROM	TO
1	182 low noise input to twisted pair, bare wire ends	(**Ab1**) Input on front of 182 SVM	(**Cb10-11**) Terminal block on 7065 Hall card
2	Keithley 7065 Hall effect card		(**Ca1**) Slot #1 in the 7001 switch system mainframe
3	6167 Guarded adapter for 220 current source (set **Db3** for guarded operation)	(**Db4**) Input on 6167 (**Db1**) single banana plug on 6167	(**Da1**) Output on back of 220 current source (**Da2**) Guard output on back of 220
4	673-011, coaxial low noise cable, 1.2 m long	(**Ea6**) Front of 485 current meter, coaxial BNC	(**H1-inside**) Current meter bulkhead BNC
5	673-011, coaxial low noise cable, 1.2 m long	(**Cb1**) Current output on 7065 Hall card	(**H1**) Current meter coaxial BNC bulkhead, **OR** (**H2**) Shorted BNC bulkhead for I>2 mA
6	673-403, 7500 return current cable assembly	(**Da3-4**) Double cable end banana, GND to output common	(**H2-inside**) Shorted coaxial BNC bulkhead, and (**Ea4-5**) single cable end banana, GND to analog low
7	673-007, Triaxial cable, 2-slot, 0.9 m long	(**Cb6**) Current input on 7065 Hall card	(**Db2**) Output of 6167 on back of 220
8	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (1)	(**Cb2**) Sample input #1 on 7065 Hall card	(**B1**) Junction box of sample holder module
9	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (2)	(**Cb3**) Sample input #2 on 7065 Hall card	(**B2**) Junction box of sample holder module
10	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (3)	(**Cb4**) Sample input #3 on 7065 Hall card	(**B3**) Junction box of sample holder module
11	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (4)	(**Cb5**) Sample input #4 on 7065 Hall card	(**B4**) Junction box of sample holder module

3.4.6 -LVWR-HS (HB): Low Voltage, Wide Resistance Range, High Sensitivity Measurement Configuration, Hall Bar Stuctures

Highest resistance measurement capability using the Keithley 7065 Hall effect switch card. The buffer amplifiers on the 7065 Hall effect switch card can be bypassed for low resistance measurements.

Operation to ±8 V, ±2 mA (±100 mA with manual recabling).

High sensitivity option (750HS) for improved measurement of low voltages.

Sample geometries: Hall bar or 6-wire ONLY.

For metered operation with sample currents less than 2 mA: connect triaxial cable 673-006 and Adapter to connection point H1 (Current Meter, I < 2 mA) and make sure current meter is on.

For unmetered operation allowing sample currents greater than 2 mA: connect triaxial cable 673-006 and Adapter to connection point H2 (Shorted) and specify an sample current of 2 mA or larger. For unmetered operation over a range of currents, also do the following: make sure the Hall System Software is closed, shut off power to the current meter, and restart the Hall software.

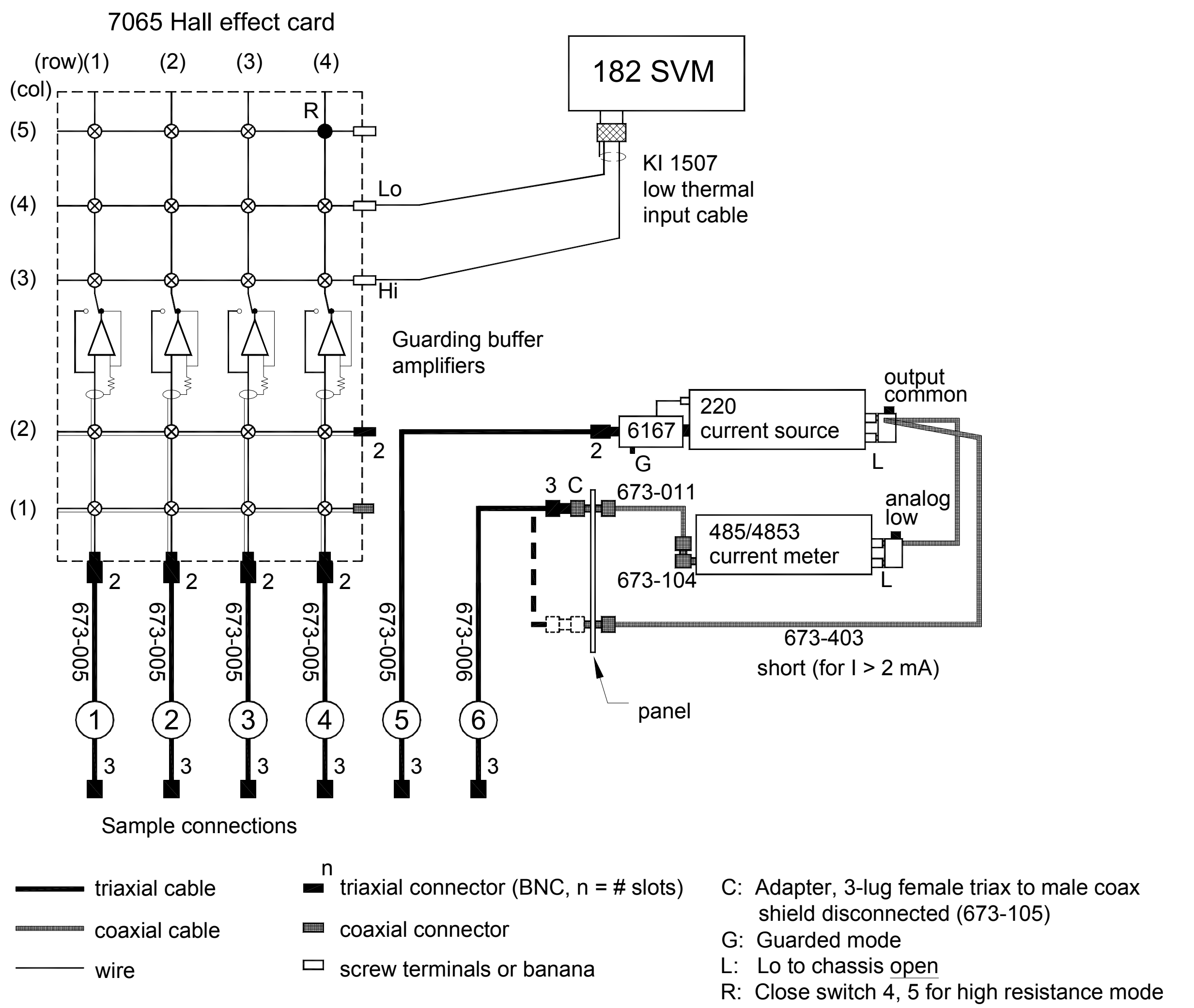


Figure 3-23 Hall-WRR-HS-HB measurement configuration schematic (dwg. 106-97-00 rev. B).

Table 3-10 -LVWR-HS-HB measurement configuration connection list.

#	CONNECTION	FROM	TO
1	182 low noise input to twisted pair, bare wire ends	(**Ab1**) Input on front of 182 SVM	(**Cb10-11**) Terminal block on 7065 Hall card
2	Keithley 7065 Hall effect card		(**Ca1**) Slot #1 in the 7001 switch system mainframe
3	6167 Guarded adapter for 220 current source (set **Db3** for guarded operation)	(**Db4**) Input on 6167 (**Db1**) single banana plug on 6167	(**Da1**) Output on back of 220 current source (**Da2**) Guard output on back of 220
4	673-011, coaxial low noise cable, 1.2 m long	(**Ea6**) Front of 485 current meter, coaxial BNC	(**H1-inside**) Current meter bulkhead BNC
5	673-403, 7500 return current cable assembly	(**Da3-4**) Double cable end banana, GND to output common	(**H2-inside**) Shorted coaxial BNC bulkhead, and (**Ea4-5**) single cable end banana, GND to analog low
6	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (1)	(**Cb2**) Sample input #1 on 7065 Hall card	(**B1**) Junction box of sample holder module
7	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (2)	(**Cb3**) Sample input #2 on 7065 Hall card	(**B2**) Junction box of sample holder module
8	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (3)	(**Cb4**) Sample input #3 on 7065 Hall card	(**B3**) Junction box of sample holder module
9	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (4)	(**Cb5**) Sample input #4 on 7065 Hall card	(**B4**) Junction box of sample holder module
10	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (5)	(**Cb6**) Current input on 7065 Hall card	(**B5**) Junction box of sample holder module
11	673-105, Adapter, coax to 3-lug triax, triax shield isolated, guard to coax shield	(**H1**) Current meter bulkhead BNC for I < 2 mA, **OR** (**H2**) Shorted bulkhead BNC	(to be completed by connection # 12)
12	673-006, Triaxial cable, 3-slot, 3 m long, marked (6)	(see connection # 11) triax end of adapter	(**B6**) Junction box of sample holder module

3.4.7 -LVWR-SWT: Low Voltage, Wide Resistance Range, Fully Automated Switching Measurement Configuration

High resistance measurement capability using the Keithley 7065 Hall effect switch card. The second switch card and additional cabling decrease the maximum accurately measurable resistance by about a factor of two. The buffer amplifiers on the 7065 Hall effect switch card can be bypassed for low resistance measurements.

Operation to ±8 V, ±100 mA.

Fully automated switching option (750SWT) adds a Keithley 7152 4x5 Low Current Matrix Switch Card. Allows computer controlled switching between sample geometries and metered or unmetered sample currents.

Sample geometries: van der Pauw, 4-wire, Hall bar or 6-wire.

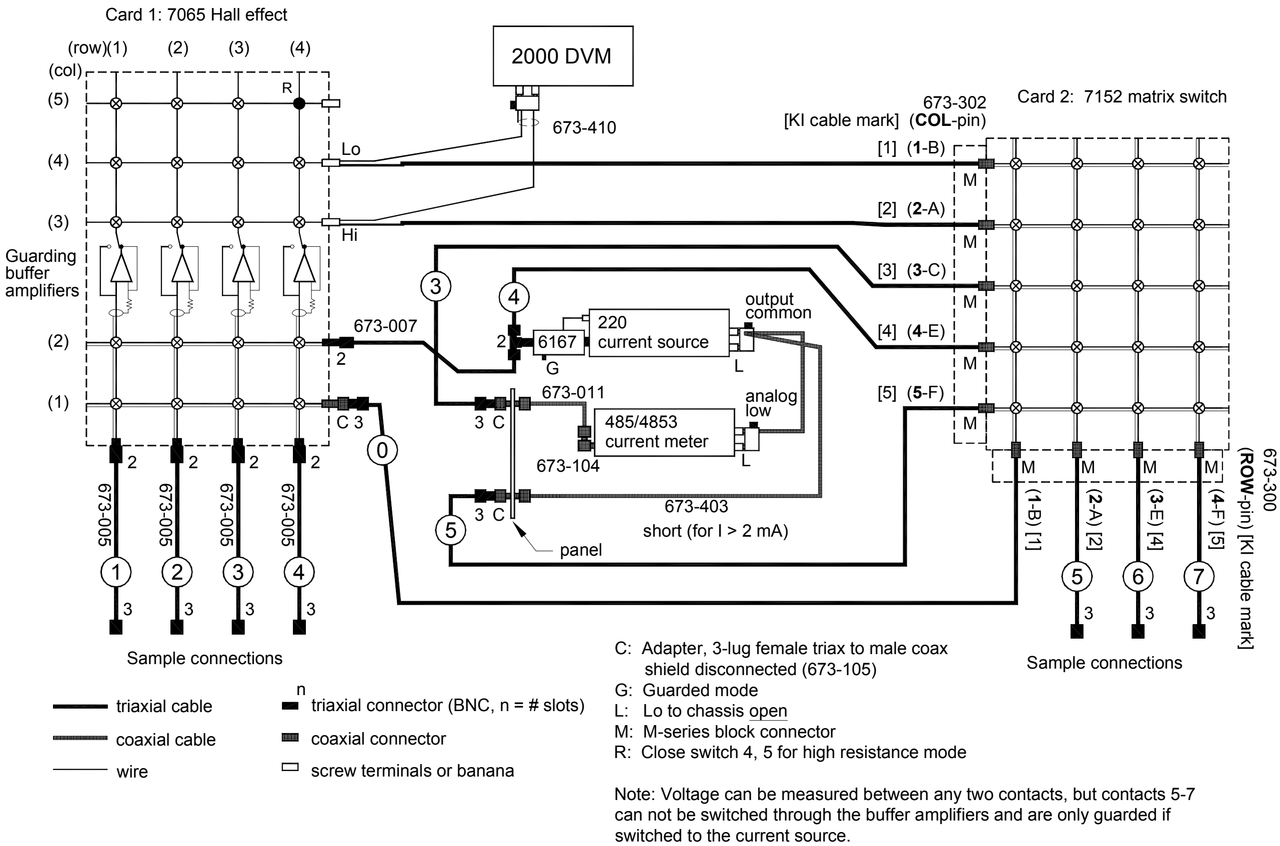


Figure 3-24 Hall-WRR-SWT measurement configuration schematic (dwg. 107-97-00 rev. B).

Table 3-11 -LVWR-SWT measurement configuration connection list.

#	CONNECTION	FROM	TO
1	6167 Guarded adapter for 220 current source (set **Db3** for guarded operation)	(**Db4**) Input on 6167 (**Db1**) single banana plug on 6167	(**Da1**) Output on back of 220 current source (**Da2**) Guard output on back of 220
2	673-102, Triaxial tee, (1) 2-slot to (2) 2-lug	(**Db2**) Output on back of 6167 Guarded adapter	(to be completed by connections # 11.4, 12)
3	673-011, coaxial low noise cable, 1.2 m long	(**E6**) Front of 485 current meter	(**H1-inside**) Current meter bulkhead BNC
4	673-403, 7500 return current cable assembly	(**Da3-4**) Double cable end banana, GND to output common	(**H2-inside**) Shorted coaxial BNC bulkhead, and (**Ea4-5**) single cable end banana, GND to analog low
5	673-105, Adapter, BNC to 3-lug triax, triax shield isolated, guard to coax shield	(**Cb1**) Current output on 7065 Hall card	(to be completed by connection # 17.1)
6	673-105, Adapter, BNC to 3-lug triax, triax shield isolated, guard to coax shield	(**H1**) Current meter bulkhead coaxial BNC	(to be completed by connection # 11.3)
7	673-105, Adapter, BNC to 3-lug triax, triax shield isolated, guard to coax shield	(**H2**) Shorted bulkhead coaxial BNC	(to be completed by connection # 11.5)
8	673-410, Banana to twisted pair, bare wire ends	(**Aa3-4**) Input on 2000 DVM, GND tab to Lo	(**Cb10-11**) Terminal block on 7065 Hall card
9	Keithley 7065 Hall effect card		(**Ca1**) Slot #1 in the 7001 switch system mainframe
10	Keithley 7152 4x5 Low current matrix switch card		(**Ca2**) Slot #2 in the 7001 switch system mainframe
11	673-302, Cable assembly, M-series connector to (2) bare ends, (3) 3-slot triax	(**Cc2**) Column input on 7152 switch card, (tape marker #**1**) bare (tape marker #**2**) bare (tape marker #**3**) trx3 (tape marker #**4**) trx3 (tape marker #**5**) trx3	 (**Cb10**) Lo term. 7065 card (**Cb11**) Hi term. 7065 card (**H1**) Current meter Adapter (**Db2**) Triaxial tee on 6167 (**H2**) Shorted Adapter
12	673-007, Triaxial cable, 2-slot, 0.9 m long	(**Cb6**) Current input on 7065 Hall card	(**Db2**) Triaxial tee on back of 6167
13	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (1)	(**Cb2**) Sample input #1 on 7065 Hall card	(**B1**) Junction box of sample holder module
14	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (2)	(**Cb3**) Sample input #2 on 7065 Hall card	(**B2**) Junction box of sample holder module
15	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (3)	(**Cb4**) Sample input #3 on 7065 Hall card	(**B3**) Junction box of sample holder module
16	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (4)	(**Cb5**) Sample input #4 on 7065 Hall card	(**B4**) Junction box of sample holder module
17	673-300, Cable assembly, M-series connector to (5) 3-slot triax, 3 m long	(**Cc4**) Row output on 7152 switch card, (Sample input #**0**, tape marker #1) trx3 (Sample input #**5**, tape marker #2) trx3 (Sample input #**6**, tape marker #4) trx3 (Sample input #**7**, tape marker #5) trx3 (Sample input #**8**, tape marker #3) trx3	 (**Cb1**) Adapter on 7065 current output (B**5**) Junction box of sample holder module (B**6**) Junction box of sample holder module ( ) user defined ( ) not connected

3.4.8 -LVWR-HS-SWT: Low Voltage, Wide Resistance Range, High Sensitivity, Fully Automated Switching Measurement Configuration

High resistance measurement capability using the Keithley 7065 Hall effect switch card. The second switch card and additional cabling decrease the maximum accurately measurable resistance by about a factor of two. The buffer amplifiers on the 7065 Hall effect switch card can be bypassed for low resistance measurements.

Operation to ±8 V, ±100 mA.

High sensitivity option (750HS) for improved measurement of low voltages.

Fully automated switching option (750SWT) adds a Keithley 7152 4x5 Low Current Matrix Switch Card. Allows computer controlled switching between sample geometries and metered or unmetered sample currents.

Sample geometries: van der Pauw, 4-wire, Hall bar or 6-wire.

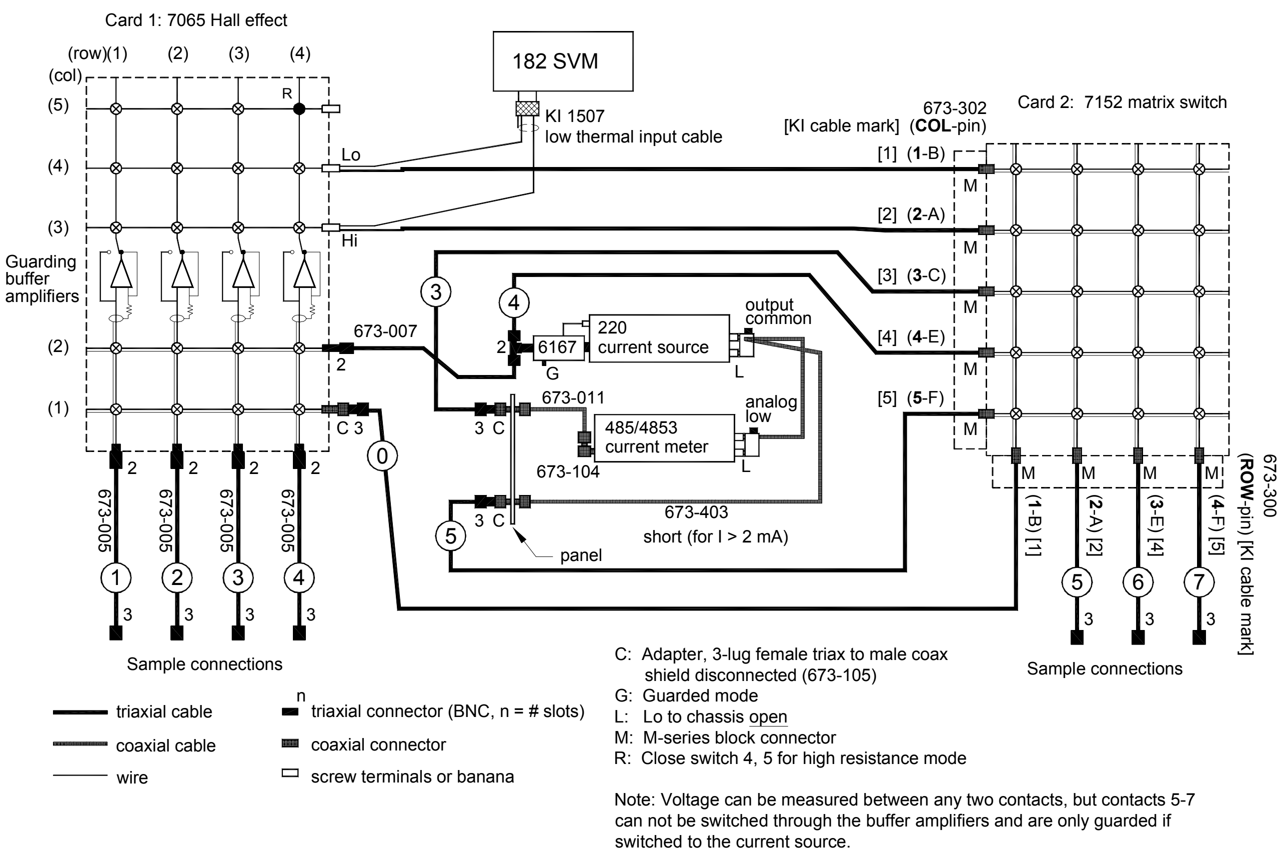


Figure 3-25 -LVWR-HS-SWT measurement configuration schematic (dwg. 108-97-00 rev. B).

Table 3-12 -LVWR-HS-SWT measurement configuration connection list.

#	CONNECTION	FROM	TO
1	6167 Guarded adapter for 220 current source (set **Db3** for guarded operation)	(**Db4**) Input on 6167 (**Db1**) single banana plug on 6167	(**Da1**) Output on back of 220 current source (**Da2**) Guard output on back of 220
2	673-102, Triaxial tee, (1) 2-slot to (2) 2-lug	(**Db2**) Output on back of 6167 Guarded adapter	(to be completed by connections # 11.4, 12)
3	673-011, coaxial low noise cable, 1.2 m long	(**E6**) Front of 485 current meter	(**H1-inside**) Current meter bulkhead BNC
4	673-403, 7500 return current cable assembly	(**Da3-4**) Double cable end banana, GND to output common	(**H2-inside**) Shorted coaxial BNC bulkhead, and (**Ea4-5**) single cable end banana, GND to analog low
5	673-105, Adapter, BNC to 3-lug triax, triax shield isolated, guard to coax shield	(**Cb1**) Current output on 7065 Hall card	(to be completed by connection # 17.1)
6	673-105, Adapter, BNC to 3-lug triax, triax shield isolated, guard to coax shield	(**H1**) Current meter bulkhead coaxial BNC	(to be completed by connection # 11.3)
7	673-105, Adapter, BNC to 3-lug triax, triax shield isolated, guard to coax shield	(**H2**) Shorted bulkhead coaxial BNC	(to be completed by connection # 11.5)
8	182 low noise input to twisted pair, bare wire ends	(**Ab1**) Input on front of 182 SVM	(**Cb10-11**) Terminal block on 7065 Hall card
9	Keithley 7065 Hall effect card		(**Ca1**) Slot #1 in the 7001 switch system mainframe
10	Keithley 7152 4x5 Low current matrix switch card		(**Ca2**) Slot #2 in the 7001 switch system mainframe
11	673-302, Cable assembly, M-series connector to (2) bare ends, (3) 3-slot triax	(**Cc2**) Column input on 7152 switch card, (tape marker #**1**) bare (tape marker #**2**) bare (tape marker #**3**) trx3 (tape marker #**4**) trx3 (tape marker #**5**) trx3	 (**Cb10**) Lo term. 7065 card (**Cb11**) Hi term. 7065 card (**H1**) Current meter Adapter (**Db2**) Triaxial tee on 6167 (**H2**) Shorted Adapter
12	673-007, Triaxial cable, 2-slot, 0.9 m long	(**Cb6**) Current input on 7065 Hall card	(**Db2**) Triaxial tee on back of 6167
13	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (1)	(**Cb2**) Sample input #1 on 7065 Hall card	(**B1**) Junction box of sample holder module
14	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (2)	(**Cb3**) Sample input #2 on 7065 Hall card	(**B2**) Junction box of sample holder module
15	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (3)	(**Cb4**) Sample input #3 on 7065 Hall card	(**B3**) Junction box of sample holder module
16	673-005, Triaxial cable, 2-slot to 3-slot, 3 m long, marked (4)	(**Cb5**) Sample input #4 on 7065 Hall card	(**B4**) Junction box of sample holder module
17	673-300, Cable assembly, M-series connector to (5) 3-slot triax, 3 m long	(**Cc4**) Row output on 7152 switch card, (Sample input #**0**, tape marker #1) trx3 (Sample input #**5**, tape marker #2) trx3 (Sample input #**6**, tape marker #4) trx3 (Sample input #**7**, tape marker #5) trx3 (Sample input #**8**, tape marker #3) trx3	 (**Cb1**) Adapter on 7065 current output (B**5**) Junction box of sample holder module (B**6**) Junction box of sample holder module ( ) user defined ( ) not connected

3.4.9 -HVLR: High Voltage, Low Resistance Range Measurement Configuration

Keithley 7012-S 4x10 Matrix Switch Card allows for a broad range of excitations and sample geometries, but limits accurately measurable sample resistances to a few megohms.

Operation to ±100 V, ±100 mA.

Sample geometries: van der Pauw, 4-wire, Hall bar or 6-wire.

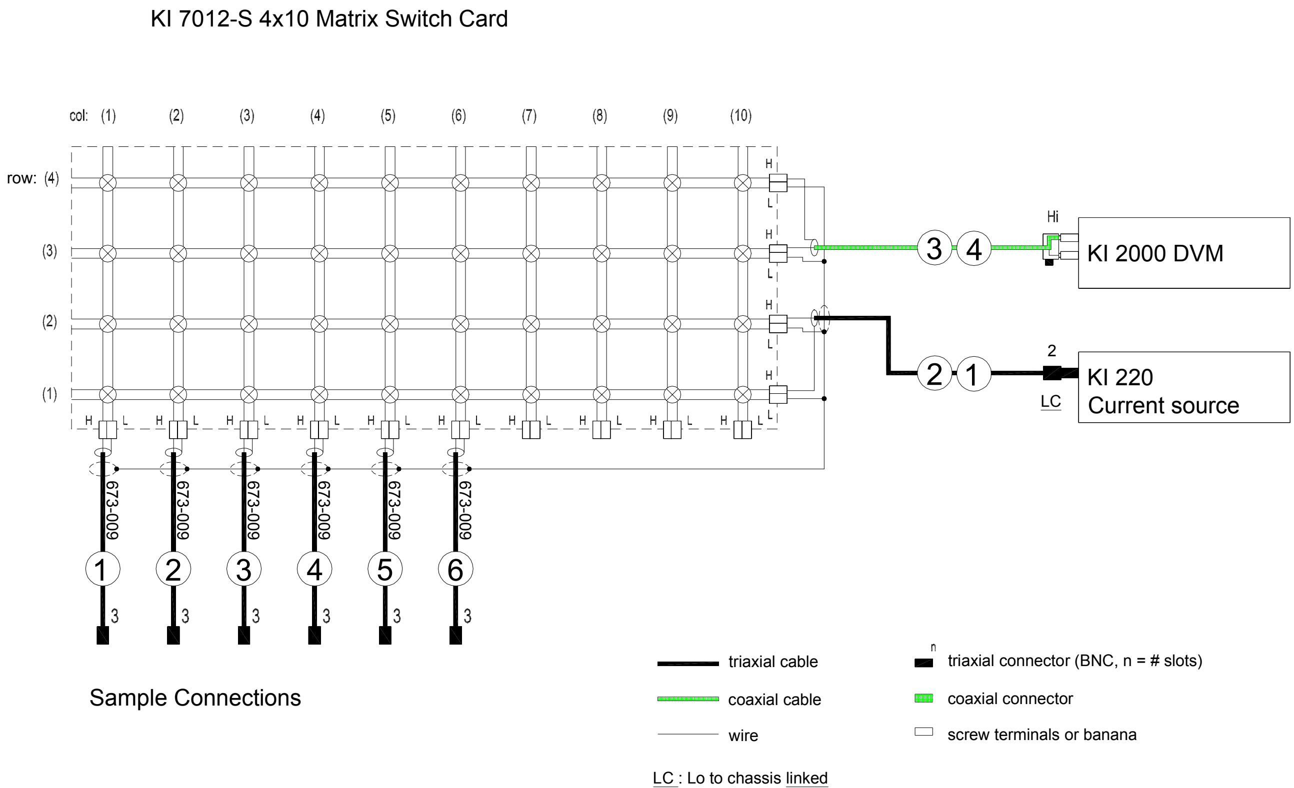


Figure 3-26 -HVLR measurement configuration schematic (dwg. 150-98-00 rev. -).

Table 3-13 -HVLR measurement configuration connection list.

#	CONNECTION	FROM	TO
1	673-410, Banana to twisted pair, bare wire ends, marked "**34**"	(**Cd1**) Row terminal block on 7012-S switch card: - Cable Hi to **Row 3 Hi** - Cable Lo to **Row 4 Hi**	(**Aa3-4**) Input on 2000 DVM, GND tab to Lo
2	Triaxial cable, unterminated to 2-slot, 0.9 m long, marked "**21**"	(**Cd1**) Row terminal block on 7012-S switch card: - Center to **Row 2 Hi** - Inner shield to **Row 1 Hi** - Outer shield to **Shield Com**	(**Da1**) Output on back of 220 current source
3	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**1**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 1 Hi** - Inner shield to **Col 1 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**1**
4	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**2**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 2 Hi** - Inner shield to **Col 2 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**2**
5	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**3**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 3 Hi** - Inner shield to **Col 3 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**3**
6	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**4**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 4 Hi** - Inner shield to **Col 4 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**4**
7	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**5**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 5 Hi** - Inner shield to **Col 5 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**5**
8	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**6**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 6 Hi** - Inner shield to **Col 6 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**6**
9	Keithley 7012-S 4x10 matrix switch card		(**Ca1**) Slot #1 in the 7001 switch system mainframe

3.4.10 -HVLR-HS: High Voltage, Low Resistance Range, High Sensitivity Measurement Configuration

Keithley 7012-S 4x10 Matrix Switch Card allows for a broad range of excitations and sample geometries, but limits accurately measurable sample resistances to a few megohms.

Operation to ±100 V, ±100 mA.

High sensitivity option (750HS) for improved measurement of low voltages.

Sample geometries: van der Pauw, 4-wire, Hall bar or 6-wire.

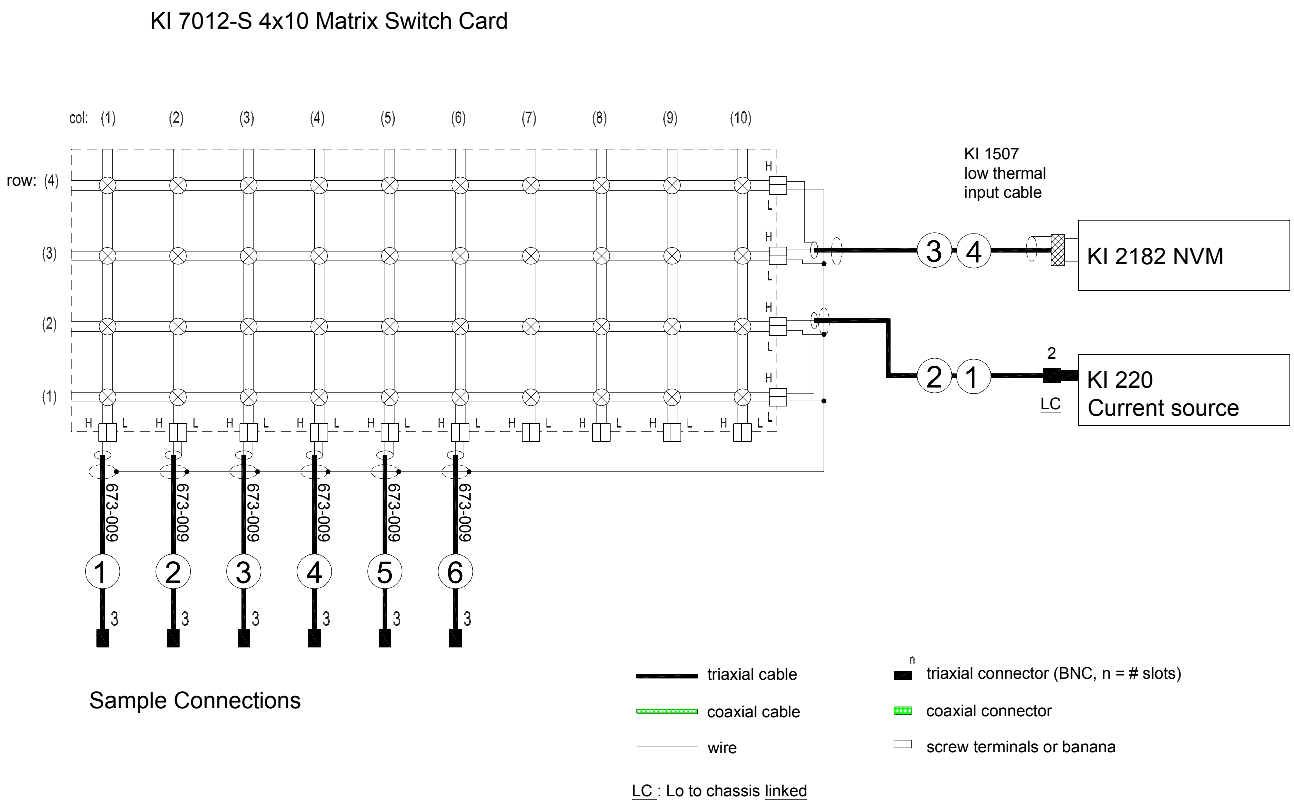


Figure 3-27 -HVLR -HS measurement configuration schematic (dwg. 151-98-00 rev. A).

Table 3-14 -HVLR -HS measurement configuration connection list.

#	CONNECTION	FROM	TO
1	182 low noise input to twisted pair, bare wire ends, marked "**34**"	(**Cd1**) Row terminal block on 7012-S switch card: - Cable Hi to **Row 3 Hi** - Cable Lo to **Row 4 Hi**	(**Ab1**) Input on front of 182 SVM
2	Triaxial cable, unterminated to 2-slot, 0.9 m long, marked "**21**"	(**Cd1**) Row terminal block on 7012-S switch card: - Center to **Row 2 Hi** - Inner shield to **Row 1 Hi** - Outer shield to **Shield Com**	(**Da1**) Output on back of 220 current source
3	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**1**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 1 Hi** - Inner shield to **Col 1 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**1**
4	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**2**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 2 Hi** - Inner shield to **Col 2 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**2**
5	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**3**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 3 Hi** - Inner shield to **Col 3 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**3**
6	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**4**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 4 Hi** - Inner shield to **Col 4 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**4**
7	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**5**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 5 Hi** - Inner shield to **Col 5 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**5**
8	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**6**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 6 Hi** - Inner shield to **Col 6 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**6**
9	Keithley 7012-S 4x10 matrix switch card		(**Ca1**) Slot #1 in the 7001 switch system mainframe

3.4.11 -LVLR: Low Voltage, Low Resistance Range Measurement Configuration

Keithley 7012-S 4x10 Matrix Switch Card allows for a broad range of excitations and sample geometries, but limits accurately measurable sample resistances to a few megohms.

Operation to ±5 V, ±1 mA.

Sample geometries: van der Pauw, 4-wire, Hall bar or 6-wire.

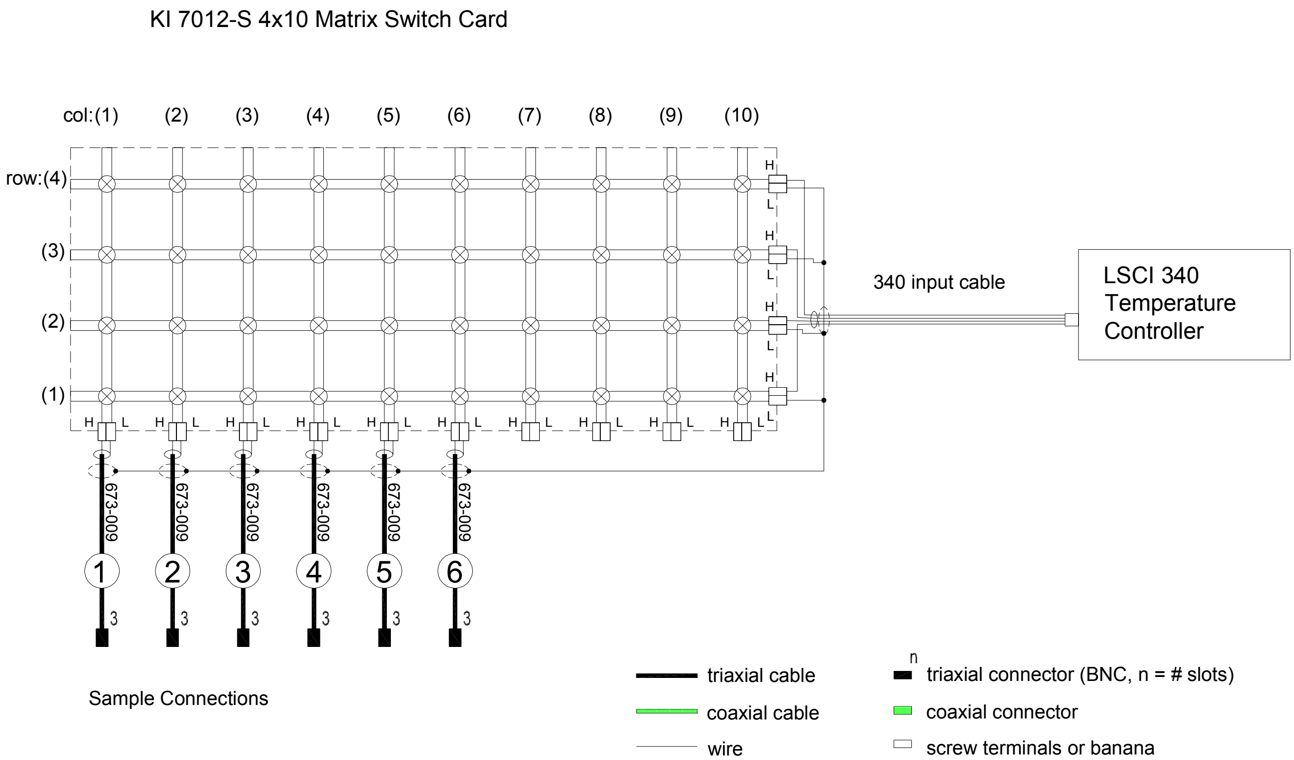


Figure 3-28 -LVLR measurement configuration schematic (dwg. 152-98-00 rev. -).

Table 3-15 -LVLR measurement configuration connection list.

#	CONNECTION	FROM	TO
1	340 input cable	(**Cd1**) Row terminal block on 7012-S switch card: - Cable 1 to **Row 1 Hi** - Cable 2 to **Row 2 Hi** - Cable 3 to **Row 3 Hi** - Cable 4 to **Row 4 Hi** - Shield to **Shield Com**	(**G8**) Input card in 340 temperature controller
2	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**1**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 1 Hi** - Inner shield to **Col 1 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**1**
3	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**2**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 2 Hi** - Inner shield to **Col 2 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**2**
4	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**3**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 3 Hi** - Inner shield to **Col 3 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**3**
5	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**4**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 4 Hi** - Inner shield to **Col 4 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**4**
6	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**5**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 5 Hi** - Inner shield to **Col 5 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**5**
7	673-005, Triaxial cable, unterminated to 3-slot, 4.5 m long, marked (**6**)	(**Cd2**) Col terminal block on 7012-S switch card: - Center to **Col 6 Hi** - Inner shield to **Col 6 Lo** - Outer shield to **Shield Com**	(**B1**) Junction box of sample module, Sample #**6**
8	Keithley 7012-S 4x10 matrix switch card		(**Ca1**) Slot #1 in the 7001 switch system mainframe

3.5 INSTRUMENT SETUP

3.5.1 System Power Up

All instruments should be checked earlier for appropriate input power settings along with the input power line. If a 450 Gaussmeter is present, connect the Hall probe before powering up the instrument.

Plug the input power cord into an outlet. Turn on the outlet strip in the instrument console. Power up all the instruments. All the front panel lights should come on. If not, check the power cord connection to the instrument or the outlet strip.

3.5.2 7001 Switch System Mainframe Setup

1. IEEE-488 address = **6**. Must set address (default is 7): **Menu** -> **GPIB** -> **Enter** -> **Address** -> **Enter** -> **06** -> **Enter** -> **Exit** -> **Exit**.
2. **Card configuration:**
    - Press Card Config: find the single key marked (SCAN/Card) with Configuration above it and press on the **Card** side.
    - -HVWR: Follow the key path: **Enter** -> **Slot 1** -> **Enter** -> hit either the < or > arrow key several times to show "**7152**" -> **Enter**.
    - -LVWR: follow the key path: **Type** -> **Enter** -> **Slot 1** -> **Enter** -> hit either the < or > arrow key several times to show "**7065**" -> **Enter**.
    - -SWT or –HVWR (second card): Follow the key path: **Enter** -> **Slot 2** -> **Enter** -> hit either the < or > arrow key several times to show "**7152**" -> **Enter**.
    - -HVLR: Follow the key path: **Enter** -> **Slot 2** -> **Enter** -> hit either the < or > arrow key, if necessary, to show "**7012**" -> **Enter**.
    - Push **Exit** several times.

3.5.3 2000 Voltmeter Setup (no -HS option)

1. IEEE-488 address = **16** (default). To check: Shift -> **GPIB** -> **Enter** to check, then -> **Exit**
2. Push in button on front panel to select **rear inputs**.

3.5.4 182 Sensitive Digital Voltmeter Setup (-HS option)

1. IEEE-488 address = **7** (default).
2. Push **Auto Range** button - should remain lit.

3.5.5 6512 Programmable Electrometer Setup (-HVWR measurement configuration)

1. Push Zero Check button on front panel to get out of zero check mode (otherwise displays only zeroes).
2. On back panel set switch to guarded **ON** position.
3. On back panel, verify link between COM and chassis ground is **removed** (should be in instrumentation accessories bag).

3.5.6 220 Current Source Setup

1. Set IEEE-488 address = **21** (default = 12) using the 220 rear DIP switch selector. Set switches to 1-0-1-0-1 in order from A5 to A1. A switch is set to 1 or 0 when that side of the rocker switch is lying flat and not sticking up. Can be checked by cycling power. Shows on screen during power up sequence as "IE 21".
2. On back panel, verify link between Output Common and chassis ground is **removed** (should be in instrumentation accessories bag). **Exception**: Systems with the –HVLR measurement configuration option must have link installed.
3. If a 6167 Guarded Adapter is attached to the back panel ouput, it must be set to **Guarded** mode.

3.5.7 485/4853 Picoammeter Setup

1. IEEE-488 address = **22** (default). To check, look at rear instrument dip switches. Should have switches 2+4+16 = 22 set on.
2. **Autorange** button pushed in (AUTO appears on display).
3. Zero check out.
4. Make sure REL and LOG are not lit on display.

3.5.8 486 or 487 Picoammeter Setup

These instructions apply to the -HVWR Configuration or a CE Mark System.

1. IEEE-488 address = **22** (default). Check and set through the front panel.
2. **Autorange** button pushed in (AUTO appears on display).
3. Zero check off.
4. Set filtering to "**digital + analog**".
5. On back panel, make sure the link between Analog Output Lo and chassis ground has been **removed** (should have been placed in the instrumentation accessories bag).

3.5.9 340 Temperature Controller Setup

These instructions apply to 750TC Option, -LVLR Configuration, or the 9500 Series. Setup of the 340 Temperature Controller depends on the number and type of heaters and sensors in the sample module. Complete setup instructions are given in Chapter 4 for each sample module type.

3.5.10 450 Gaussmeter Setup

1. Must change to IEEE-488 address = **8** (default = 12). You cannot change the address unless the Hall probe is connected. To change, push **Address** button on front panel -> change to **8** -> Terminators to Cr Lf, **Enter**.
2. Set for **Autorange**.
3. Zero Hall probe using zero gauss chamber.

3.5.11 620/622 MPS Setup (9500 Series Systems)

1. The two small white V, I MODE switches on the back of the MPS should be set to **INT**.

The following settings are performed through the front panel. Refer to the 647 MPS user's manual for instructions. Note that older 647s had lower current and voltage limits - input the maximum available for your 647 MPS.

<u>Front Panel Firmware (Dated 8 January 1997)</u>

2. Set display view angle: Function Menu -> INTERFACE SETUP -> VW ANGLE: **8**.
3. Go to Function Menu -> INSTR. SETUP, set the following:
   IMAX SET: **50 A**
   Compliance: **5 V**
   Fld Enable: **<ON>**
   B Units: **kG**
   kG/A: **1.123** (set from datasheet)
   IMAX SET: **50 A**
   Compliance: **3.0 V**
   Normal Display.
4. Set: I Step Limit **OFF**. Follow: Function menu -> I STEP LIMIT/ZERO -> toggle CURRENT STEP LIMIT to OFF -> Normal Display.
5. Leave the IEEE-488 address at its default value of **12**. To check, follow: Function Menu -> INTERFACE SETUP -> IEEE/SIO -> IEEE ADD: **12** -> Normal Display.

3.5.12 647 MPS Setup (7504, EM4 electromagnet systems)

1. The two small white V, I MODE switches on the back of the MPS should be set to **INT**.
2. Cooling water must be turned on to proceed if the flow switch has been connected. Verify that the normal front panel display is showing.

The following settings are performed through the front panel. Refer to the 647 MPS user's manual for instructions. Note that older 647s had lower current and voltage limits - input the maximum available for your 647 MPS.

<u>New Front Panel Firmware</u>

3. Set display view angle: Function Menu -> INTERFACE SETUP -> VW ANGLE: **8**.
4. Set maximum current: Function Menu -> INSTR. SETUP: IMAX SET: **75 A.**
5. Set compliance voltage: Function Menu -> INSTR. SETUP: COMPLIANCE: **32 V** -> Normal Display.
6. Set: I Step Limit **OFF**. Follow: Function menu -> Next -> Next -> I STEP LIMIT -> toggle to OFF -> Normal Display.
7. Leave the IEEE-488 address at its default value of **12**. To check, follow: Function Menu -> INTERFACE SETUP -> IEEE/SIO -> IEEE ADD: **12** -> Normal Display.

<u>Old Front Panel Firmware</u> (release date: 1-JUN-1995)

3. Set display view angle: Function Menu -> SETUP -> VW ANGLE: **8**.
4. Set maximum current: Function Menu -> SETUP -> IMAX SET: **75 A**.
5. Set compliance voltage: Function Menu -> SETUP -> VMAX SET: **32 V** -> Normal Display.
6. Set: I Step Limit **OFF**. Follow: Function menu -> Next -> Next -> I STEP LIMIT -> toggle to OFF -> Normal Display.
7. Leave the IEEE-488 address at its default value of **12**. To check, follow: Function Menu -> SETUP -> IEEE/SIO -> IEEE ADD: **12** -> Normal Display.

3.5.13 665 or 668 MPS Setup (7507 or 7512, EM7 or EM12 electromagnet systems)

1. Turn ON the AC POWER on the Magnet Power Supply (MPS).
2. Verify that the flow switch is connected.
3. Turn on cooling water.
   NOTE: These instructions are for air-cooled models.
4. Set the 665/668 MPS for LOCAL operation:
   - **I MODE** setting selected
   - **LOCAL** setting selected
   - CURRENT LIMIT potentiometer set to **10.0** and locked
   - VOLTAGE LIMIT potentiometer set to **10.0** and locked
   - LOCAL REFERENCE potentiometer set to **5.0**
5. Push the Instrument Power **RESET**, then **ON** buttons on the 665/668 MPS front panel. Allow time for the relays to close and the Status READY, then ON lamps to light.
6. Test the power supply in manual mode first to verify operation at full positive and negative currents:
   - Turn the Local Reference potentiometer slowly up to **10.0** (take about 1 minute to ramp up) and verify that the Current Output meter reads full positive current (665: +100 A; 668: +130 A).
   - Turn the Local Reference potentiometer slowly down to **0.0** (take about 2 minutes to ramp down) and verify that the Current Output meter reads full negative current (665: -100 A; 668: -130 A).
   - Turn the Local Reference potentiometer slowly up to **5.0** (take about 1 minute to ramp up) to return to zero current output.
7. Push the Instrument Power **OFF** button. Allow time for the relays to close and the Status ON lamp to go out.

8. Set the 665/668 MPS for REMOTE operation:
   - **REMOTE** setting selected
   - LOCAL REFERENCE potentiometer set to **5.0** and locked
9. Push the Instrument Power **RESET**, then **ON** buttons to leave power supply on and ready for remote control operation.

When setup and initial testout are complete and the power supply is to be shut down, continue with:

10. Push the Instrument Power **OFF** button. Allow time for the relays to close and the Status ON lamp to go out.
11. Turn OFF the AC POWER.
12. Turn off cooling water.

3.6 SOFTWARE SETUP

Lake Shore normally performs software setup prior to shipment; it is not required during a typical system installation. This section is included only for reference in case a newer version of the operating system or Hall System Software is installed on the computer.

See the ReadMe file installed in the Hall program directory for the most current computer system requirements, installation instructions, and tips on known problems with the software.

3.6.1 Software Installation

Insert disk #1 into the disk drive and Run "A:setup" (assuming disk drive A is used) or double click the **Setup** program icon or filename. Follow the prompts to configure the software.

Check the ReadMe.txt file installed in the Hall program directory for the most current information and requirements pertaining to the version installed. Verify system requirements are met before attempting to run the software.

3.6.2 Windows Operating System Setup

See the ReadMe file in the Hall program directory for the most current recommended Windows operating system settings.

1. After restarting Windows, the Lake Shore window appears on the desktop. If the directory does not appear, find and open it. The Lake Shore directory contains shortcuts to many of the important programs and documents. Create a shortcut to the Lake Shore directory and place it on the desktop.
2. Create a shortcut to the Hall program. Right click and drag the Hall program from the Lake Shore directory onto the desktop, but away from other shortcut icons (the idea is to make it stand out from everything else). Select 'create a shortcut here' from the menu which appears.
3. Remove HP Lock program. Follow the path: **Start** button on desktop screen -> **Settings** -> **Add/Remove Programs** -> **Install/Uninstall** tab -> select "**HP Lock**" from the menu, click the **Add/Remove** button, and respond **OK** to remove. Restart computer.
4. Set for No Power Management. Follow the path: **Start** button on desktop screen -> **Settings** -> **Power** -> **Power** tab -> uncheck "**Allow Windows to manage power use on this computer**", and click the **Apply** button. Restart computer.
5. Set the Task bar at the bottom of the screen to 2 row height.
6. Set Clock. Right click on clock icon in lower right corner of screen and set the date and time if incorrect.

3.6.3 Multiple-Boot System Setup

This section is necessary ONLY if the system is to be operated with different measurement system configurations requiring separate IDEACFG.ini files (e.g. operation as both 7500 Series HMS and 9500 Series CHMS). If in doubt, check the sales order for the **750MB** option or check the BOM for the **Partition Magic** program, either indicating the system should be set up for multiple-boot systems.

The following instructions are written for two boot drives. If more boot drives are required, adjust as needed.

1. Make sure all of the previous steps (communications card, printer, network setup, etc.) have been completed or additional work will be required for each boot drive set up.
2. Locate the program **Partition Magic** which also includes in the package the program **Boot Magic**.
3. Install **Partition Magic** on the **C**: drive.
4. Create **two each** of the following boot disks: 1) Partition Magic Rescue Disk, 2) Partition Magic Help Disk, and 3) Boot Magic Rescue Disk. Ship one set with the system and archive the other set with the sales order folder.
5. Run **Partition Magic** and **Resize** the **C**: drive to about 1.5 times the size of the contents of the hard disk. Example: if the **C**: drive currently contains 300 MB of software, resize to 450 MB.
6. **Rename** the C: drive as "7500 Electromagnet HMS".
7. **Copy** this partition to create a hidden partition of the same size containing an identical operating system. **NOTE**: If more than two boot drives are needed (system has more than two configurations), copy to create the number needed.
8. Restart the computer.
9. Run **Partition Magic** and **Rename** the hidden partition as "9500 Cryo HMS".
10. **Create** a partition equal to all remaining space on the hard drive and make this the **D**: drive. **Rename** it "Hall Data".
11. Restart the computer.
12. Install the **Boot Magic** program on the **C**: drive.
13. Run **Boot Magic** and click **Add**. Select the hidden volume named "9500 Cryo HMS".
14. Make sure the "7500 Electromagnet HMS" volume is the default.
15. Restart the computer.

3.6.4 File Structure

See the ReadMe file on disk #1 of the Hall System Software installation disks for the most current information on file structure requirements. The following file structure requirements apply to Hall software versions through 1.6.

The destination directory where the Hall program installs must be on the same drive and at the same level as the WINDOWS directory. The name of the Hall program directory is limited to 8 characters (no spaces). The default name and location are currently C:\IDEAHALL.

Names of all Hall experiment files are limited to 8 characters (no spaces). The program automatically adds the appropriate extension.

To be run, Hall experiment files (*.hal) must be inside the Hall program directory, but not within a sub directory (folder). Create all Hall experiment files within the Hall program directory. All data files created and used by the Hall experiment must also be present at the same directory level. Examples of such files include:

*.hpf	Magnetic field profile file	for Variable Field Measurements
*.cpf	Current profile file	for Variable Current Measurements
*.tpf	Temperature profile file	for Variable Temperature Measurements
*.ary	Array (B, T) profile file	for B,T Array Measurements

After running, Hall programs can be moved to another directory (folder). The programs can be opened for viewing from within the Hall program, but can not be run. The program and all associated data files must be moved back to the Hall program directory before being run.

3.6.5 Configuration File Modification (ideacfg.ini)

The initialization file 'ideacfg.ini' resides in the C:\WINDOWS directory. It contains information about the Hall measurement system necessary for Hall program operation. Information includes: hardware, instrumentation, IEEE-488 addresses, driver programs, last Hall experiment run, etc. The entries are case sensitive. Do not modify the initialization program without first consulting Lake Shore. General notes:

1. Edit the initialization file 'ideacfg.ini' with any text editor. Notepad is a convenient editor provided with the Windows operating system.
2. To comment a line out, add the character "`x`" at the beginning of the line.
3. Physical instruments have addresses corresponding to IEEE-488 addresses. No two physical instruments can have the same IEEE-488 address. Virtual instrument drivers [VIRTUAL RESISTANCE, VIRTUAL FIELD CONTROL, V340] all have an address = 12, but this is not the same as an IEEE-488 address, so there is no conflict.
4. The last Hall experiment run is identified at the end of the section headed **`[HALL]`**. Two example lines are:
   ```
   Last experiment=SiBLR_B1.hal
   Last experiment=none
   ```
   If a file becomes corrupted and causes the Hall program to crash on opening, change the last experiment to "none", save the ideacfg.ini file, and restart Windows and the Hall program. It should then start properly with no experiment file initially open.
5. The tolerance between the specified magnetic field (induction) and the field considered close enough for a measurement sequence to begin is specified in the section headed **`[HALL]`** with a line:
   ```
   Field Tolerance=10
   ```
   The default units are gauss (G) unless accompanied by a line "MODE=PerCent", in which case the number is the percent of the requested field. Percent mode is normally not used for Hall measurements because of the need to make measurements at zero field. The field tolerance can be made greater if a sample is not strongly field dependent and high accuracy is not as important as slightly more rapid measurement. Do not set field tolerance less than the combined noise and control range of the field control program, typically about 1-2 gauss.
6. Some Hall system measurement configurations can switch between circuits optimized for the measurement of either high or low resistance samples. The breakpoint resistance used to switch between high and low resistance ranges is specified in the section headed **`[HALL]`** with a line:
   ```
   High Resistance Threshold=100000
   ```
   A typical value is 100,000 ohms, but it it can be changed either higher or lower.
7. The maximum number of iterations allowed when automatically determining the sample excitation current (in constant voltage or power modes) is specified in the section headed **`[HALL]`** with a line:
   ```
   Maximum Current Iterations=100
   ```
   Fewer iterations reduces the time potentially wasted determining an excitation for an unpredictable sample. However, too few iterations, and the program will have problems finding a suitable excitation current even for good samples.
8. The electromagnet characterization file to be used is specified in the section
   ```
   [VIRTUAL FIELD CONTROL]
   Last Config File=EM7_6_2.CFG
   ```
   A different electromagnet characterization file can be specified by editing the ideacfg.ini file (not the preferred method) or by running the Field Control program and loading a different file or running a new magnet characterization.

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4. SAMPLE MODULE SETUP AND OPERATION

Contents:

4.1 MODEL 75013 SCSM - SAMPLE CARD SAMPLE MODULE

The Lake Shore Model 75013 SCSM normally ships with all 7500 Series Hall measurement systems. Figure 4-1 shows the sample module with components labeled, but without the hardware necessary to mount to a specific electromagnet.

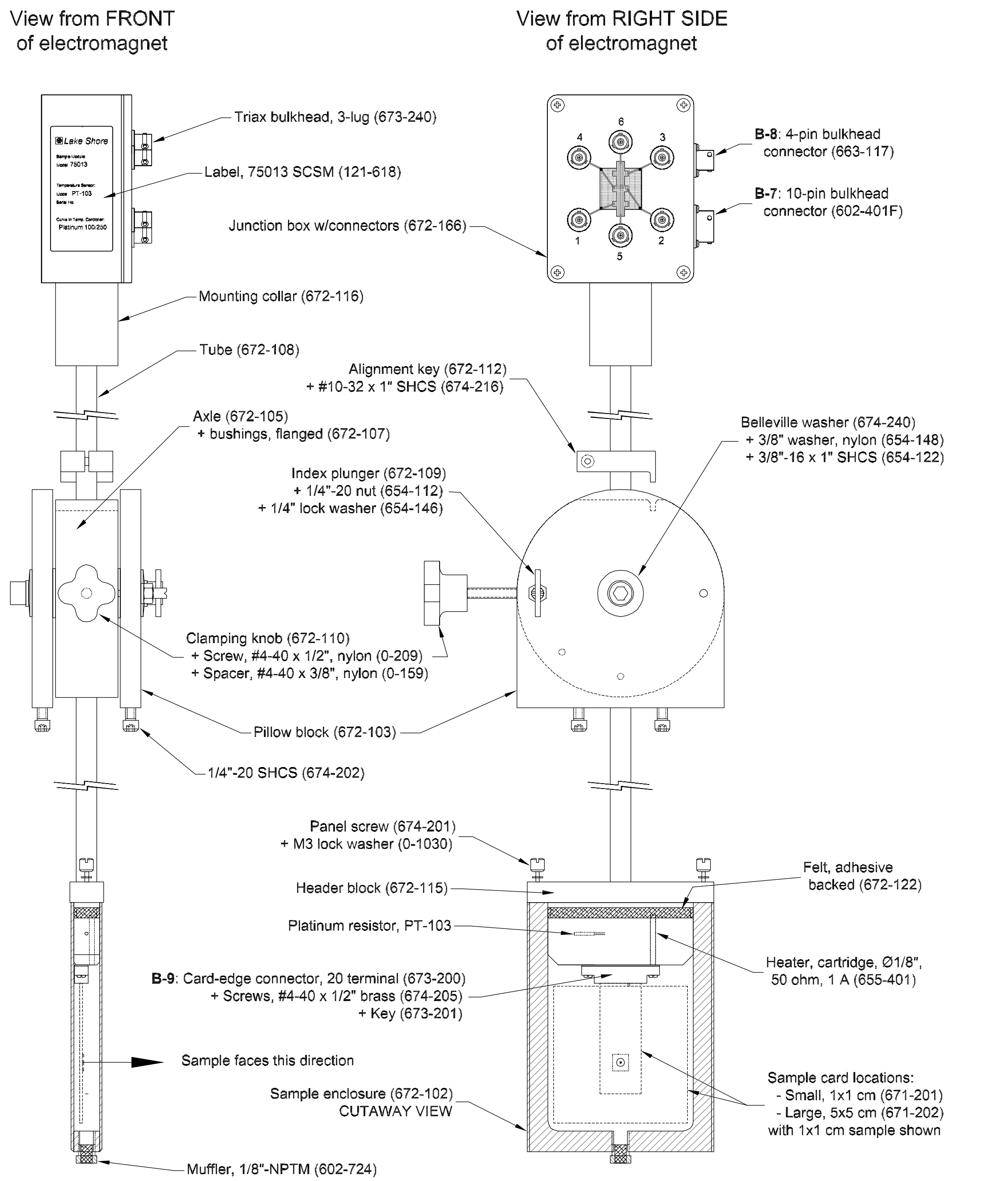


Figure 4-1. Model 75013 SCSM Assembly Overview

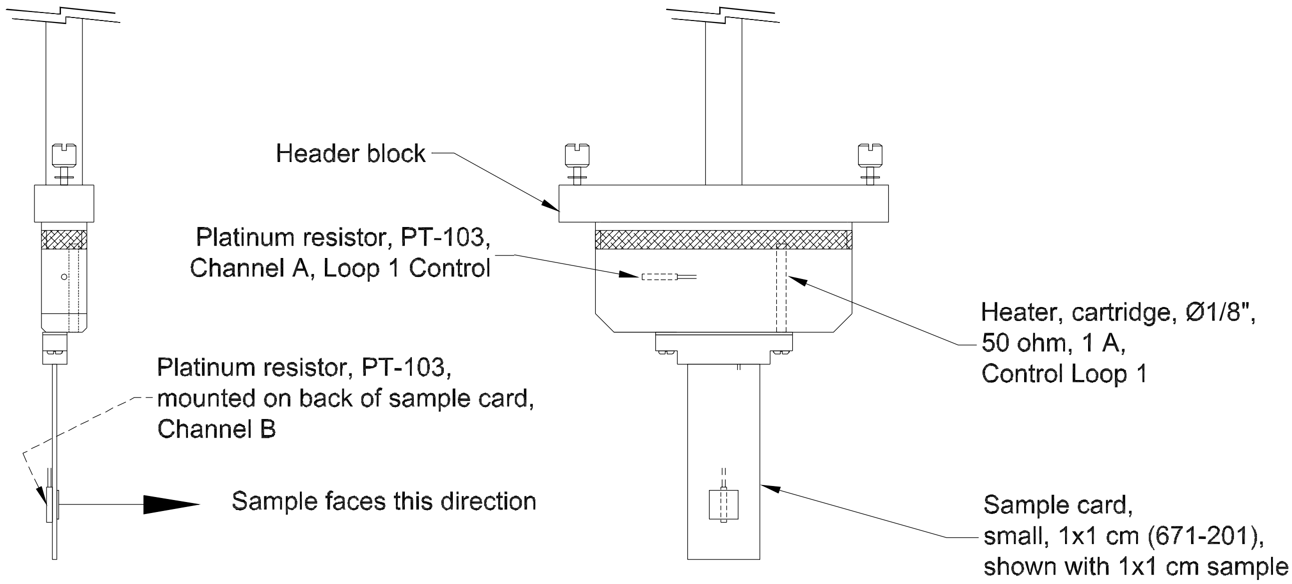


Figure 4-2. Temperature Monitoring and Control Instrumentation in the 75013 SCSM.
NOTE: The platinum resistor on the back of the sample card is optional.

Table 4-1. Sample Connection Wiring for the 75013 SCSM.
The wire resistance is measured from the connector on the junction box to the card edge connector.

Connector	Pin	Use	Wire R [Ω]
B-1	**1**	Sample card pad # 1	25
B-2	**2**	Sample card pad # 2	25
B-3	**3**	Sample card pad # 3	25
B-4	**4**	Sample card pad # 4	25
B-5	**5**	Sample card pad # 5, I+ for Hall bars	25
B-6	**6**	Sample card pad # 6, I– for Hall bars	25
B-7	**A**	Sample card pad 10; "Sensor" temperature sensor (Channel **B**), V–	8
	B	Sample card pad 9; "Sensor" temperature sensor (Channel **B**), V+	8
	C	Sample card pad 8; "Sensor" temperature sensor (Channel **B**), I–	8
	J	Sample card pad 7; "Sensor" temperature sensor (Channel **B**), I+	8
	D	Heater, 50 Ω, 1 A, in header block (Loop 1), I+	8
	E	Heater, 50 Ω, 1 A, in header block (Loop 1), I–	8
	G	"Control" temperature sensor (Channel **A**), V–	8
	H	"Control" temperature sensor (Channel **A**), V+	8
	F	"Control" temperature sensor (Channel **A**), I–	8
	K	"Control" temperature sensor (Channel **A**), I+	8
B-8		unused	

4.1.1 Setting up the Model 75013 SCSM

Setup must be performed in the following cases:

1. Initial setup following shipping or long term storage.
2. Quick setup following sample module exchange in the electromagnet.

The 75014 CCRSM can be removed from an electromagnet and stored on a stand without detatching many of the connections, so Case 2 is simpler and often does not require all the steps in the initial setup. Table 4-2 lists the steps required for setup. The table gives an overview and also can be used as a checklist.

Table 4-2. Model 75013 SCSM Setup Steps.
Reference refers to the relevant section in this manual.
An asterisk (*) indicates the full procedure is not always required.

Initial	Quick	Description	Reference	
1		Unpacking, Assembly and Familiarization	4.1.1.1	
2	1	Installation in an Electromagnet	4.1.1.2	
3	2*	Alignment	4.1.1.3	
4	3	Electromagnet Gap Setting, Dewar and Cradle Insertion	4.1.1.4	
5	4	Gaussmeter Probe Orientation and Installation	4.1.1.5	
6	5*	Temperature Controller Setup (750TC option only)	4.1.1.6	

4.1.1.1 Unpacking, Assembly and Familiarization

1. **Unpack sample module**. The 75013 SCSM is shipped in a long cardboard box with the sample module. Additional hardware for mounting to an electromagnet is shipped disassembled. Bags of sample mounting accessories, spare parts, and other accessories are also included. Check the packing list to make sure all items were received. If possible, save the packaging in case future shipping is required.
2. Remove the sample enclosure. Loosen the two panel screws on top of the header block, then pull the black sample enclosure straight down.
3. Inspect the sample card plugged into the card edge connector (refer to sections 4.1.3.1 or 4.1.3.5 before inserting or removing sample cards. The 75013 SCSM is typically shipped with the last sample tested during qualification by Lake Shore. This sample can be removed and returned to its slot in the box of sample cards or left in place for checkout of the sample module. One side of the sample card has an area for mounting samples surrounded by contact pads numbered 1 to 6. The sample should face the same direction as the junction box. Note that the junction box has six numbered triaxial bulkhead connectors in the same pattern and orientation as the six numbered contacts on the sample card. Inside the triaxial connectors are schematic pictures of wired samples for van der Pauw (4 connections) and one type of Hall bar (6 connections) measurements. The schematic picture on the junction box serves as a quick reference for connecting samples.
4. Inspect the felt strip around the header block. Many semiconductors are light sensitive and Hall effect measurements are normally performed with the sample in the dark. The felt helps to make a light-tight seal between the header block and sample enclosure. A roll of similar felt is in the muffler on the bottom of the sample enclosure. If the felt becomes worn, replace it. Extra felt is in the 75013 SCSM spare parts kit provided.
5. Replace the sample enclosure and tighten the panel screws. Note the star washers under the panel screws. The star washers are important for providing electrical contact between the body of the 75013 SCSM and the sample enclosure for grounding and shielding. The electrical resistance should be less than 1 ohm between the muffler on the bottom of the sample enclosure and the outer shells of the triaxial BNC bulkhead connectors on the junction box. Check this resistance.

6. Loosen the clamping knob just enough to allow the rod to move, then move the rod a short distance through the axle to get a feel for the motion. Between the clamping knob and the rod is a piece of nylon which serves to prevent damage to the smooth rod surface. Overtightening the clamping rod can damage the nylon piece. If the clamping knob is removed, be sure the nylon piece is in place before replacing the clamping knob.
7. The alignment key has a tongue which fits snugly into a slot in the axle, assuring repeatable alignment of the sample. Push the rod to engage the alignment key in the axle slot and tighten the clamping knob.
8. The index plunger in the right side pillow block allows the 75013 SCSM assembly to lock into one of three positions: vertical, 45 degrees, or horizontal. Pull the index plunger T-handle out and rotate 90 degrees so the handle rests in the fully retracted position. The pillow block can now rotate relative to the axle. Rotate so the flat on the pillow block is parallel to the sample module rod. Now rotate the T-handle so it drops in the slot and rotate the pillow block until the plunger clicks into position. The pillow block should now be locked in position with the flat parallel to the rod. Rotate the other pillow block so the flats are parallel.
9. Mount the 75013 SCSM to its base plate. Orient the sample module with the pillow blocks on top of the base plate (flat side) and the sample enclosure end pointing in the same direction as the U-shaped cutout in the base plate. Insert four screws (1/4"-20 × 3/4" SHCS) up through the bottom of the base plate (side with recesses for the screw caps) into the two pillow blocks and tighten. When rotated into the vertical position (as shown in Figure 4-3), the clamping knob must extend over the U-shaped cutout in the base plate and the junction box and sample will both face to the right.

4.1.1.2 Installation in an Electromagnet

The Model 75013 SCSM mounts on top of an electromagnet. See Figure 4-3 for a typical installation on an EM4 electromagnet platform. Following is the installation procedure:

1. The 75013 SCSM should be mounted to its base plate. See the previous section for instructions, if necessary.
2. **EM4 (4 inch) electromagnets**: Screw the two side plates to the top plate of the magnet stand. Insert the six screws with stainless steel washers from the underside of the magnet stand top plate.

   EM7 or EM12 (7 or 12 inch) electromagnets: Screw the saddle assembly to the top of the magnet frame (see following paragraph for saddle assembly instructions). The pole saddle side plates should rest on the magnet poles with cork or other cushioning material in between. Insert screws through the back bar into the electromagnet frame and tighten. Check for level. Shimming with washers between the back bar and the electromagnet frame might be necessary.

   To assemble an EM7 or EM12 saddle: Insert two screws (3/8"-16 × 1" SHCS) through the outer holes in the back bar so the screw caps fit in the recesses. Screw the two magnet pole saddle side plates to the back bar. Check for fit on top of the electromagnet before tightening the screws. The two remaining holes in the back bar should align with threaded holes drilled in the top front of the electromagnet frame and the saddles should rest on the coils.
3. Pull out the index plunger T-lock handle and rotate the sample module rod to the horizontal position (rod parallel to the 75013 SCSM base plate). Set the base plate across the tops of the two side (or saddle) plates attached in the last step. The sample enclosure end and the U-shaped cutout in the base plate must point towards the front of the magnet. The sample and the junction box should face to the right when viewed from the front of the magnet.

4. Bolt the base plate to the side plates using six screws (3/8”-16 x 1” SHCS) with plastic washers. The right rear screw is typically used to hold the cable clamp in place. Use nylon washers on both sides of the cable clamp. The front left screw is typically used to hold the liquid nitrogen funnel. For now, just put two plastic washers on the front left screw.

   If the cable clamp is not already installed on the sample cables, do the following: Wrap a 60 cm (2 foot) long piece of 2 cm (3/4 inch) cable wrap around the cables near the junction box end to cover the portion between 30 to 100 cm (1 to 3 feet) away from the junction box. Find the steel cable clamp. The clamp might require enlargement of the holes to 10 mm (3/8 inch) - use a step drill and a vise. Wrap the strap around the cable bundle just past the section with the 2 cm (3/4 inch) cable wrap - about 1 m (3 feet) from the junction box. Remove the base plate 3/8 inch bolt from the top right rear corner and use to bolt down the strap. Attach the cables to the junction box and check for proper cable movement with full range of junction box motion.

5. Set rotational friction. The two large screws (3/8”-18 x 1” SHCS) in the axle hubs are used to adjust ease of rotation. The sample module should not rotate under its own weight, but should not be difficult to rotate. Tighten the screws to increase the rotational friction. If the screws loosen during rotation, do the following: a) remove the screws, keeping the nylon washer and Belleville washer on the screw, b) dab a small amount of removable threadlock onto the ends of the screws, c) insert the screws into the axle ends, tighten and adjust rotational friction, and d) wait for the threadlock to set or the screws might loosen after sample module rotation.

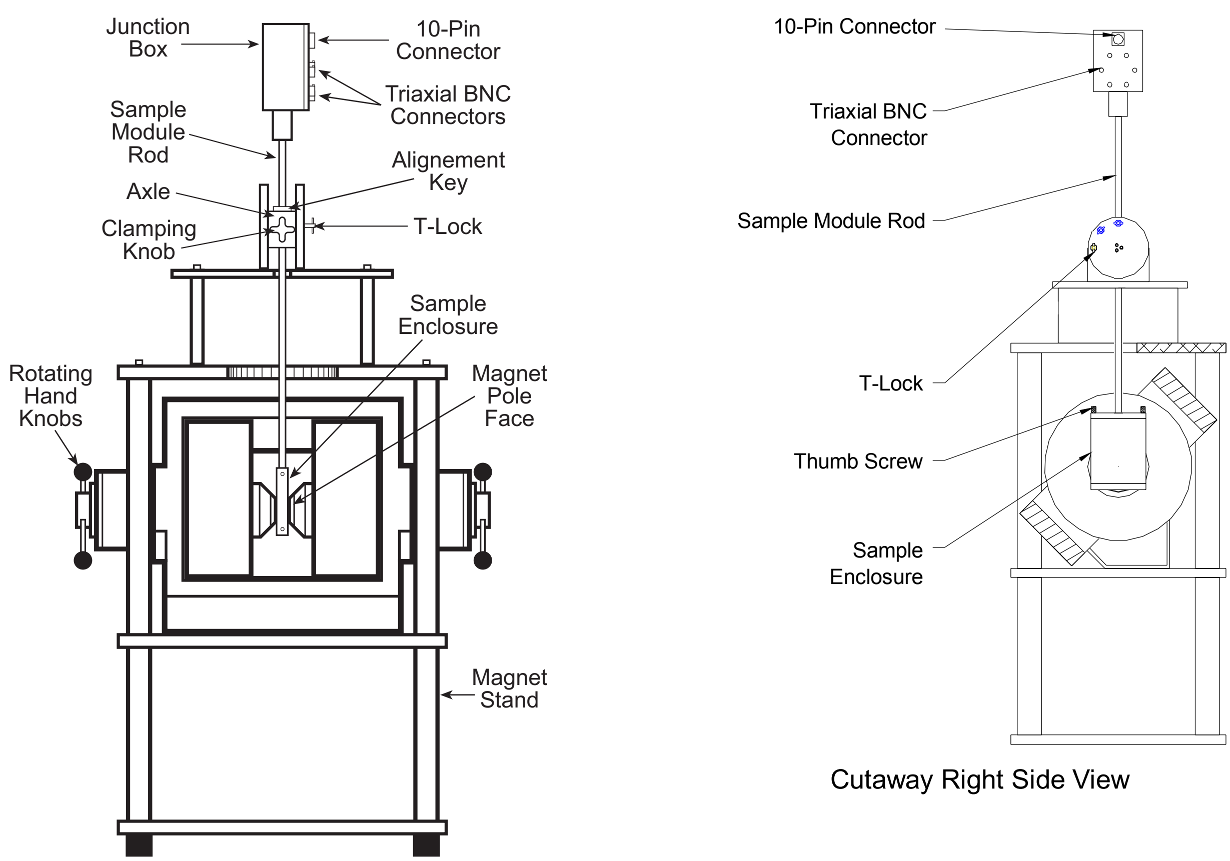


Figure 4-3. Model 75013 SCSM in an EM4 Electromagnet Platform
Shown with older style large junction box.

4.1.1.3 Alignment

Align the sample position relative to the magnet pole faces after installing the 75013 SCSM. The following procedure describes how to align the sample position during initial setup. A quick setup can be performed by skipping the steps as indicated.

1. Start with the sample module bolted to the electromagnet stand (check bolt tightness before proceeding), but with no dewar, cradle, or Gaussmeter probe installed.
2. Disconnect sample cables and any auxiliary cables from the junction box on the sample module. This is done to ease alignment of the sample module.
3. Crank out both electromagnet poles.
4. Insert a blank 1x1 cm sample card (PN 671-201) in the card edge connector, but leave off the sample enclosure. See Section 4.1.3.1 for sample card insertion procedure.
5. Return sample holder to vertical position and secure in place with the index plunger (T-lock).
6. Crank in left magnet pole to a position near the sample card.
   Quick setup: skip to step 14 (Lower the sample enclosure…).
7. Locate alignment key on sample module rod and loosen the set screw with a 5/32 inch (4 mm) hex key. **NOTE:** older models with an alignment pin rather than a tongue require a 7/64 inch hex key. If you have an older model 75013 SCSM, consider upgrading the mechanical assembly!
8. Hold sample module rod and loosen clamping knob to allow the sample to move vertically.
9. Lower sample until the bottom of the sample card aligns with the top of the magnet pole face as shown in Figure 4-4. Use the clamping knob to secure the sample rod in position.

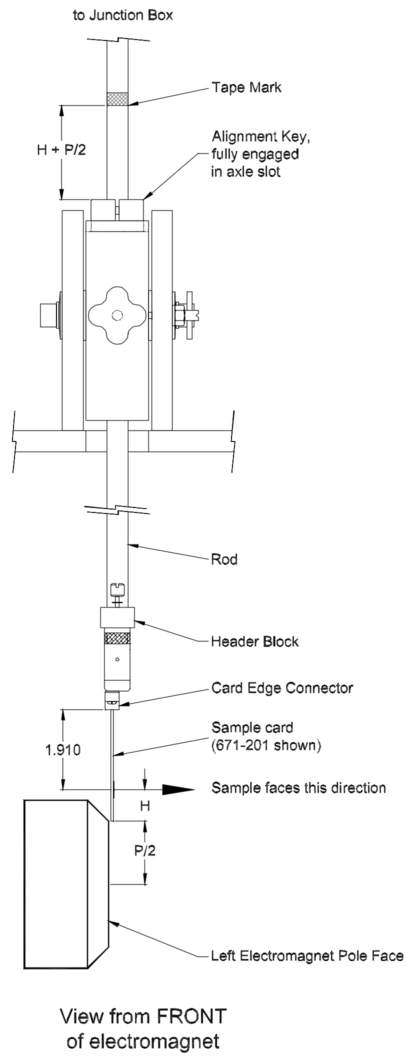


Figure 4-4. Setting Sample Vertical location in the 75013 SCSM.

10. Lower alignment key into place. The tongue on the alignment key must be fully inserted in the slot. Measure up from its top surface a distance equal to the height of the sample center above the bottom of the sample card (H) plus one half the pole face diameter (P/2). Use the numbers given in Table 4-3 for common geometries. Mark the position on the rod.
11. Wrap a piece of electrical tape around the rod above the mark.
12. Back out the left magnet pole to allow clearance for the sample module header block.
13. Loosen the clamping knob and rotate the junction box so it faces to the right.
14. Lower the sample enclosure between the magnet poles until the top of the alignment key reaches the tape. The tongue on the alignment key must be fully inserted in the slot. Tighten clamping knob to secure in place. The center of the sample mounting space should now be aligned between the centers of the magnet pole faces.
15. Crank in left magnet pole until it nearly touches the sample card. If necessary, loosen clamping knob and rotate rod until the plane of the sample card is exactly parallel to the magnet pole face (* see note below for advanced alignment method). Tighten clamping knob to secure in place.

Quick setup note: re-alignment is often possible by loosening the 3/8 inch diameter base plate bolts, shifting the base plate to align the sample card parallel to the pole face, and tightening the bolts. This is often easier than adjusting the alignment key.

16. Tighten alignment key set screw.
17. Check the location of the sample enclosure between the magnet poles and make any necessary adjustments.

* Advanced alignment method: Mount a semiconductor sample with an easily measurable Hall voltage. Lock the magnet poles in place with a 25 mm (1 inch) gap. Manually set the magnetic flux density to a value in the 0.5 – 1 tesla (5 – 10 kG) range. Run the Resistance program to apply a suitable current to the sample and measure the Hall voltage. While displaying the Hall voltage, rotate the rod until the Hall voltage is a maximum. Tighten clamping knob to secure in place. Proceed with the next step (15).

Table 4-3. Distances for sample vertical location in the 75013 SCSM

	Distance H + P/2 mm (in.)	
Magnet pole face diameter P, mm (in.)	1x1 cm sample card, PN 671-201, H = 19 mm (0.75 in.)	5x5 cm sample card, PN 671-202, H = 38 mm (1.5 in.)
25.4 (1)	32 (1.25)	51 (2.00)
50.8 (2)	44 (1.75)	64 (2.50)
76.2 (3)	57 (2.25)	75 (3.00)
101.6 (4)	70 (2.75)	89 (3.50)
152.4 (6)	95 (3.75)	114 (4.50)
177.8 (7)	108 (4.25)	127 (5.00)
203.2 (8)	121 (4.75)	140 (5.50)
254.0 (10)	146 (5.75)	165 (6.50)
304.8 (12)	171 (6.75)	190 (7.50)

4.1.1.4 Electromagnet Gap Setting, Dewar and Cradle Insertion

In general, the smaller the gap between the electromagnet poles, the higher the achievable magnetic flux density and the better the uniformity. Smaller pole faces increase the magnetic flux density, but decrease the uniformity. The following sections cover setup for the following cases:

1. Room temperature operation of the 75013 SCSM allows the smallest gaps, down to 25 mm (1 inch), if the sample enclosure is used and even less if it is removed.
2. Use of the dewar and cradle increases the gap to about 56 mm (2.2 inches), but allows operation at liquid nitrogen temperature or provides a more stable thermal environment for operation near room temperature.

4.1.1.4.1 Setting Electromagnet Gap for Room Temperature Operation

The 75013 SCSM can be operated without the sample enclosure if the samples are not light sensitive or if light is not allowed to reach the sample by some other means.

Use of standard and repeatable gaps, such as 25 mm (1 inch), is recommended. The electromagnet can then be characterized once and the characterization file saved. Future use of the same gap only requires reloading the characterization file. The Field Control program should still work if the gap is changed by less than 50%, but the maximum flux density will be different.

To make room for the Gaussmeter probe, the gap to the right of the sample (when viewed from the front of the electromagnet) will need to be about 3-4 mm (~1/8 inch) larger than the gap to the left.

Do not set the gap on the left so small that the sample enclosure scrapes against the poles during insertion and removal. Lock the electromagnet poles in place when finished.

4.1.1.4.2 Dewar and Cradle Insertion

The dewar mounts in a cradle assembly that positions it between the magnet pole pieces. The magnet poles directly support the cradle. While there are different cradles for 4-inch and 7-inch electromagnets, the mounting procedure is the same.

1. Inspect the dewar and cradle. The dewar bottom rests on the two bare threaded brass rods, held firmly between the two clear plastic side disks. Finger tighten the brass cap nuts, then use a wrench for no more than an additional half turn; over-tightening may warp or crack the plastic sides. Fill any gap between the top of the dewar and the plastic sides with vacuum grease or Silicone RTV sealant to prevent cold vapor from streaming down between the two. Remove excess grease with a cloth.
2. EM7 electromagnet with 3 inch pole faces ONLY: Install a 7 inch diameter plastic ring insert on each side of the dewar cradle with the conical side facing out. The conical surfaces will rest directly on the magnet poles. Place the rings inside the Teflon coated studs and push the rings until they rest flush against the plastic side pieces.
3. Back magnet poles out far enough to insert the dewar and cradle.
4. Hold cradle upright by the handle and position it between the magnet poles. The side with the Gaussmeter probe slot should be on the right when facing the magnet from the front.
5. Crank in left magnet pole until cradle is supported on the left side and nearly pushed to the center.
6. Crank in right magnet pole, stopping before it touches the clear plastic side of the cradle.
7. Hold cradle against left magnet pole and adjust left pole until the dewar is centered. The sample enclosure should fit down inside the dewar when it is centered.
8. Hold cradle by the handle and tip it forward and back continuously while cranking in the right magnet pole. Stop as soon as cradle becomes more difficult to move, indicating that both poles are in contact with the cradle faces.
9. Back out the right pole about one quarter turn and lock in position.
10. Check that dewar is still centered and the sample enclosure easily slides inside. Make any necessary adjustments.
11. Install liquid nitrogen funnel assembly where it can swing near the dewar, normally the top front left 3/8 inch mounting bolt on the magnet stand. Nylon washers should be both above and below the funnel support bar to allow smooth rotation. Removable threadlock might be needed on the bolt into the magnet stand to keep it from loosening when the funnel assembly is swung back and forth. Do not over tighten the bolt. The natural curl of the hose should be towards the dewar.

4.1.1.5 Gaussmeter Probe Orientation and Installation

The snowflake pattern adjacent to the name "Lake Shore" indicates the tail of the magnetic field vector. Lake Shore electromagnets are configured with the magnetic field pointing left to right for positive current when viewed from the front of the magnet. The probe is properly oriented when the snowflake pattern is facing to the left and the active region is centered on the magnetic pole face.

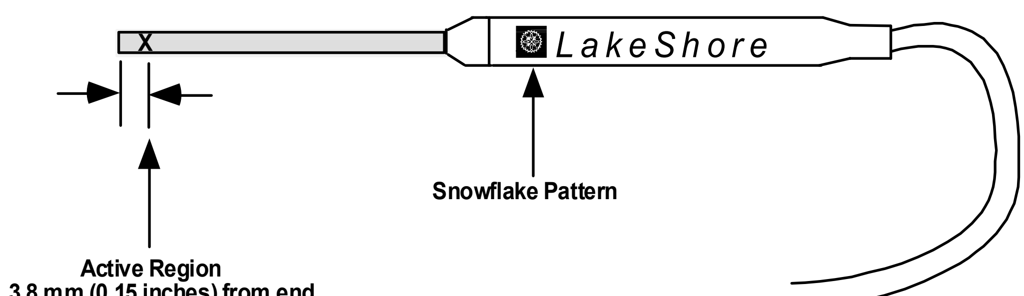


Figure 4-5. Gaussmeter Probe Orientation

CAUTION: A Gaussmeter Probe reversed in orientation reverses the sign of readings (i.e. a positive magnetic field reads as a negative field). Correct sign of readings is critical to magnetic field control! If unsure of correct orientation, use procedure below:

1. With the magnet power supply OFF, place the Gaussmeter probe in the electromagnet noting the orientation of the Lake Shore Snowflake symbol.
2. Turn the power supply ON in MANUAL mode. Manually set a positive current of a few amperes corresponding to approximately +0.05 tesla (+500 gauss).
3. Read the front panel display of the Model 450 and ensure the field reading is positive. If the field reading is negative, reverse the orientation of the Gaussmeter probe.

When done, reduce current to zero and turn OFF power supply.

4.1.1.5.1 Gaussmeter Probe Installation for Room Temperature Operation

Operation of the Model 75013 SCSM at room temperature with the narrowest possible electromagnet pole gap requires a Gaussmeter Probe (Figure 4-5) and Gaussmeter Probe Holder (Figure 4-6).

CAUTION: Handle the Gaussmeter Probe carefully. The tip is very fragile. Any excess force can alter the calibration or cause the sensor to break. Broken sensors are not repairable.

WARNING: If the electromagnet has been moved and not yet powered to full current, the magnet coils may shift the first time it energizes, allowing the Gaussmeter probe holder to fall out and possibly damage the probe. After moving the electromagnet, manually run it to full current before installing the Gaussmeter probe holder.

1. Place sample enclosure in position between the electromagnet poles. The gap between the sample enclosure and the right electromagnet pole face should be 6-10 mm (1/4 to 3/8 inch). The gap on the left can be smaller. Lock the electromagnet poles in place.
   NOTE: Locate the Gaussmeter probe tip between sample enclosure and the right electromagnet pole face.
2. Insert Gaussmeter probe holder between coils of electromagnet (see Figure 4-6). The probe mounting hole can be above or below threaded rod, as desired. Turn the two knurled endpieces to wedge the assembly in place. Do not over-tighten or the threaded rod bends and buckles.
3. Rotate the mounting block on the threaded rod until it is aligned near the right hand pole face (when viewed from the front of the electromagnet).

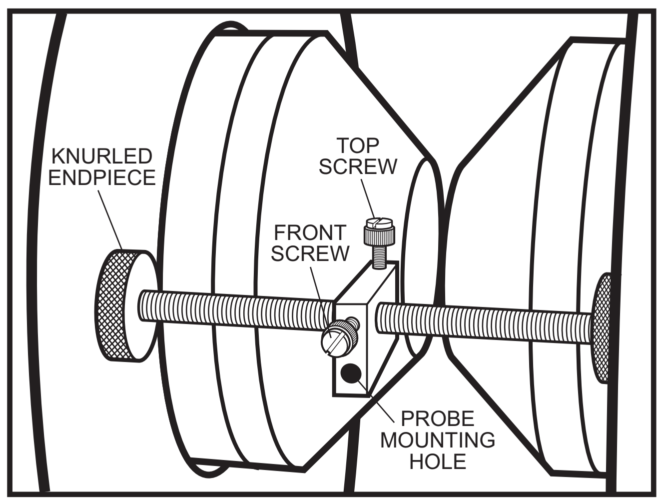


Figure 4-6. Gaussmeter Probe Holder Installation in an Electromagnet. The 75013 SCSM is not shown, but should be present during installation.

4. Tighten the front screw to lock the mounting block against the threaded rod. Do not over-tighten.
   CAUTION: Handle the Gaussmeter probe carefully. The sensor mounted in the tip is fragile. Stressing the probe tip may alter the sensor calibration. Any excess force can easily break the sensor. Broken sensors are not repairable.
5. Insert Gaussmeter probe through Probe Mounting with the Snowflake pattern facing to the *left*. The Top Screw must clamp onto the large diameter portion of the probe handle.
6. Orient Gaussmeter probe tip 2-3 mm (~0.1 inch) away from face of right hand electromagnet pole face with the tip parallel to the pole face. The magnetic fields very close to the pole face can be nonuniform, so placement of the tip directly against the electromagnet pole face is not recommended. The location of the mounting block along the threaded rod might require adjustment.

7. Move probe holder assembly forward or backward to position the sensitive portion of the probe tip over the center of the electromagnet pole face. If necessary, loosen the knurled endpieces to allow movement, then re-tighten. Make sure the probe is straight and properly oriented with snowflake pattern facing to the left so the wide side of the probe tip is parallel to the electromagnet pole face. Adjust as necessary.
   HINT: Locate the Gaussmeter probe where it will not block the sample enclosure rotation path. Leave path clear to allow installation of new sample cards without readjusting the Gaussmeter probe.
8. For positive verification of proper Gaussmeter probe operation, follow the procedure following the caution at the beginning of Section 4.1.1.5.

4.1.1.5.2 Gaussmeter Probe Installation in Dewar Cradle

To insert the Gaussmeter Probe in the dewar cradle (refer to Section 4.1.1.4.2 for dewar insertion procedure), follow the procedure below.

CAUTION: Handle the Gaussmeter probe carefully. The tip is very fragile. Any excess force can alter the calibration and cause the sensor to break. Broken sensors are not repairable.

1. Properly orient the Gaussmeter probe with the Snowflake pointing towards the left.
2. Carefully insert probe into dewar cradle insertion slot. The tip must enter the small rectangular slot at the end of the large square slot. Slight resistance will be felt as the probe tip pushes against the wiper strip (designed to hold the probe tip against the right hand side of the slot). Insert Gaussmeter probe until a firm stop is felt. Do not force.
3. Check probe position to verify proper orientation. The snowflake pattern and Lake Shore name should be facing to the left. The entire probe body will be within the slot.
4. Route the electrical cable through the space below the magnetic poles and to the back of the 450 Gaussmeter. The 450 Gaussmeter must be turned OFF when the probe is connected.
5. For positive verification of proper Gaussmeter probe operation, follow the procedure following the caution at the beginning of Section 4.1.1.5.

4.1.1.6 Temperature Controller Setup (750TC option only)

The Model 750TC Option adds a Model 340 Temperature Controller (or Model 330 for systems shipped prior to 1997), but is not required for operation of the 75013 SCSM. The temperature controller does allow the Hall program to record temperatures during measurements, which can be valuable information. Newer models of the 75013 SCSM include a heater in the header block for limited temperature control near ambient temperature or for faster heating to room temperature following operation in liquid nitrogen.

Temperature sensor and heater locations are shown in Figure 4-2. A temperature sensor mounted directly to the sample card provides the best measure of the actual sample temperature. The platinum sensor in the header block is above the sample card, but can be used for control of the header block temperature and as an indication of sample temperature.

The following procedure configures the Model 340 inputs for one platinum resistance temperature sensor (PT-103) in the sample module header block, a possible second platinum temperature sensor on the sample card, and single loop temperature control if a heater is present in the header block.

1. Connect all cables listed in Table 4-4 (see Figure 4-7).
2. **For Quick setup only**: Skip the remainder of this section and proceed directly to Section 4.1.3.2. To determine if a quick setup is possible, check if a configuration file already exists. Use either Windows Explore and look in the Windows directory, or start the Model 340 program and select the menu item: File -> Load. Typical file names relevant to this sample module might look like "75013PT1.34c". Note that some work can be saved by first loading a configuration file similar to one to be set up.

Table 4-4. Connection List for Model 340 to Model 75013 SCSM.
Connection designations refer to Figures 3-7 or 3-8.

#	CONNECTION	FROM	TO
1	655-451, Auxiliary input cable (see Table 4-5)	(**G-16**) cable 6-pin circular connector **A** connected to Model 340 **Channel A** (**G-17**) cable 6-pin circular connector **B** connected to Model 340 **Channel B** (**G-5, 6**) Cable dual banana connector connected to Model 340 **heater output** (**G-7**) Cable single banana connector - cable shield	(**B-7**) Junction box of Sample Module, 10-pin circular connector socket (marked BLUE)

Table 4-5. Cable 655-451 Wiring. Connects 75013 SCSM 10-pin connector (B-7) to Model 340
Connection designations refer to Figures 3-7 or 3-8.

Connection	Pin	Use	Connection	Pin
B-7	**A**	Sample card pad 10; "Sensor" temperature sensor (Channel **B**), V-	(**G-17**) on Model 340	**2**
	B	Sample card pad 9; "Sensor" temperature sensor (Channel **B**), V+		**4**
	C	Sample card pad 8; "Sensor" temperature sensor (Channel **B**), I-		**1**
	J	Sample card pad 7; "Sensor" temperature sensor (Channel **B**), I+		**5**
	D	Heater, 50 Ω, 1 A, in header block (Loop 1), I+	(**G-5**) on Model 340	**Hi**
	E	Heater, 50 Ω, 1 A, in header block (Loop 1), I-	(**G-6**) on Model 340	**Lo**
	G	"Control" temperature sensor (Channel **A**), V-	(**G-16**) on Model 340	**2**
	H	"Control" temperature sensor (Channel **A**), V+		**4**
	F	"Control" temperature sensor (Channel **A**), I-		**1**
	K	"Control" temperature sensor (Channel **A**), I+		**5**

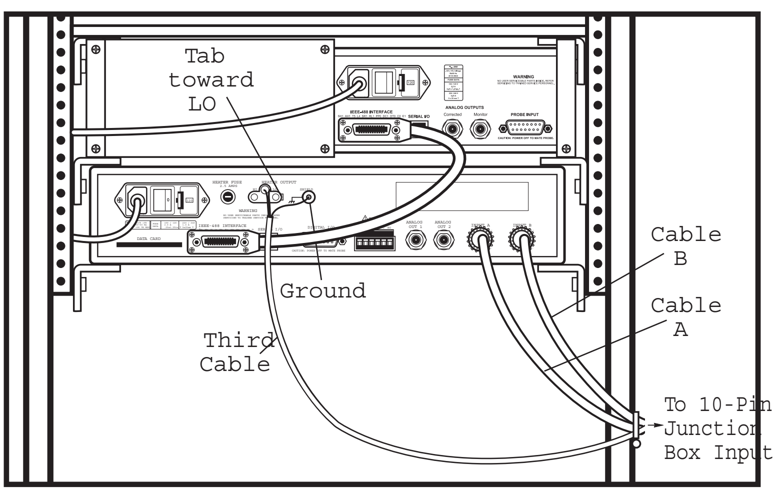


Figure 4-7. Typical Model 340 connections to the 75013 SCSM

3. Exit any programs using the Model 340. The Model 340 must be in LOCAL mode to change settings through the front panel.
4. Set up the Model 340 through the front panel as specified in the following procedure. For further information, refer to the Model 340 User's Manual. (For setup of a Model 330, refer to the Model 330 User's Manual.)

- **Input Setup**

		(Model 340 front panel button) Input Setup
Input:	**A**	Enter
Enable:	**ON**	^ Enter
Type:	**Plat. 100/250**	^ Enter
Curve:	**4 PT-100**	^ Enter
		Save Screen
Input:	**B**	^ Enter
Enable:	**ON**	^ Enter
Type:	**Plat. 100/250**	^ Enter
Curve:	**4 PT-100**	^ Enter
		Save Screen, Save Screen

- **Display Format**

		(Model 340 front panel button) Display Format
Input Displays:	**2**	^ Enter
Display 1:	A TEMP K	Enter
Display 2:	B TEMP K	Enter
		Save Screen
		Display Format
		<MORE>
Control Loops:	**NONE (LOOP1)**	^ Enter (LOOP1 if heater, else NONE)
Large Output:	OFF	Enter
Heat Display:	**POWER**	^ Enter
		Save Screen

- **Interface**

		(Model 340 front panel button) Interface
IEEE-488		
Terminator:	CR LF	Enter
EOI:	ON	Enter
Address:	**14**	Enter
		Save Screen

- **Analog Outputs**

		(Model 340 front panel button) Analog Outputs
1:		Enter
Mode:	**OFF**	Enter
Bipolar:	**OFF**	Enter
		Save Screen
2:		^ Enter
Mode:	**OFF**	^ Enter
Bipolar:	**OFF**	Enter
		Save Screen, Save Screen

- **Loop 1**

		(Model 340 front panel button) Loop 1
		Control Channel
Loop 1 Channel:	**A**	Enter
		Loop 1
		Setpoint
Setpoint:	0.000 K	Enter

- **Loop 2** (not normally used)

		(Model 340 front panel button)
		Loop 2
		Control Channel
Loop 2 Channel:	**B**	^ Enter
		Loop 2
		Setpoint
Setpoint:	0.000 K	Enter

- **Control Setup**

		(Model 340 front panel button)
		Control Setup
Loop:	**1** Control Setup	Enter
Enable:	**OFF (ON)**	Enter (ON If heater, else OFF)
Power Up:	OFF	Enter
Setup Unit:	TEMP K	Enter
Htr Ω:	**50**	50 Enter
Control Mode:	Manual PID	Enter
Filter:	OFF	Enter
		Save Screen
		<MORE>
Loop:	**1** Control Limits	Enter
Temp:	**325 K**	325 Enter
+slope:	0.0%	Enter
- slope:	0.0%	Enter
Max Htr I:	1.00 A	Enter
Max Range:	50 W	Enter
		Save Screen
		<MORE>
		Control Setup
Loop:	**2** Control Setup	^ Enter
Enable:	**OFF**	^ Enter
Power Up:	OFF	Enter
Setup Unit:	TEMP K	Enter
Control Mode:	Manual PID	Enter
Filter:	OFF	Enter
		Save Screen
		<MORE>
Loop:	**2** Control Limits	Enter
Temp:	**325 K**	325 Enter
+slope:	0.0%	Enter
- slope:	0.0%	Enter
		Save Screen, Save Screen

Table 4-6. Model 340 Software Loop 1 Domain settings for the 75013 SCSM

Domain #	Begin T [K]	End T [K]	P	I	D	Htr Power (range)	Slew rate [K/min]	First: Wait Time [min]	Second: F/C/V	Third: Wait Time [min]
1	0	90	50	5	0	5	20	5	* < 0.1	10
2	90	280	50	5	0	5	20	5	* < 0.1	10
3	280	325	50	5	0	5	20	5	* < 0.1	10
4	325	1000	0	0	0	0	100	0	none	0

* Function (of Function/Condition/Value): **Sample drift** [K/min]

5. Insert a sample card with a platinum sensor mounted on it in the 75013 SCSM. Refer to Section 4.1.2.5.
6. **Start up only the Model 340 program** and display the virtual front panel. Assign the input channels as follows:
   Control = A
   Sample = B
7. Set up Loop 1 Domains if the heater is to be used (otherwise skip this step).
   a. Close the Model 340 software front panel.
   b. Select menu item: Utilities -> Domain File Name and input a file name. A suggested format is: **75013L1A.ini** to indicate **L**oop **1**, set **A**. Change the last letter for variations such as a set of domains with shorter settle times when temperature accuracy is not as important. Note that this temperature control domain file will be located in the Windows directory.
   c. Select menu item: Utilities -> Domains and input the data from Table 4-6. Note that these domains might not be suitable for your application. The temperature controller and software help files contain additional information about determining suitable control parameters.
8. Save the configuration with two temperature sensors. Select menu item: File -> **Save As…** and enter a file name. A suggested format is **75013PT2.34c**" to signify the Model 75013 SCSM with 2 platinum temperature sensor s. Note that the virtual front panel might have to be closed temporarily to get the Save As dialog box to show on the computer screen.
9. Change the input channel assignments in the Model 340 Software front panel to:
   Control = A
   Sample = A
10. Unplug the sample card from the 75013 SCSM and verify that the front panel on the computer display now shows the same room temperature reading under both Control and Sample.
11. Save the configuration with one temperature sensor. Select menu item: File -> **Save As…** and enter a file name. A suggested format is **75013PT1.34c**" to signify the Model 75013 SCSM with only 1 platinum temperature sensor connected to channel A.
12. Check that the configuration files were saved. Select menu item: File -> Load. A dialog box appears with a list of Model 340 configuration files (.34c extensions). Click Cancel, or select a configuration file to load and click OK. This step is performed as part of normal sample module operation in Section 4.1.3.2.
13. Exit the Model 340 software program.

4.1.1.7 Removal, Storage and Shipping

Removal of the 75013 SCSM from the electromagnet stand:

1. Disconnect all cables from the junction box.
2. Rotate the Sample Enclosure out from between the magnet poles and lock in place with the sample module tube in horizontal position (parallel to the base plate).
3. Use a 7/16-inch hex key to remove the six (6) bolts holding the base plate to the electromagnet stand.
4. The sample module and attached base plate are now free of the stand and may be removed.

Storage:

1. The sample module and base plate can be stored on a shelf or hanging from wall hooks.
2. The storage area should be dry, clean, and maintained at temperatures comfortable for humans.

Shipping:

1. Ship the 75013 SCSM in its original shipping container or suitable replacement.
2. Foam the 75013 in place or provide sufficient support and padding.

4.1.2 Sample Mounting for the Model 75013 SCSM

This section provides step-by-step instructions for mounting a samples for measurements in the Model 75013 SCSM. Contact to the sample is made with either soldered wires or needle probes, depending on the sample card in use.

Each sample card has 20 gold-plated contact fingers. The contact fingers on the front side connect to sample contact pads 1-6 and auxiliary contact pads 7-8. The contact fingers on the back side connect to auxiliary contact pads 9-10 and to the driven shields for signal lines 1-6. Routing the driven shields onto the card minimizes leakage currents, allowing more accurate measurements on very high resistance samples.

Standard sample mounting 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. Card mounted samples can be stored for rapid insertion and measurement in the 75013 SCSM.

The prober sample card has tungsten needle probes to contact the sample. Samples contactable with the needle probes can be rapidly mounted and demounted.

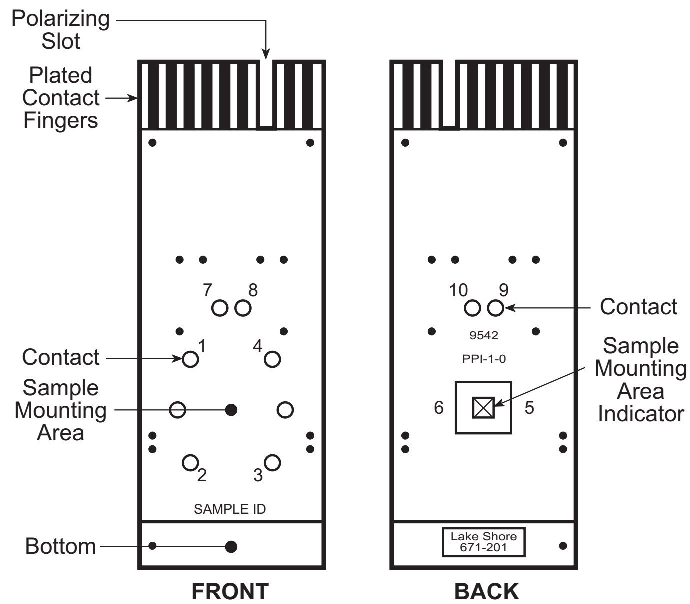


Figure 4-8. Front and Back View of the 671-201 Sample Card for Nominally 1×1 cm Samples

Note that contact size and metallurgy can have a significant impact on measurement accuracy. Sample preparation and contacting is the user's responsibility. See Appendix A: Hall Measurement for general Hall effect measurement theory and a discussion of Hall sample geometries. See Appendix B: Electrical Contacts to Semiconductors for references to literature on contact formation. The following procedures assume that the sample is directly contactable or that contact metallization is already present.

The auxiliary contacts are available for a temperature sensor, heater, light source, sample bias, additional sample contacts, or other use. The auxiliary contacts are not guarded and their use might not be directly supported by the hardware or software supplied.

Sample Mounting Materials List

- Sample mounting card (provided by Lake Shore)
- Lead wire (provided by Lake Shore)
- Soldering iron with fine pointed tip
- Indium (provided by Lake Shore), silver paste, conductive epoxy, or other contacting material
- Glass microscope slide
- Magnifying lens
- Tweezers
- Cotton swabs
- Adhesive such as 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: Sample cards are reusable. Don't use permanent adhesive if sample is to be removed from sample card.

4.1.2.1 Sample Preparation

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

1. Select a sample card (large or small with solder contacts, or prober sample card).
2. Verify the sample fits in the sample mounting space. Samples can be cut to size by many methods (e.g. scratch and break, diamond sawing, etching), depending on the sample material and form (e.g. bulk crystal, wafer, thin film).
3. Clean the sample.
4. Pattern the sample or identify contact regions. See **Appendix A: Hall Effect Measurement Theory and Practice** to determine where to attach leads to sample. Patterning by photolithography or grit blasting might be possible, but are outside the scope of this document.
5. Prepare the contact regions. Some materials require etching of the surface. Other materials require alloying with a suitable contact metal followed by annealing. See **Appendix B: Electrical Contacts to Semiconductors**.

4.1.2.2 Probe Sample Card

The prober sample card has tungsten needle probes to contact the sample. Samples contactable with the needle probes can be rapidly mounted and demounted. A prober sample card with a 50 mm diameter sample wafer (but only two probers making contact to the sample) is shown in Figure 4-9. Mount samples as follows:

1. Move the probe tips out of the sample mounting region. The probe tips can be picked up and swung out of the way using fingers or tweezers.
2. Locate the sample in the center of the prober card. Hold the card up to a light to see the sample mounting area indicator on the back side. The "X" marks the center of the sample mounting area (as well as the 'tail' of the positive magnetic field vector oriented up through the sample).
3. Pick up one probe tip at a time and place on the desired contact location on the sample. Some samples might have metallized contact pads. Ohmic contact can be made by direct contact to some semiconducting samples, typically those with higher electrical conductivity. Ohmic contacts can sometimes be formed by running current through the contacts, typically a current significantly higher than the measurement current. Be careful, excessive currents could damage sensitive samples!

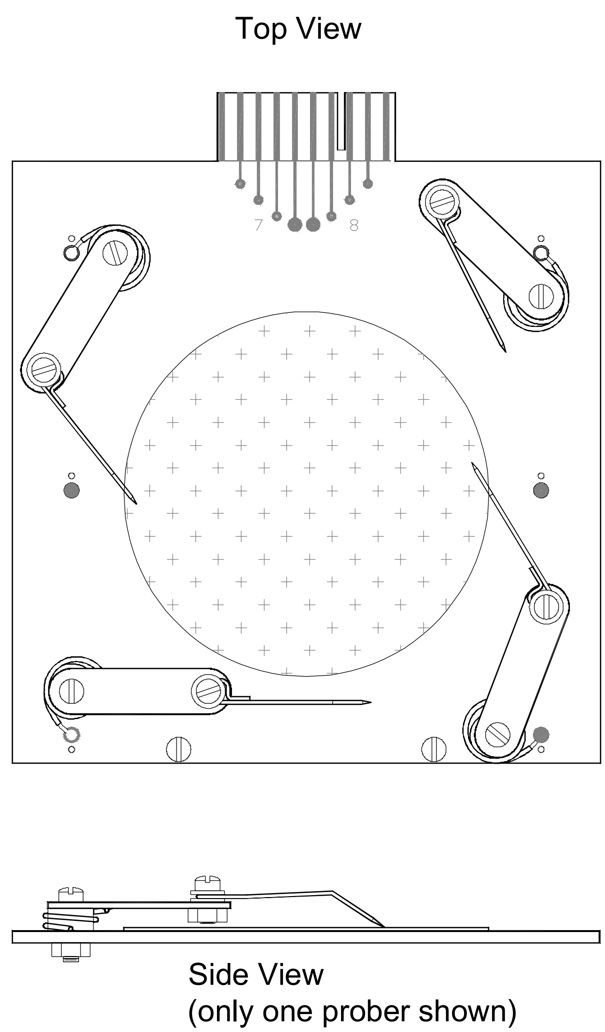


Figure 4-9. Prober Sample Card (nominal 5×5 cm) for van der Pauw Measurements. A circular sample is shown with two probe contacts.

NOTES:

The force required to move the prober arms can be changed by tightening or loosening the nylon screws and nuts. The force of the prober on the sample can be adjusted by swinging the probe tip over the edge of the card and then bending the probe needle up or down as required.

Nothing (sample, arms, or probers) should extend beyond the edges of the prober card or they might contact the inside of the sample enclosure.

Heavy samples might require additional support. A small amount of temporary adhesive such as rubber cement could be used. The two nylon screw heads at the bottom of the prober sample card can be used as rests for 75 mm (3 inch) diameter wafers. Similar rests could be added as needed.

Accurate van der Pauw measurements require the probes to be as near a sample edge as possible. Some compromise might be necessary if the edge of the sample is not uniform. Symmetrically placed probes on a symmmetrical sample generally improve measurement accuracy by minimizing misalignment voltages. For further discussion of this subject, see **Appendix A: Hall Effect Measurement Theory and Practice**.

4.1.2.3 Solder Contact Sample Cards

Standard sample mounting 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. Card mounted samples can be stored for rapid insertion and measurement in the 75013 SCSM. Pre-mounted samples are included in the box of sample mounting cards provided with each 75013 SCSM. Use these as examples.

4.1.2.3.1 Attaching Leads to the Sample

Attach wire leads to samples with solder, silver paste, conductive epoxy, wire bonding, spot welding, or other means. Only indium solder lead attachment is covered here. The following procedure assumes the sample is directly contactable or that contact metallization is already present.

Lead wire (75 µm diameter silver-plated copper) is provided by Lake Shore. Recommended Lead Wire: 50-100 µm diameter copper, silver-plated copper, or gold wire.

Indium soldered lead attachment procedure:

NOTE: A magnifying lens may be necessary to complete the following procedure.

1. Heat soldering iron. Indium melts at 156.6 °C, so it does not require a very hot iron. **CAUTION**: High temperature soldering can damage some samples.
2. Cut indium or other suitable solder metal and place on glass slide.
3. Using soldering iron, melt solder metal onto tip of soldering iron and place a small amount of solder on each contact point on the sample. See Appendix A: Hall Effect Measurement Theory and Practice for contact point locations.
4. Cut the multi-stranded lead wire to proper length. Length is determined by the distance between the sample—where the lead attachment is made—and the contact on the sample mounting card. Allow enough wire for strain relieving bends.
5. Unravel cut lead wire into single strands of wire.
6. Using tweezers, place one end of lead wire at the proper sample contact point. Hold wire in place with tweezers.
7. Solder wire to sample contact point.
8. Repeat for all leads to sample contact points.

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

4.1.2.3.2 Mounting Sample On Sample Card

NOTES:

- Be careful not to damage the sample surface. Scratches can alter measurement readings, especially with thin film samples. Lightweight samples often can be lifted by a contact wire, avoiding contact with the sample.
- Always use tweezers or gloved hands to handle the sample. Oil from your skin can alter measurements on high resistance samples and can alter chemically reactive sample materials.

1. Select a sample mounting card. Do not touch the gold plated contact fingers at top of card. Fingerprints might create electrically conductive paths that can change measurement readings on high resistance samples.
2. Using a wire, stick, or small brush, place a small amount of adhesive in the center of the sample mounting area on the front side of card. Hold the card up to a light to see the sample mounting area indicator on the back side. The "X" marks the center of the sample mounting area (as well as the 'tail' of the positive magnetic field vector oriented up through the sample).
3. Using tweezers, place the sample in the center of the sample mounting area on the adhesive.
4. Using a cotton swab, press down gently on sample. Continue pressing down gently for a few seconds and then release. Allow adhesive to dry if necessary.

4.1.2.3.3 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 mounting card. See Figure 4-10 or 4-11 for sample mounting card contacts.

1. Using tweezers, bend the lead wire to allow some strain relief. Hold lead wire in place on sample mounting card contact.
2. Solder lead wire to sample card contact.
3. Clip or fold excess wire. See Figure 4-10.
4. Repeat for all leads to sample mounting card contacts.
5. Write sample name in the Sample ID space on front side of card.

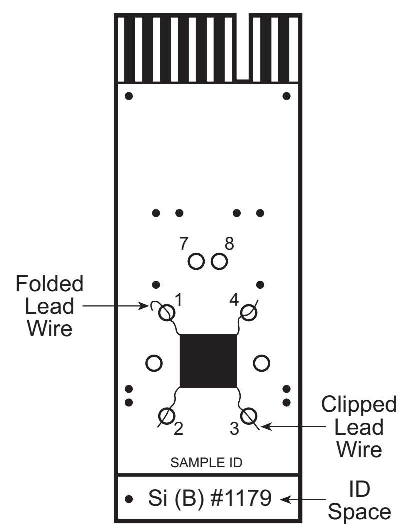


Figure 4-10. Sample Card with Mounted van der Pauw Sample and Leads.

4.1.2.3.4 Sample Removal

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.

CAUTION: 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 card. Remove typical "permanent" inks from card with isopropyl alcohol or acetone.

4.1.2.4 Using Auxiliary Contacts

The auxiliary contacts shown in Figure 4-8 are available for a temperature sensor, heater, light source, sample bias, additional sample contacts, or other use. The auxiliary contacts are not guarded and their use might not be directly supported by the hardware or software supplied.

The four auxiliary contacts, numbered 7–10 on the sample card, are connected to the 10-pin bulkhead connector on the junction box (labeled B-7 in Figure 4-1). Wiring assignments are given in Table 4-5.

4.1.2.5 Mounting a Temperature Sensor to a Sample Card

A temperature sensor can be mounted to a sample card and electrically connected using the auxiliary contacts shown in **Figure 4-8**. Either a 2-wire or a 4-wire temperature sensor can be connected.

The four auxiliary contacts, numbered 7-10 on the sample card, are connected to the 10-pin bulkhead connector on the junction box (labeled B-7 in Figure 4-1). Wiring assignments are given in Table 4-5.

The 75013 SCSM is presently provided with one sample card (671-201) with a Lake Shore Model PT-103 platinum resistance temperature sensor mounted on the back side, directly underneath the sample mounting area. Appendix C tabluates the resistance of the platinum sensor as a function of temperature.

As an example, the following procedure used to mount a PT-103 sensor on a sample card.

1. Sample card should be clean and free of defects. Hold cards by edges. Do not touch the gold plated contact fingers.
2. Apply a small amount of rubber cement to one side of the PT-103 platinum resistor, then center the resistor body over the 'X' on the back side of a sample card as shown. Pb-Sn solder the leads to the contact pads numbered '9' and '10'. Trim off any excess lead wire. The resistor might need to be held in place with a weight or tape while the rubber cement dries.
3. Cut 2 lengths of 30 AWG Teflon insulated wire (Lake Shore type HD-30, or equivalent) 20 mm (0.75") long. Use a thermal stripper to remove 3 mm (1/8") of insulation from each end. **NOTE:** Cut longer for mounting on a larger sample card.
4. Pb-Sn solder one end of one insulated wire to contact pad numbered '9'. Solder one end of the other wire to contact pad '10'.
5. Push the free ends of the insulated wires through the two plated through holes shown in the drawing. Pb-Sn solder the other ends of the insulated wires to contact pads '7' and '8' on the front side of the card (9->7, 10->8).
6. If rosin flux was used, clean the contacts of flux residue using isopropyl alcohol scrubbed with a short bristle brush. Rinse with de-ionized (DI) water and blow dry with nitrogen gas.

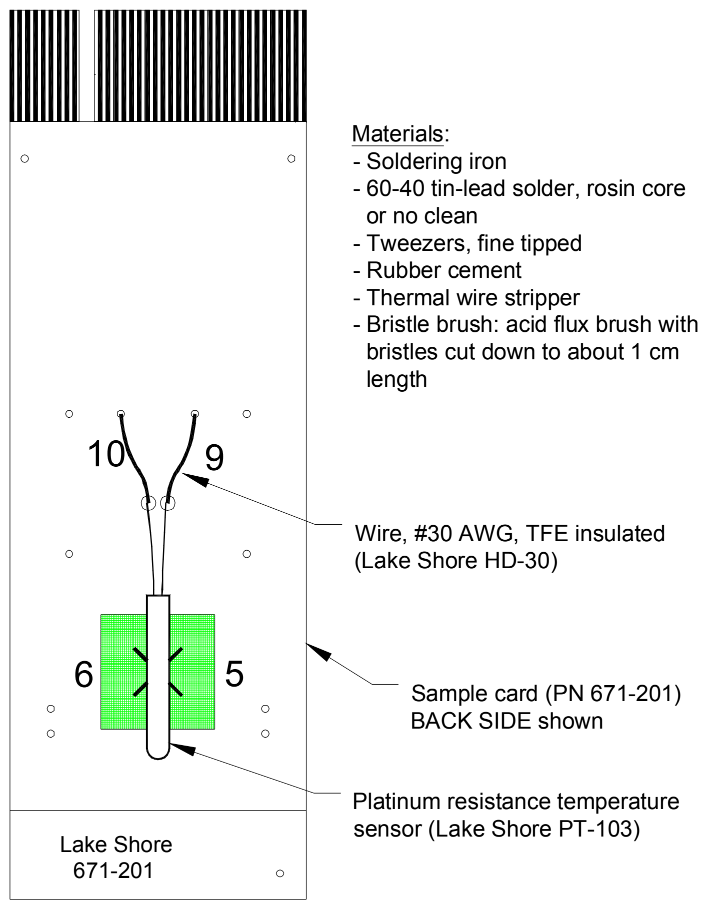


Figure 4-11. Mounting a Platinum Temperature Sensor on a Sample Card.

4.1.3 Operation of the Model 75013 SCSM

Basic mechanical operation is covered in Section 4.1.1.1 – Unpacking, Assembly and Familiarization.

4.1.3.1 Sample Card Insertion

1. Swing the sample enclosure end of the sample module out of the electromagnet and lock in place at either the 45 degree or horizontal positions.
2. Remove the sample enclosure.
3. Grasp the sample card by the edges being careful not to touch the gold-plated contact fingers.
4. Orient the sample card so the mounted sample faces the same direction as the front of the sample module junction box.
5. Align the contact fingers with the card edge connector on the bottom end of the sample module. Check that the alignment key in the card edge connector lines up with the slot in the sample card.
6. Firmly push the sample card straight into the connector. Wiggling the card should be avoided as it can loosen the polarization key in the card edge connector.
7. Check that the sample card protrudes straight out of the connector. Straightness can be checked by holding a straight edge against the side of the header block.

   Note that the Hall voltage is proportional to the cosine of the angle β between the magnetic field vector and the normal to the sample plane (which is equivalent to the sine of the angle α between the magnetic field vector and the sample plane) as shown in Figure 4-12. The measurement error introduced in quantities proportional to the Hall voltage (e.g. carrier concentration, mobility) is tabulated in Table 4-7. Holding the sample card parallel to the magnet pole faces (and thus perpendicular to the magnetic field) to within 3 mm over the 65 mm exposed length of a small sample card gives a measurement error of only 0.1%, adequate for many measurements.

Table 4-7. Measurement error contributed by a small sample card tilted with respect to the magnetic field.
Refer to for parameter descriptions. The length L was taken as 65 mm.

	x (mm)							
	1	**2**	**3**	**4**	**5**	**6**	**8**	**10**
cos β = sin α	0.99988	0.99953	0.99893	0.99810	0.99704	0.99573	0.99240	0.98809
error (%)	0.012	0.047	0.107	0.190	0.296	0.427	0.760	1.191

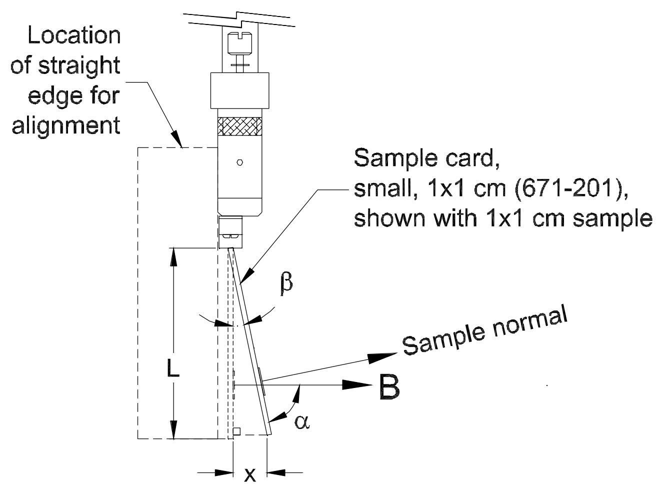


Figure 4-12. Geometry of a Sample Card Tilted Relative to the Magnetic Field

4.1.3.2 Verify Temperature Controller Setup (750TC option only)

The temperature controller must be set up for the Sample Module in use. If no temperature controller configuration file exists, create one (see Section 4.1.1.6). Note that there is no indication of the current configuration (unlike the Field Control software driver program).

1. Start the Model 340 software driver program on the computer and load the appropriate configuration file. To do this, select the menu item: File -> Load. A dialog box will appear with a list of configuration files (.34c extensions). Select one and click on OK. The Model 340 will be configured, but there is no indication of the current configuration.
2. Open the Front Panel and check that the input channels are reading properly and assigned as follows:
   Control = A
   Sample = B (or A if the sample card has no temperature sensor)

4.1.3.3 Room Temperature Operation

1. Replace sample enclosure and tighten the two thumb screws.
2. Release T-Lock handle and rotate sample module rod back to vertical. The index plunger should lock the sample enclosure in place between the magnet poles.
3. Check the location and orientation of the Gaussmeter Hall probe. The Hall probe should be zeroed using the zero gauss chamber every 3 to 6 months or before experiments requiring the highest possible measurement accuracy.
4. Run the Hall System Software to perform the experiment. See Chapter 5.

4.1.3.4 Liquid Nitrogen Temperature Operation

Liquid nitrogen sample module operation (T≈77 K) is similar to room temperature operation.

NOTE: Remove sample enclosure from dewar before rotating to horizontal position. To remove the sample enclosure from the dewar, hold sample module rod with hand, unscrew clamping knob, lift sample module rod up until sample enclosure is out of dewar, and tighten clamping knob until the sample module rod is secured in place.

Table 4-8. Dewar Specifications for the Model 75013 SCSM

Initial Cool Down (warm dewar and sample holder)	
Time:	5-10 minutes
LN2 consumption:	2 liters
Subsequent Cool Downs (cold dewar, warm sample holder)	
Time:	5 minutes
LN2 consumption:	1 liter
Hold Time after Filling with LN2	
At 77 K: 30-60 minutes, depending on sample size	
Time to Warm Sample Holder from 77 to 290 K	
In dewar:	5-8 hours
Out of dewar in 296 K room air:	50-80 minutes
Out of dewar with 1000 watt Hot Air Gun:	10-20 minutes

1. Return sample module to vertical with sample enclosure above magnet gap.
2. Loosen clamping knob and lower module rod until alignment key slides into place. sample enclosure is now inside dewar.
3. Rotate funnel to front of magnet stand.
4. Place the Styrofoam cover over the top of the dewar.
5. Place the rubber transfer hose into the dewar through the hole in the dewar cover.
6. Pour liquid nitrogen into funnel to fill dewar. Wait until liquid stops boiling vigorously and level stabilizes.
7. Check the location and orientation of the Gaussmeter Hall probe. The Hall probe should be zeroed using the zero gauss chamber every 3 to 6 months or before experiments requiring the highest possible measurement accuracy.
8. Run the Hall System Software to perform the experiment. See Chapter 5.
9. Refill the dewar with liquid nitrogen during the experiment as necessary.

4.1.3.5 Sample Card Removal

1. Swing the sample enclosure end of the sample module out of the electromagnet and lock in place at either the 45 degree or horizontal positions.
2. Remove the sample enclosure.
3. Grasp the sample card by the edges being careful not to touch the gold-plated contact fingers.
4. Firmly pull the sample card straight out of the connector. Wiggling the card should be avoided as it can loosen the polarization key in the card edge connector.

4.1.4 Service and Maintenance for the Model 75013 SCSM

4.1.4.1 Card Edge Connector Replacement

The card edge connector should be replaced if the connector body breaks or if the contacts become too worn to provide reliable contact.

1. Use a permanent marker to number the front of a new 20-terminal card-edge connector (673-200) as shown in Figure 4-13.

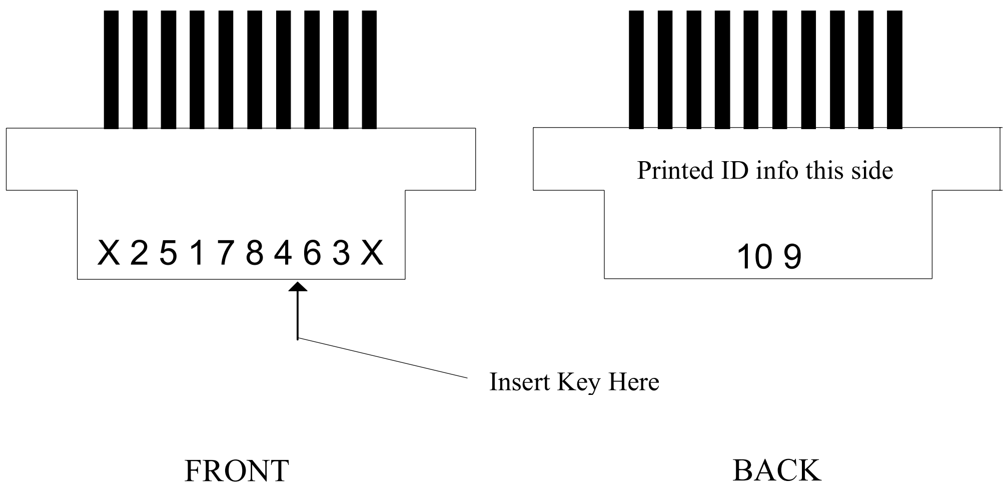


Figure 4-13. Card Edge Connector Numbering

2. Insert a key (673-201) into the slot between female contacts #4 and #6 to check for fit. Remove key and coat edges with Eastman 910 cyanoacrylate adhesive. Insert key in slot to glue in place. Be careful not to get adhesive on the contacts!
3. Solder the QT-36 quad twist wires to the card edge connector according to Table 4-9. The QT-36 wires consist of two twisted pairs (Red-Green and Yellow-Green). Make sure to identify the correct green wire in each pair.

Table 4-9. QT-36 Wiring to the Card Edge Connector

	QT-36 wire colors			
	Red	Green	Yellow	Green
Use	I+	I–	V+	V–
10-pin connection	J	C	B	A
Card connection	7	8	9	10

4. Solder each of the six coaxial cables to the corresponding numbered terminal on the edge card connector as shown in Figure 4-13. The center conductor is soldered to a terminal on the front of the connector, while the outer conductor is soldered to the terminal directly behind. Insulate the connections using Teflon heat shrink tubing as shown. Before heating the shrink tubing, thoroughly rinse the connector and solder joints in distilled water, then blow dry with nitrogen gas (cleaning is not necessary if no-clean solder is used).

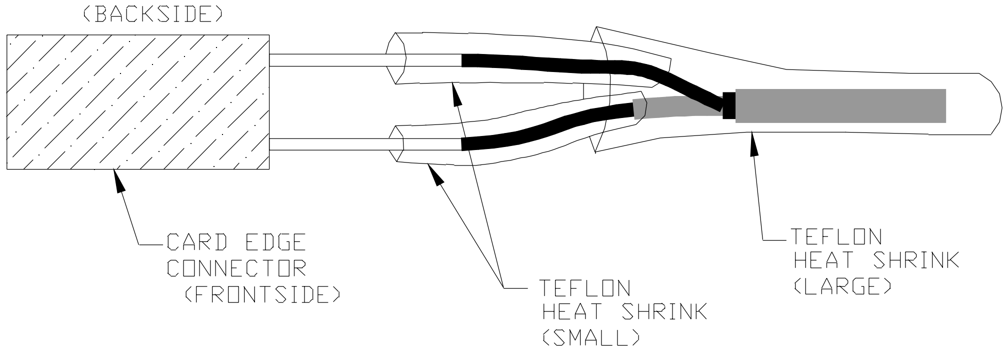


Figure 4-14. Coaxial Cable to Card Edge Connection

5. Attach the card-edge connector to the header block using two #4-40 × 1/2" brass screws. Orient the connector so the back side of the connector block (contacts 9-10) is closest to a side of the header block. This is done so that a sample on a sample card plugged into the card-edge connector will face in the same direction as the lid of the junction box.
6. Before use, perform the alignment procedure.

4.1.4.2 Key Replacement in Card Edge Connector

The card edge connector key is required to assure proper sample orientation. Use this procedure if the key falls out or is damaged.

1. Remove any remaining pieces of the old key from the card edge connector.
2. Insert a key (673-201) into the slot between female contacts #4 and #6 to check for fit (see Figure 4-13). Remove key and coat edges with Eastman 910 cyanoacrylate adhesive. Insert key in slot to glue in place. Be careful not to get adhesive on the contacts!

4.1.4.3 Clamping Knob Nylon Pad Replacement

Between the clamping knob and the rod is a piece of nylon which serves to prevent damage to the smooth rod surface. Overtightening the clamping rod can damage the nylon piece. If the clamping knob is removed, be sure the nylon piece is in place before replacing the clamping knob. Following are instructions for replacing the Nylon pad.

1. Remove the clamping knob from the axle.
2. Tightly screw the nylon #4-40 x 1/2" slot head screw (0-209) into the 3/8" long nylon spacer (0-159). Use a razor blade to trim off the screw thread protruding from the end of the spacer.
3. Locate the radial hole in front of the axle that extends down to the sample tube. Drop the screw and spacer assembly down the hole, **screw head end first**.
4. Screw clamping knob into the same hole in the axle so it locks the sample tube in the axle. The nylon screw and spacer prevent the clamping knob from marring the sample tube.

4.1.4.4 Felt Replacement

If the felt strip around the header block becomes worn, replace it. Extra felt is in the 75013 SCSM spare parts kit provided.

1. Locate the 6.4 mm x 229 mm (1/4" by 9") strips of adhesive backed black felt in the Ziploc bag containing 75013 accessories and spare parts (671-101). **NOTE:** other adhesive backed felt can be used, but not all adhesives are suitable for use at liquid nitrogen temperature. The brand supplied is: Presto Felt made by Kunin Felt, Hampton, NH, USA; UPC code: 0-28981-09204-3.
2. Cut strips of adhesive backed black felt using a straight edge and razor blade on the back (non-felt) side.
3. **Header Block Felt Replacement**: Remove old felt from groove. Get a 6.4 mm × 229 mm (1/4" by 9") strip of adhesive backed black felt. Trim one end at a 45 degree angle. Peel off adhesive from this end and wrap in the groove starting in the middle of one of the large flat header sides. Do not pull hard on the felt strip or it will stretch and underfill the groove. Trim the other end to match up without leaving a gap.
4. Muffler Felt Replacement: Unscrew the muffler from the bottom of the sample enclosure. Cut a 20 mm (3/4") length of felt strip. Remove the paper backing and roll the strip, sticky-side out, to create a cylinder 6 mm (1/4") tall. Insert the felt cylinder into the muffler, then screw the muffler into the pipe thread hole in the bottom of the sample enclosure.

4.1.4.5 Leakage Resistance and Shielding

Measurement of very high resistance samples (>10 MΩ) requires very high resistance between all combinations of signal, guard and ground. The following procedure is possible only with measurement instrumentation that drives the guards around the signal lines (-HVWR or -LVWR).

1. Measure the resistance of a bare sample card without any sample. First clean the sample card with isopropyl alcohol and demineralized water, then blow dry with warm air from a heat gun. Insert the sample card in the 75013 SCSM and cover with the sample enclosure. Measure the resistance (R14,23) in high resistance mode using the Resistance software program.
2. The resistance should be significantly greater than the specified maximum accurately measurable resistance of the measurement system. Note that a leakage resistance of 100 times the maximum sample resistance would lead to a 1% measurement error.
3. If the resistance is low, check the resistance between signal and guard and between guard and ground. A convenient way to do this is to remove the sample card and probe the card edge connector contacts. Likely places to look for shorts are the connections between the coaxial cable and the bulkhead or card edge connectors. Look for stray wires or improperly cleaned connections.
4. Replace the sample enclosure and tighten the panel screws. Note the star washers under the panel screws. The star washers are important for providing electrical contact between the body of the 75013 SCSM and the sample enclosure for grounding and shielding. The electrical resistance should be less than 1 ohm between the muffler on the bottom of the sample enclosure and the outer shells of the triaxial BNC bulkhead connectors on the junction box. Check this resistance.

4.1.4.6 Liquid Nitrogen Dewar Pumpout

If the rectangular liquid nitrogen dewar frosts up excessively and is unable to maintain liquid nitrogen for the times specified in , then the vacuum has likely degraded and the dewar must be evacuated. Use the following procedure. An alternative is to return the dewar to Lake Shore for service.

The seal-off valve on the dewar body (faces to the rear when installed in the cradle in the electromagnet) is a Cryolab/Circle Seal Model SV8-084-5W2. A Cryolab/Circle Seal Model VO8-084-5L2 Valve Operator is required to open the seal-off valve, evacuate the dewar, and reseal the valve. This valve operator is available from Lake Shore. See Chapter 7 - Options, Accessories, and Cables.

The customer must supply a vacuum pump and gauging to evacuate the dewar to a pressure of 10^{-3} Pa (8×10^{-6} torr) or lower prior to operation. Pumpout of the vacuum space can be performed using a turbo, turbomolecular, cryo, diffusion or other low ultimate pressure (10^{-5} Pa or 10^{-7} torr) dry vacuum pump. The dewar can be removed from the cradle and taken to a vacuum pumping station for pumpout.

1. The dewar should be at room temperature for vacuum pumpout.
2. Connect vacuum line between the vacuum pump and the valve operator, but *do not open the seal-off valve* yet.
3. Remove dust cap from the seal-off valve and clean out excess vacuum grease.
4. Push the Cryolab valve operator onto the seal-off valve body and tighten in place with a 1-3/16" (30.2 mm) wrench.
5. Start vacuum pump and pump out vacuum line to a pressure less than 1.3 Pa (or 10 millitorr or 10 microns).
6. To open the seal-off valve:
   a. Push the Cryolab valve handle in and turn clockwise to screw into the plug.
   b. Pull out on the handle to remove the valve plug.
7. Pump out the dewar to a pressure less 10^{-3} Pa ($8x10^{-6}$ torr).
8. Close the vacuum valve:
   a. Push in Cryolab valve operator handle to insert plug into seal-off valve.
   b. Rotate handle counter clockwise to unscrew handle from plug.
   c. Pull handle back out.
9. Turn off vacuum pump and vent vacuum hose.
10. Remove valve operator from seal-off valve body.
11. Repack the seal-off valve with vacuum grease (Dow Corning High Vacuum Grease, or equivalent) and replace the dust cap.

4.1.4.7 Heater Installation or Replacement

A heater can be located in the bottom of the header block. Older sample modules do not have a heater mounting hole, but one can be added. The following procedure describes initial installation or replacement of the heater.

1. Locate the hole for the heater in the bottom of the header block (see Figure 4-15). If necessary, remove a defective heater or drill the required hole.
2. IF there is no existing heater, attach DT-32 (duo twist, 32 AWG phosphor bronze) wires to the 10-pin connector inside the junction box. Connect yellow to pin D and green to pin E. Pass the other end of the wire set down through the tube and out the bottom of the header block.
3. Connect one end of the DT-32 wire set to the heater leads. Use Teflon or Kynar shrink tube to insulate the connections. There is no polarity to the heater leads.
4. Apply a small amount of Apiezon H grease to the heater. Insert the heater into the 0.125 inch diameter hole in the bottom of the header block. Make sure the heater is secure and no wiring is electrically shorted. If the heater is loose, wedge it in place with a piece of shim stock (use a non-magnetic metal such as copper or brass).
5. Tuck any loose wiring up inside the header block.

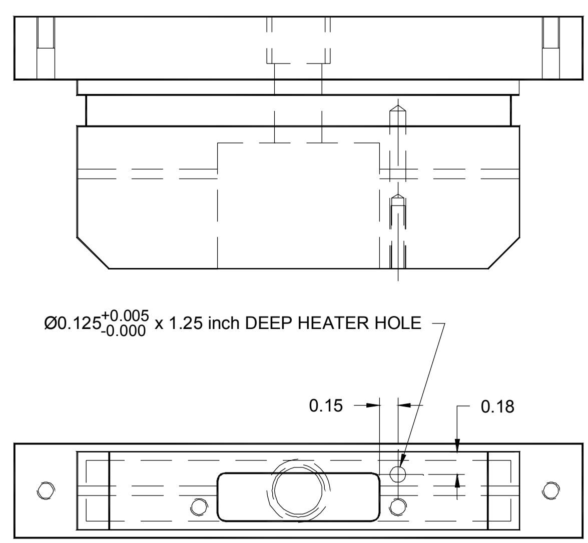


Figure 4-15. Heater Location in the 75013 SCSM Header Block.

4.2 MODEL 75014 CCRSM - CLOSED CYCLE REFRIGERATOR SAMPLE MODULE

The Model 75014 Closed Cycle Refrigerator Sample Module (75014 CCRSM) 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 a closed cycle refrigerator (CCR) against two heater circuits powered by a temperature controller. An assembly overview is shown in Figure 4-17. The 75014 CCRSM consists of the following components:

- APD OmniPlex Cryostat (see Figure 4-17 and Table 4-10) modified specifically for this application, including added:
  - Rotation Stage
  - Flush/Fill Unit
  - Mounting Base Plate
- Sample Insert (see Figures 4-19 and 4-20)
- APD Compressor for the CCR
- APD Helium Gas Lines for the CCR
- Power Booster for a Model 340 Loop 2 Heater Output

Also required for operation of the Model 75014 CCRSM, but not provided:

- Model 750TC Temperature Controller option
- Vacuum pump

Optional additional equipment:

- Water chiller for the CCR compressor
- Model 75014WT windowed tail field installation kit

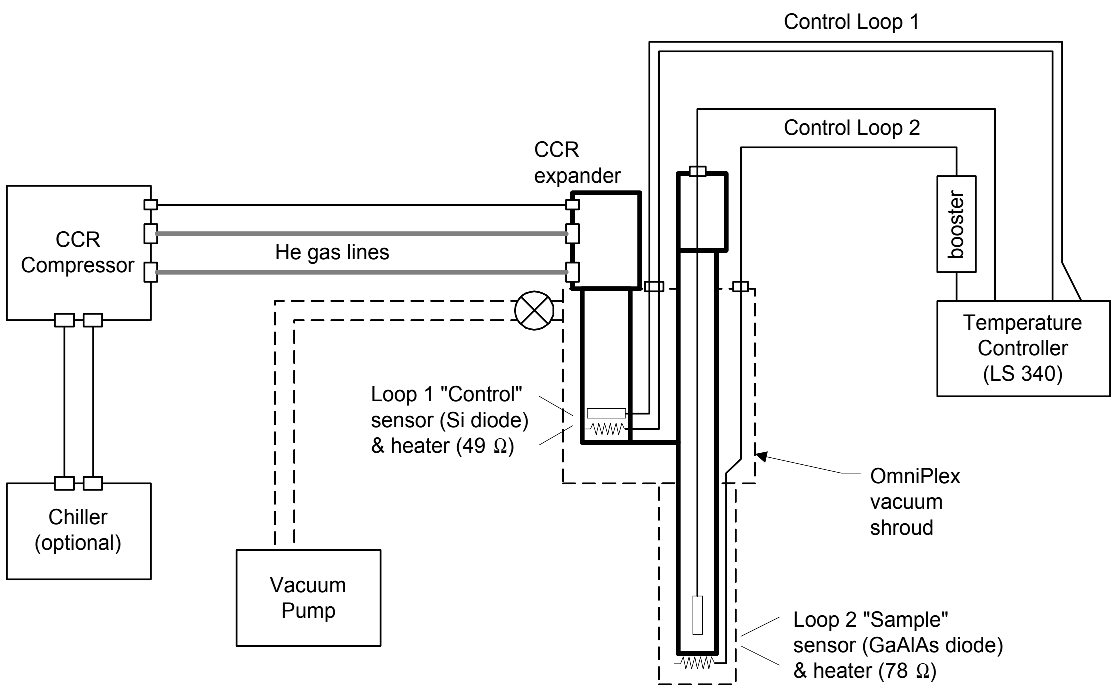


Figure 4-16. Model 75014 CCRSM Operational Schematic.
The electromagnet and measurement systems are not shown.

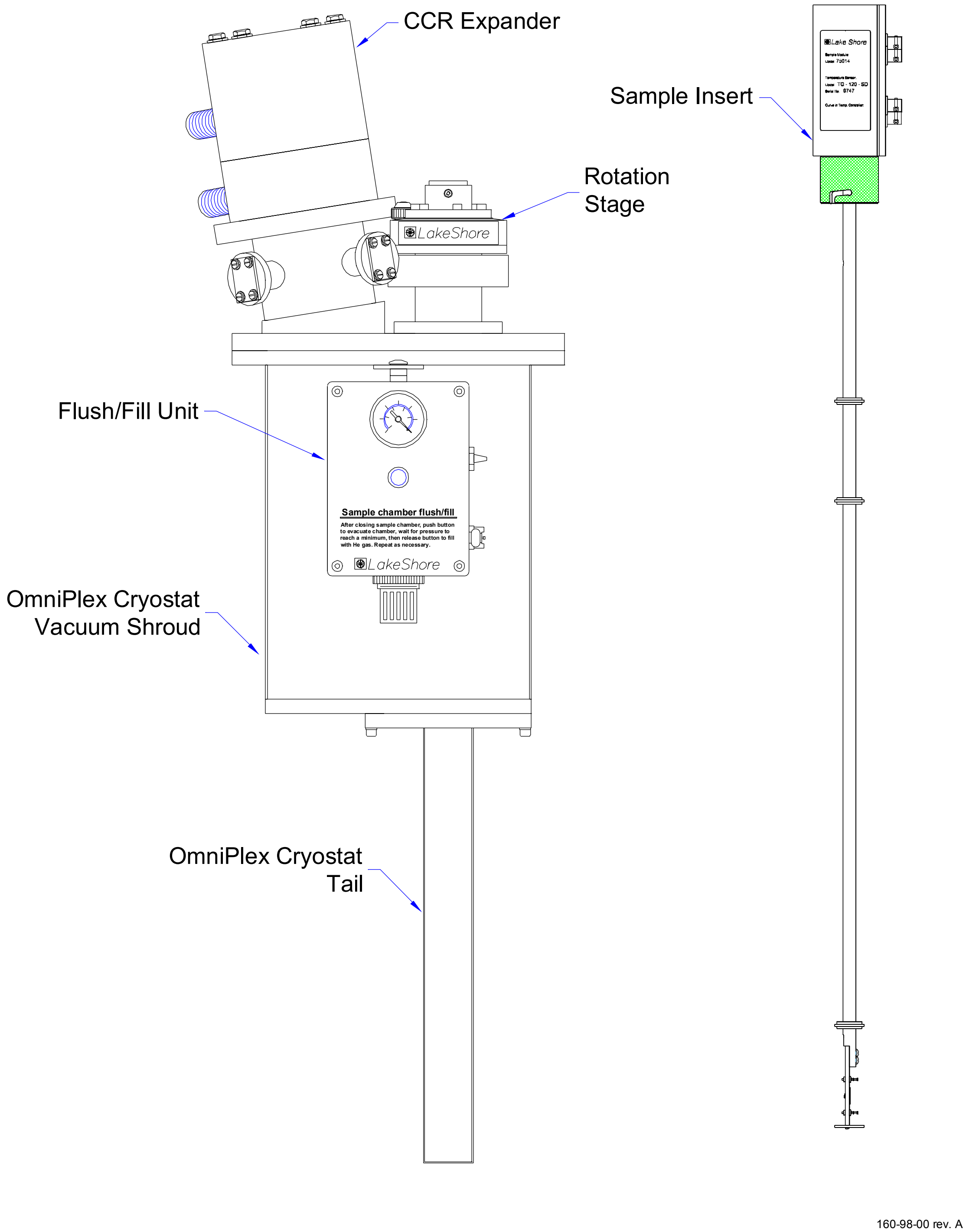


Figure 4-17. Model 75014 CCRSM Assembly Overview.
View from front of electromagnet

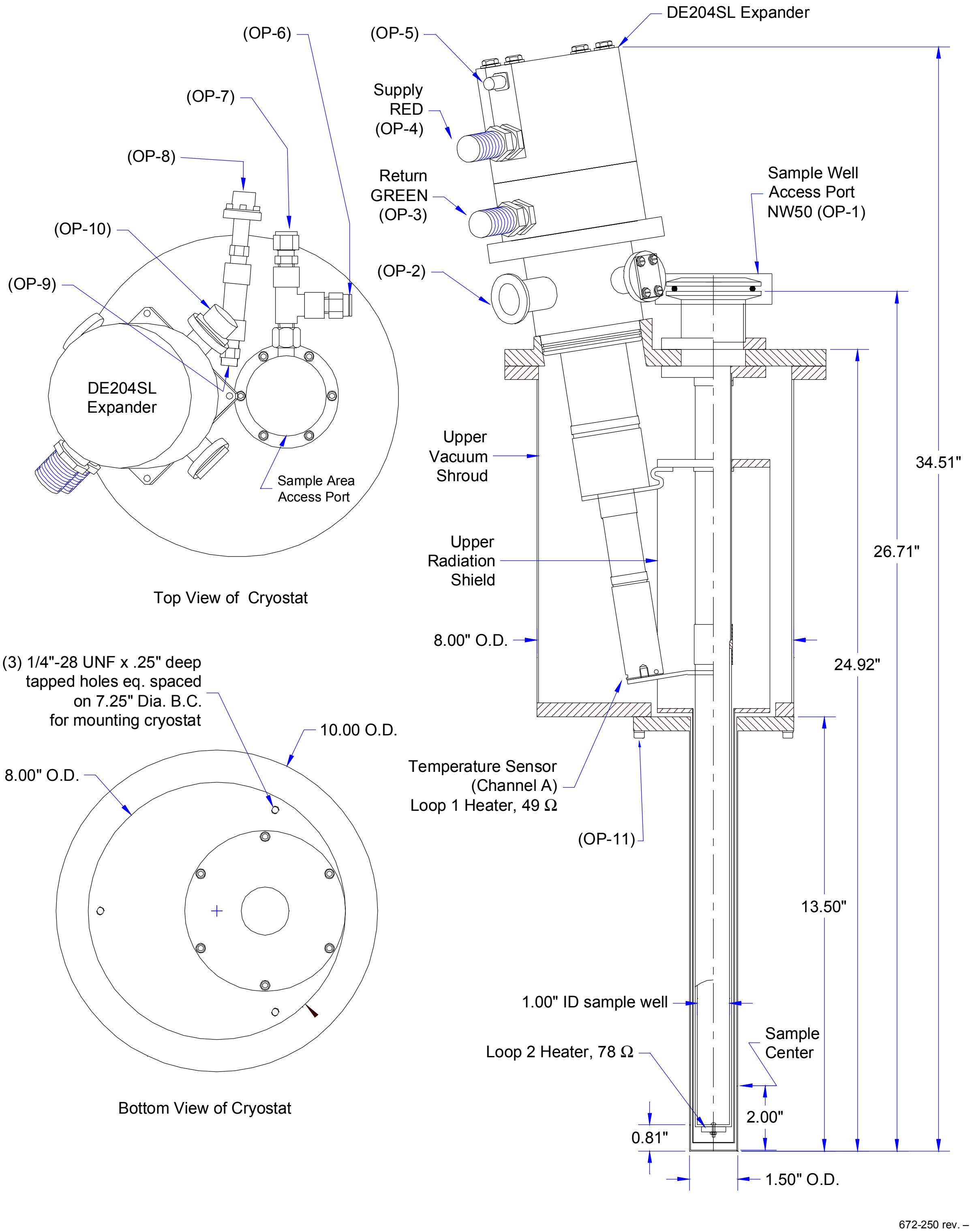


Figure 4-18. OmniPlex Cryostat for the Model 75014 CCRSM.
View from front of electromagnet. Newer units have the expander rotated 90 degrees from the orientation shown, so the connection ports face towards the rear.

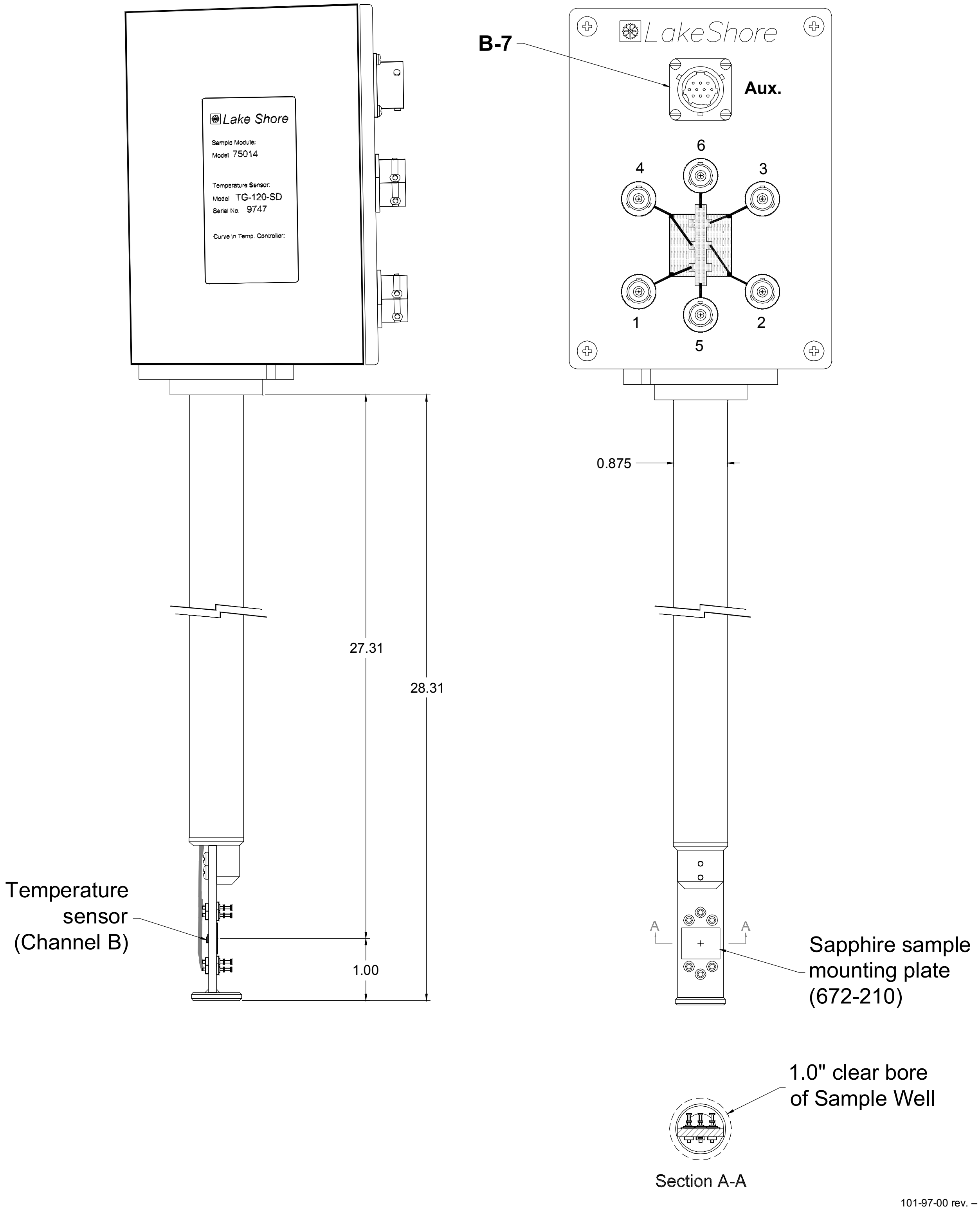


Figure 4-19. Model 75014 CCRSM Sample Insert, Style A.
Distinguishing features are the large junction box and stainless steel tube.

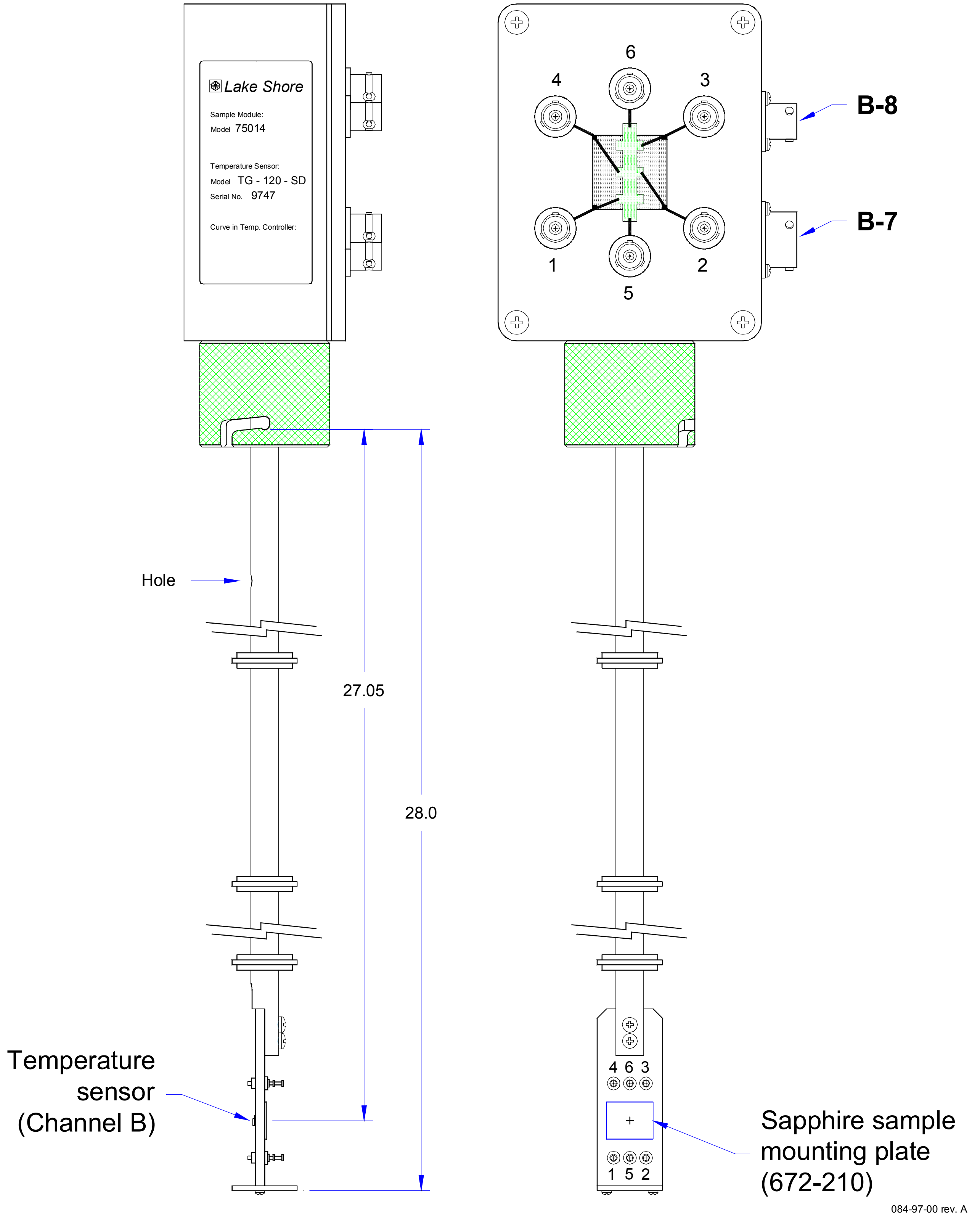


Figure 4-20. Model 75014 CCRSM Sample Insert, Style B.
Distinguishing features are the small junction box and G-10 phenolic tube.

Table 4-10. OmniPlex Cryostat Connection Point and Interface Designations.
The locations of the connections listed below are shown in Figure 4-18.

OP-		OmniPlex Cryostat
	1	Sample well access port, NW-50 flange, 25.4 mm (1.0 inch) clear bore
	2	Vacuum shroud pumpout port, NW-25 flange
	3	Return helium gas connection to compressor (GREEN)
	4	Supply helium gas connection from compressor (RED)
	5	Expander power, 4-pin circular connector, from compressor (BLUE)
	6	Sample well relief valve, 28 kPa (4 psig) cracking pressure
	7	Sample well exchange gas inlet, Swagelok for 6.35 mm (1/4 inch) OD tube
	8	Loop 2 heater (78 Ω), 2-pin circular connector (RED)
	9	Vacuum shroud relief valve, 28 kPa (4 psig) cracking pressure
	10	Loop 1 temperature sensor and heater (49 Ω), 10-pin circular connector (RED), see Table 4-12
	11	Tail vacuum shroud

Table 4-11. Sample Connection Wiring for the 75014 Sample Insert.
The wire resistance is measured from the connector on the junction box to the sample contact post.

Connector	Pin	Use	Wire R [Ω]
B-1	**1**	Sample connection # 1	35
B-2	**2**	Sample connection # 2	35
B-3	**3**	Sample connection # 3	35
B-4	**4**	Sample connection # 4	35
B-5	**5**	Sample connection # 5, I+ for Hall bars	35
B-6	**6**	Sample connection # 6, I– for Hall bars	35
B-7	**A**	Sample card pad 10; "Sensor" temperature sensor (Channel **B**), V–	8
	B	Sample card pad 9; "Sensor" temperature sensor (Channel **B**), V+	8
	C	Sample card pad 8; "Sensor" temperature sensor (Channel **B**), I–	8
	J	Sample card pad 7; "Sensor" temperature sensor (Channel **B**), I+	8
	D	unused	
	E		
	G	unused	
	H		
	F		
	K		
B-8		unused	

Table 4-12. Wiring of OmniPlex Loop 1 Cable (# 263941B11).
Connects OmniPlex cryostat 10-pin connector for Loop 1 heater and temperature sensor (OP-10) to the Model 340.

Connection	Pin	Use	Connection	Pin
OP-10	**A**	I+ Temperature sensor excitation current (Channel **A**)	(**G-16**) on Model 340	**5**
	B	V+ Temperature sensor output voltage (Channel **A**)		**4**
	C	V– Temperature sensor output voltage (Channel **A**)		**2**
	D	I– Temperature sensor excitation current (Channel **A**)		**1**
	E	I+ Heater (Loop 1), 49 Ω	(**G-5**) on Model 340	**Hi**
	F	I– Heater (Loop 1)	(**G-6**) on Model 340	**Lo**
	G			
	H			
	J			
	K			

4.2.1 Setting Up the Model 75014 CCRSM

Setup must be performed in the following cases:

1. Initial setup following shipping or long term storage.
2. Quick setup following sample module exchange in the electromagnet.

The 75014 CCRSM can be removed from an electromagnet and stored on a stand without detatching many of the connections, so Case 2 is simpler and often does not require all the steps in the initial setup. Table 4-13 lists the steps required for setup. The table gives an overview and also can be used as a checklist.

Table 4-13. Model 75014 CCRSM Setup Steps.
Reference refers to the relevant section in this manual. An asterisk (*) indicates the procedure is not always required.

Initial	Quick	Description	Reference	
1		OmniPlex Unpacking and Assembly	**4.2.1.1**	
2	**1**	OmniPlex Installation in the Electromagnet	**4.2.1.2**	
3	**2**	Sample Well Helium Purge Gas Connection	**4.2.1.3**	
4		Compressor Set Up and Initial Test	**4.2.1.4**	
5	**3**	Gaussmeter Probe Installation and Orientation	**4.2.1.5**	
6	**4**	Check OmniPlex connections	Table 4-12	
7	**5***	Rotation Stage Alignment	**4.2.1.6**	
8	**6***	Temperature Controller Setup	**4.2.1.7**	
9		Power Booster Installation	**4.2.1.8**	

4.2.1.1 OmniPlex Unpacking and Assembly

1. Verify that the site chosen for the electromagnet and associated hardware is adequate for a Model 75014 CCRSM:
   - Ceiling clearance of at least 2 m (6.5 ft.) above the floor for sample holder insertion or removal.
   - Locate compressor close enough to the electromagnet for the 3 m (10 ft.) helium gas hoses to reach.
   - The cryostat is heavy; move it with great care. The tail can be damaged by bumping into other objects, especially the magnet pole pieces.
   - Construct a stand to hold the cryostat when not mounted on the magnet. The stand must be sturdy and not tip over or allow the tail of the cryostat to bump against anything. Locate the stand where helium gas line removal is not necessary when moving the cryostat between the magnet and the stand.
2. Locate OmniPlex manual. The manual consists of the following sections:
   1) General: General for Laboratory Systems, #262347A,
   2) System: OmniPlex Top Loading Exchange Gas Cryostat, #260634A,
   3) Compressor (shipped with compressor): APD Model HC-4 MK2-1 Helium Compressor, #263961A,
   4) Expander: Expanders, Two-stage, #257519A,
   5) Gas Lines: Gas Lines, #261320A
3. Unpack OmniPlex sample module. Ships in a long cardboard box. Do not lift by the plastic shipping tail. The OmniPlex is top heavy (expander end) and can be difficult for one person to lift. Set OmniPlex on a solid, clean table with the expander lying down against the table surface. Save packaging in case future shipping is required.
4. Remove shipping tail. Remove the (6) #10-24 × 5/8" SHC screws holding the tail to the vacuum shroud. Save screws for Tail Vacuum Shroud installation. Carefully pull shipping tail off of sample well tail. The shipping tail should have foam wraps inside. Slip them over the sample well tail with a screwing motion. Save the white PVC shipping tail with the packing materials in the shipping box.
5. Install Tail Radiation Shield. (**NOTE:** The Tail Radiation Shield is sometimes shipped already installed.) Locate and unpack the tail radiation shield and screws. Carefully slide the Tail Radiation Shield over the Sample Well Tail. Carefully peel back any tape ends to allow the radiation shield flange to seal flush. Rotate the Tail Radiation Shield to match the tape marks so it is in the same orientation as the last time it was assembled. Use a 7/64" hex wrench to install the (6) #6-32 × 3/8" SHC screws. Reattach the tape to hold the superinsulation to the Tail Radiation Shield.

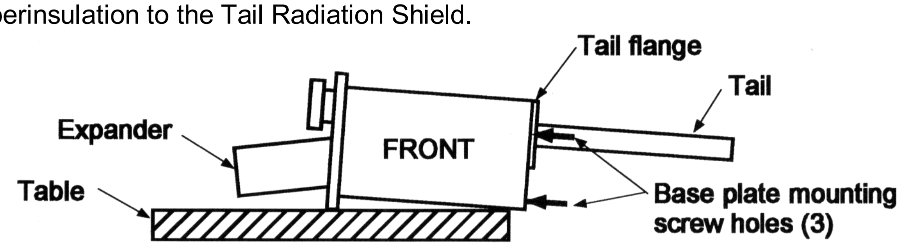


Figure 4-21. OmniPlex Orientation for Base Plate Installation

6. Install Tail Vacuum Shroud. Locate and unpack the tail vacuum shroud and its O-ring. Clean and install the O-ring in the groove of the Tail Vacuum Shroud. Carefully slide the Tail Vacuum Shroud over the Tail Radiation Shield. Rotate to align so the part number sticker is at the outer diameter of the vacuum shroud and the screw holes are aligned. Use a 5/32" hex wrench to install the (6) #10-24 × 5/8" SHC screws.
7. Install the base plate. Hang tail end of OmniPlex vacuum shroud just over edge of table (Figure 4-21). Orient base plate according to the appropriate instructions below.

   EM4 base plate only (672-136): The smoothest surface should be oriented towards the base of the OmniPlex (will face up when OmniPlex is mounted on the EM4 magnet stand). The tail goes through the hole in the base plate. Align the three small holes with the screw holes in the base of the OmniPlex vacuum shroud.

   EM7 base plate only (672-142): Note that the large hole in the base plate for the tail is not centered. The thin section must be on the back side of the OmniPlex (the 4-pin electrical connector faces the back). The 1/4" screw hole farthest from the large center hole must be under the expander side of the OmniPlex (down in the orientation shown in Figure 4-21). Align the three small holes with the screw holes in the base of the OmniPlex vacuum shroud.

Use a 3/16" hex wrench to attach the base plate using (3) #1/4"- 28 SHC screws (674-217) and small OD split lock washers (674-218).

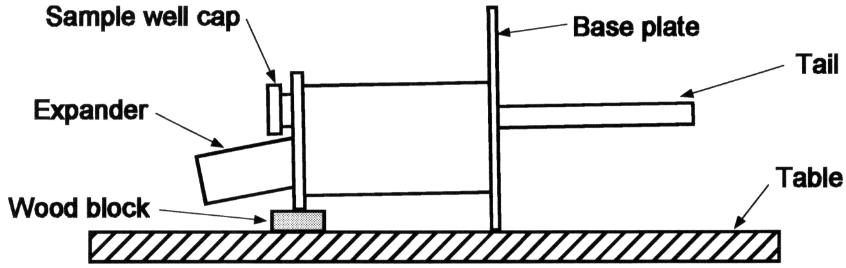


Figure 4-22. OmniPlex Orientation on Table Surface

8. Lift the OmniPlex back on the table and orient as shown in Figure 4-22. Use a wood block to keep the OmniPlex from resting on the expander. A 2×4 (40 mm thick) blocki is about right with the EM4 base, but a slightly thicker block is required with the EM7 base.

4.2.1.2 OmniPlex Installation in the Electromagnet

The Model 75014 CCRSM mounts on top of an electromagnet. Below are directions for mounting to different magnet systems.

Installation on EM4 (4 inch) electromagnet stand:

1. Back out magnet poles to allow plenty of clearance for the cryostat tail. Make sure the path is clear between the location of the 75014 CCRSM and the magnet stand.
2. Install electromagnet shims (672-137) if it has not been done already. Unbolt electromagnet from stand and raise enough to slip a 3.2 mm (1/8") thick shim under each of the two supports. The shims raise the magnet by the same amount as the base plate attached to the OmniPlex vacuum shroud.
3. Carry the 75014 CCRSM to the magnet and set in a vertical position with the Base Plate on top of the magnet stand. Be careful not to hit the OmniPlex tail on anything.
4. From the front of the magnet, the Expander should be on the Left and the Flush/Fill box should be facing forward. Align the 3/8" bolt holes in the Base Plate. Note that the head of one screw on the underside of the base plate will drop into one of the left center hole on top of the electromagnet stand.
5. Install the five 3/8"-16 × 1.5" socket head cap screws (654-123) with 3/8" nylon washers (654-148) through the top of the Base Plate. From the bottom side put on a nylon washer and a hex nut (654-166). Do not over-tighten.

Installation on EM7 (7 inch) electromagnet frame only:

1. Back out magnet poles to allow plenty of clearance for the cryostat tail. Make sure the path is clear between the location of the 75014 CCRSM and the magnet stand.
2. Install plastic guide rails (672-144) on insides of electromagnet coil saddles (672-145L and 672-145R), if it has not been done already. Each guide rail is secured with three shoulder screws 5/16" OD × 3/4" long (674-215) such that the 3/8" holes are aligned with the 3/8" holes in the sides of the coil saddles.
3. Carry the 75014 CCRSM to the magnet and set in a vertical position with the Base Plate on the plastic guide rails between the saddle sides. Be careful not to hit OmniPlex tail on anything.
4. From the front of the magnet, the Expander should be on the Left and the Flush/Fill box should be facing forward. Align the 3/8" bolt holes in the Base Plate with the holes in the saddle sides.
5. Install the six 3/8"-16 × 1.5" SS SHCS (654-123) with 3/8" nylon washers (654-148) through the saddle sides. Do not over-tighten.

4.2.1.3 Sample Well Helium Purge Gas Connection

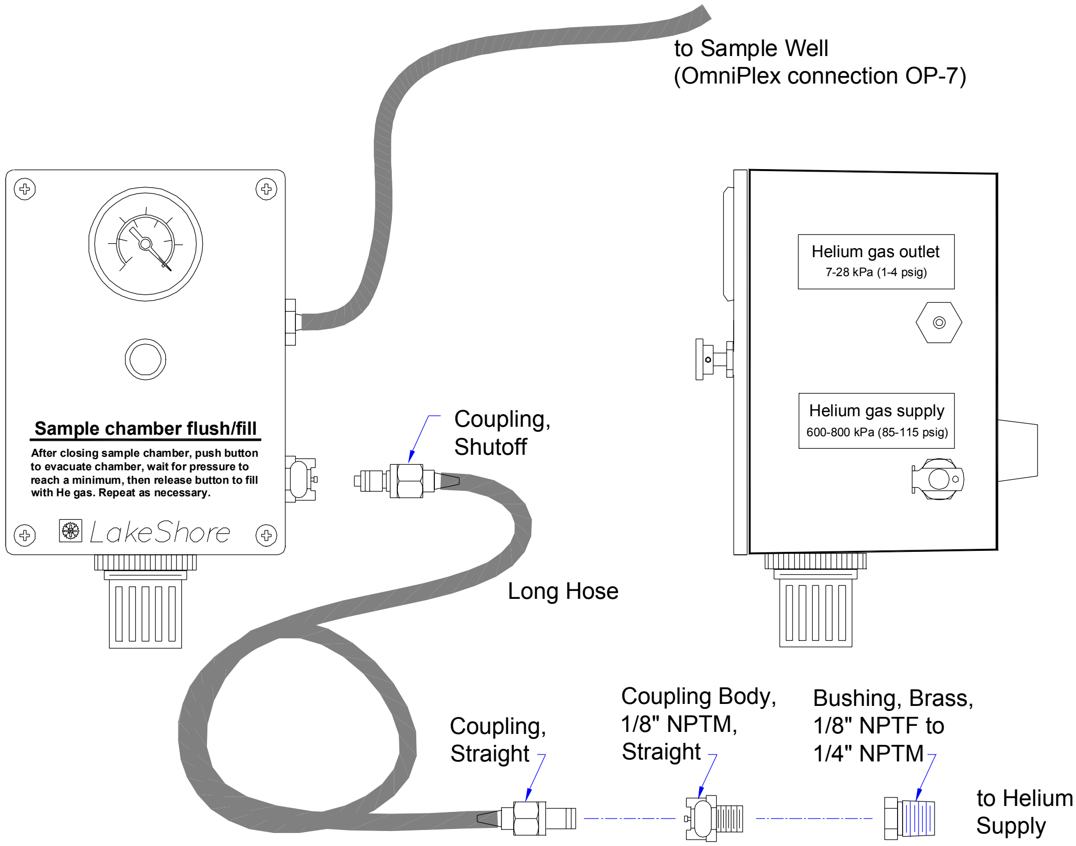


Figure 4-23. Sample Chamber Flush/Fill Unit

The helium exchange gas sample environment requires a source of He gas (standard grade) with delivery pressure of 600-800 kPa (85-115 psig). The customer supplies the helium gas source. A urethane hose 3 m (10 ft.) long and 1/8" ID connects to the Flush/Fill unit. The other end fits a 1/8" barb fitting. Use a 1/8" barb fitting with 1/8" and 1/4" NPTM fittings or a quick disconnect to connect to the helium gas source.

1. Attach one end of the 60 cm (24") piece of urethane tubing by pushing onto the Helium Gas Outlet hose barb on the side of the Flush/Fill unit.
2. Install the other end of the urethane hose in the 1/4" ID Swagelok fitting on the sample well manifold.
3. Remove the 0.75 psig relief valve on the sample well manifold and replace with a Relief Valve, 4 psig, 1/4" NPTM (602-611). Use Teflon tape to seal the threads. The 0.75 psig relief valve can be used in house, but is not needed on the 75014 CCRSM.
4. Insert the connector end of the long urethane supply hose into the supply inlet port in the side of the Flush/Fill unit.
5. Chain a high pressure helium gas cylinder within reach of the supply hose. The pressure regulator must be capable of supplying helium gas at a regulated gauge pressure of 600-800 kPa (85-115 psi).
6. Connect the free end of the Flush/Fill supply hose to the pressure regulator on the helium cylinder. A 1/8" NPTM hose barb (672-274) is supplied along with a 1/8"NPTF to 1/4"NPTM adapter bushing (209-045), but we more commonly use quick connect fittings in house.
7. Verify that the sample well plug is in place.

8. Set the helium cylinder regulator pressure in the proper 600-800 kPa (85-115 psi) range and open any valves to supply helium to the Flush/Fill unit.
9. Listen for any leaks or hoses popping off. Check for slow leaks by closing the main helium supply tank valve and watching the regulator supply pressure gauge. The pressure should not drop more than 1000 kPa (145 psi) within 10 minutes and is more typically one tenth this leak down rate. Correct any leakage problems and open the main supply valve.
10. Get a balloon and stretch over the Relief Valve on the sample well manifold.
11. Push the valve button on the front of the Flush/Fill unit and check that the pressure drops to about -25 mm Hg (-80 kPa).
12. Release the valve button. The sample well should fill with helium gas until the pressure gauge is pegged. If the balloon fills with gas, the sample well pressure regulator sticking out from the bottom of the Flush/Fill box is set too high. Otherwise, use this regulator to increase the sample well pressure until the balloon just begins to fill, then back off about 1/4 turn.
13. Briefly press the valve button and try to achieve a sample well pressure of -5 mm Hg (-15 kPa). If this pressure can be achieved and the sample well does not refill and pressurize with helium gas, then the sample well regulator is not set high enough. Adjust the regulator setting until a stable pressure of -5 mm Hg is not possible after releasing the valve button, but the balloon does not fill.
14. The Flush/Fill unit is now ready for loading of the Sample Insert.

4.2.1.4 Compressor Set Up and Initial Test

1. Uncrate the compressor.
2. **Connect water to the compressor**. Do not use the supplied hoses for testing prior to shipment to the customer. Note that the compressor must be turned on for the internal solenoid valve to open, so no water will flow until the compressor is turned on.
3. Follow the **Compressor Checkout** instructions in the System section of the APD manual. Note that the helium gas lines are not connected during the checkout. Turn on the compressor and adjust the water flow rate to 3 L/min (0.8 gpm). Run the compressor for one hour.
4. **Turn the compressor OFF**.
5. **Install the helium gas lines**. Follow the instructions under Install Gas Lines in the System section of the APD manual. Verify couplings are clean before making a connection. Use two wrenches when tightening a coupling, as shown in the APD manual.

   Connect helium gas lines to Compressor in the following order: **Supply** (right/red) then **Return** (left/green).

   Connect helium gas lines to the Expander (in 75014 CCRSM) in the following order: **Return** (bottom/green) then **Supply** (top/red).

   Screw the dust caps together and store in the tool box.
6. **Install Expander Cable**. Connect one end of expander cable to expander receptacle on compressor. Connect the other end of the cable to expander 4-pin circular bulkhead cable plug on OmniPlex expander just above the helium gas line connections (both plug and blukhead marked **BLUE**).

4.2.1.5 Gaussmeter Probe Installation and Orientation

Operation of the Model 75014 CCRSM requires a Gaussmeter Probe (Figure 4-5) and Gaussmeter Probe Holder (Figure 4-6).

CAUTION: Exercise care when handling the Gaussmeter Probe. The tip is very fragile. Any excess force can alter the calibration or cause the sensor to break. Broken sensors are not repairable.

WARNING: If electromagnet has been moved and not yet powered to full current, the magnet coils may shift the first time the electromagnet is energized, allowing the Gaussmeter probe holder to fall out and possibly damaging the Gaussmeter probe. After moving the electromagnet , *manually* run the electromagnet to full current before installing the Gausmeter probe holder.

1. The gap between the tail of the OmniPlex and the right hand electromagnet pole face should be 3-6 mm (1/8 to 1/4 inch). The gap on the left side can be smaller. Lock the electromagnet poles in place. **NOTE**: The Gaussmeter probe tip is to be located between OmniPlex tail and the right hand electromagnet pole face.
2. Insert Gaussmeter probe holder between the coils of the electromagnet (see Figure 4-6). Note that the Probe Mounting Hole can be above or below the threaded rod, as desired. Turn the two knurled endpieces to wedge the assembly in place. Do not overtighten or the threaded rod will bend and buckle.
3. Rotate the mounting block on the threaded rod until it is aligned near the right hand pole face (when viewed from the front of the electromagnet).
4. Tighten the front screw to lock the mounting block against the threaded rod. Do not overtighten. **CAUTION:** Exercise care when handling the Gaussmeter probe because the sensor mounted in the tip is fragile. Stressing the probe tip may alter the sensor calibration. Any excess force can easily break the sensor. Broken sensors are not repairable.
5. Insert Gaussmeter probe through Probe Mounting with the Snowflake pattern facing to the *left*. The Top Screw must clamp onto the large diameter portion of the probe handle.
6. Locate Gaussmeter probe in contact with the right side of the OmniPlex tail and with the tip parallel to the electromagnet pole face. The magnetic fields very close to the pole face can be nonuniform, so placement of the tip directly against the electromagnet pole face is not recommended. The location of the mounting block along the threaded rod might require adjustment.
7. Move probe holder assembly forward or backward to position the sensitive portion of probe tip over the center of the electromagnet pole face. The knurled endpieces might need loosened to allow movement, then re-tightened. Verify the probe is straight and properly oriented with snowflake pattern facing to the left so the wide side of the probe tip is parallel to the electromagnet pole face. Adjust as necessary.

CAUTION: A Gaussmeter Probe reversed in orientation reverses the sign of readings (i.e. a positive magnetic field reads as a negative field). Correct sign of readings is critical to magnetic field control! If unsure of correct orientation, use procedure below:

1. With the magnet power supply OFF, place the Gaussmeter probe in the electromagnet noting the orientation of the Lake Shore Snowflake symbol.
2. Turn the power supply ON in MANUAL mode. Manually set a positive current of a few amperes corresponding to approximately +0.05 tesla (+500 gauss).
3. Read the front panel display of the Model 450 and ensure the field reading is positive. If the field reading is negative, reverse the orientation of the Gaussmeter probe.
4. When done, reduce current to zero and turn OFF power supply.

4.2.1.6 Rotation Stage Alignment

The rotation stage ships mounted on the OmniPlex sample well access port (**OP-1**). Alignment is normally not required unless the rotation stage is removed or rotated for some reason.

Accurate Hall effect measurements require that the sample be perpendicular to the magnetic flux density (field). The rough alignment procedure involves physical alignment of the rotation stage relative to the pole faces, a difficult task to perform accurately and which does not take into account any misalignment contributed by the interface to the Sample Insert or by the Sample Insert itself. The fine alignment procedure involves electrical measurements and is both more accurate and more time consuming.

Below are instructions to install and align the rotation stage. Read the entire procedure before proceeding.

Installation of the rotation stage

1. Start with the plug in the quick connect on top of the rotation stage (i.e., no Sample Insert loaded).
2. Fully loosen the KF-50 quick flange clamp below the rotation stage and open it wide enough to allow rotation of the stage, but do not remove the clamp.

Rough orientation of the rotation stage

The Lake Shore nameplate on the rotation stage should face toward the front of the magnet. The rotation stage should orient the sample perpendicular to the magnetic field and facing the right magnet pole for accurate Hall effect measurements.

1. Orient the rotation stage assembly so the Lake Shore nameplate faces forwards. The fit is tight and requires tipping the rotation stage to rotate it 90 degrees or more.
2. Check orientation relative to the pole faces—the sides of the rotation stage should be parallel to the pole faces—and tighten the clamp. Exact alignment is not easy as the path between the rotation stage and the poles is not clear.

Fine alignment of the rotation stage

1. Mount a sample with a large Hall coefficient on the Sample Insert. The medium resistivity boron doped silicon sample supplied with the system is a good choice if it can be tested near room temperature.
2. Insert Sample Insert into sample well. Face junction box to the right (usual orientation) and lock in place.
3. Connect triaxial input cables to the junction box on the Sample Insert.
4. Start the Hall System Software program.
5. Activate the Resistance software program, select the menu: Sample Definition, and set up the appropriate sample type for a measurement with the following parameters:
   Hall Resistance
   Current reversal OFF (not selected)
   Two geometries OFF (not selected)
   Settle time = 120 seconds (adjust as needed)
   Excitation current of +100 uA is suggested for the medium resistivity (~10.5 Ω·cm) silicon sample near room temperature
6. Activate the Field Control program. Select the menu: Edit -> Properties and note the maximum magnetic field achievable. Select the menu: Run -> Go To Field and input a field near the maximum to get the largest signal.
7. Verify that the rotation stage is set at 0 degrees rotation.
8. Take a measurement (click on the green TAM button). Repeat as necessary to display the Hall voltage.

9. Rotate the stage about zero to find the orientation where the absolute value of the Hall voltage is maximized. This is the offset angle, Ao. The Hall voltage is displayed on the front panel of the voltmeter. If the voltmeter front panel can not be seen easily, activate the Voltmeter software program, display the front panel, and rotate the monitor for easy viewing. If the signal is too small to locate the maximal orientation accurately the following corrective actions are suggested:
   a) increase the excitation current,
   b) increase the magnetic flux density, or
   c) use a different sample with smaller sheet charge density.
10. If the offset angle, Ao, is significant - more than a few degrees - rotate the sample stage by the following process:
   a. Set the rotation stage to zero degrees. If desired, use an Allen key to tighten the knob and prevent rotation.
   b. Loosen the KF-50 clamp and rotate the stage and sample insert to maximize the Hall voltage reading (absolute value).
   c. Tighten the KF-50 clamp, being careful not to let the stage rotate during clamping.
   d. Go back to the previous step (15).
11. Record the offset angle, Ao, and note on the Sample Insert. Hall effect measurements using this Sample Insert should be made with the rotation stage set to the offset angle Ao, rather than set to zero. Note that if more than one sample insert is used with this sample module, Ao can change with the sample insert, so each one should be tested.
12. Return the magnetic flux density to zero using the Field Control program menu: Run -> Go To Field.
13. Exit the Hall program when finished.

4.2.1.7 Temperature Controller Setup

The Model 750TC Option adds a Model 340 and is required for operation of the 75014 CCRSM. This procedure configures the Model 340 inputs for one silicon diode (DT-470) on the cold end of the Expander, one GaAlAs diode (TG-120) at the sample location on the Sample Insert, and two loop temperature control.

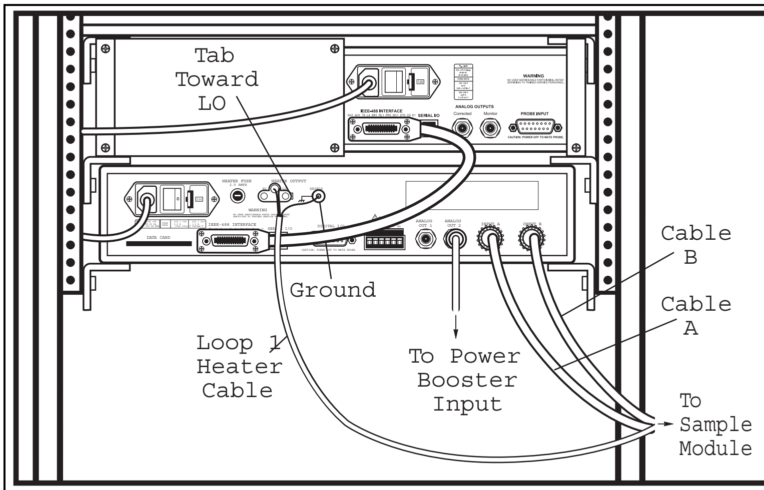


Figure 4-24. Typical Model 340
Connections to the Model 75014 CCRSM.

A schematic of the control system is shown in Figure 4-16. Temperature sensor and heater physical locations are shown in Figure 4-18.

The first control loop consists of a temperature sensor and heater attached to the cold end of the refrigerator.

The sample is located near the bottom of the copper sample well, separated from the sample well by helium exchange gas, and is a significant distance from the refrigerator cold end. A temperature sensor mounted directly to the sample insert provides a much more accurate measure of the actual sample temperature. Many temperature sensors experience unacceptably large reading errors when operated in high magnetic fields at low temperatures. For this reason a GaAlAs diode temperature sensor is used to monitor the sample temperature. The disadvantage is that each GaAlAs diode must be individually calibrated as a function of temperature and the proper calibration curve must be loaded into the temperature controller and selected for use.

The heater for the second control loop is located on the bottom of the sample well. The temperature sensor on the sample insert is used to control the second loop heater. Refer to the Model 340 manual for further information on dual control loop theory and operation.

Table 4-14. Connection List for Model 340 to Model 75014 CCRSM

#	CONNECTION	FROM	TO
1	Auxiliary input cable, 655-451 (see Table 4-15)	( ) cable 6-pin circular connector **A** NOT CONNECTED (**G-17**) cable 6-pin circular connector **B** to Model 340 Channel **B** ( ) Cable dual banana connector NOT CONNECTED ( ) Cable single banana connector NOT CONNECTED	(**B-7**) Junction box of Sample Insert, 10-pin circular connector socket (marked BLUE)
2	Loop 1 Control Cable	(**G-16**) cable 10-pin circular connector **A** to Model 340 Channel **A** (**G-5, 6**) Cable dual banana connector to Model 340 Heater Output, gnd tab to LO (**G-7**) Cable single banana connector to Model 340 Heater Output SHIELD	(**OP-10**) 10-pin pin circular connector socket on side of OmniPlex expander (marked RED)
3	Power Booster Coaxial/BNC Heater Input Cable	Power Booster terminals **7**and **14**	(**G-15**) Model 340 Analog Out 2
4	Loop 2 Heater Output Cable: APD Heater Cable (APD part 263316B8) with a 2-pin military socket connector on one end (marked BLUE)	Power Booster terminals **4, 5, 6**	(**OP-8**) 2-pin circular connector socket on rear of OmniPlex (marked BLUE)

Table 4-15. Cable 655-451 Wiring. Connects 75014 Sample Insert 10-pin connector (B-7) to Model 340

Connection	Pin	Use	Connection	Pin
B-7	**A**	V– Temperature sensor output voltage (Channel **B**)	(**G-17**) on Model 340	**2**
	B	V+ Temperature sensor output voltage (Channel **B**)		**4**
	C	I– Temperature sensor excitation current (Channel **B**)		**1**
	J	I+ Temperature sensor excitation current (Channel **B**)		**5**
	D	I+ Heater	(NOT USED)	**Hi**
	E	I– Heater		**Lo**
	G	V– Temperature sensor output voltage (Channel **A**)	(NOT USED)	**2**
	H	V+ Temperature sensor output voltage (Channel **A**)		**4**
	F	I– Temperature sensor excitation current (Channel **A**)		**1**
	K	I+ Temperature sensor excitation current (Channel **A**)		**5**

Following is the setup procedure:

1. Connect all cables listed in Table 4-14 (see Figure 4-24).
2. **For Quick setup only**: Skip the remainder of this section and proceed directly to Section 4.2.3.3 Verify Temperature Controller Setup. To determine if a quick setup is possible, check if a configuration file already exists. Use either Windows Explore and look in the Windows directory, or start the Model 340 program and select the menu item: File -> Load. Typical file names relevant to this sample module might look like "75014_S1.34c". Note that some work can be saved by first loading a configuration file similar to one to be set up.
3. Exit any programs using the Model 340. The Model 340 must be in LOCAL mode to change settings through the front panel.
4. Set up the Model 340 through the front panel as specified in the procedure below. For further information, refer to the Model 340 User's Manual and the Model 340 software help files. (For setup of a Model 330 Temperature Controller, refer to the Model 330 User's Manual.)

- **Input Setup**

		(Model 340 front panel button) Input Setup
Input:	**A**	Enter
Enable:	**ON**	^ Enter
Type:	**Silicon Diode**	^ Enter
Curve:	**1 DT-470**	^ Enter
		Save Screen
Input:	**B**	^ Enter
Enable:	**ON**	^ Enter
Type:	**GaAlAs Diode**	^ Enter
Curve:	**21 TG-120SD**	^ Enter
(21 is typical: match the sensor serial number to the calibration curve)		
		Save Screen, Save Screen

- **Display Format**

		(Model 340 front panel button) Display Format
Input Displays:	**2**	^ Enter
Display 1:	A TEMP K	Enter
Display 2:	B TEMP K	Enter
		Save Screen
		Display Format
		<MORE>
Control Loops:	**BOTH**	^ Enter
Heat Display:	**POWER**	^ Enter
		Save Screen

- **Interface**

		(Model 340 front panel button) Interface
IEEE-488		
Terminator:	CR LF	Enter
EOI:	ON	Enter
Address:	**14**	Enter
		Save Screen

- **Analog Outputs**

		(Model 340 front panel button) Analog Outputs
1:		Enter
Mode:	OFF	Enter
Bipolar:	OFF	Enter
		Save Screen

2:		^ Enter
Mode:	**LOOP**	^ Enter
Bipolar:	OFF	Enter
		Save Screen, Save Screen

- **Loop 1**

		(Model 340 front panel button) Loop 1 Control Channel
Loop 1 Channel:	**A**	Enter
		Loop 1 Setpoint
Setpoint:	0.000 K	Enter

- **Loop 2**

		(Model 340 front panel button) Loop 2 Control Channel
Loop 2 Channel:	**B**	^ Enter
		Loop 2 Setpoint
Setpoint:	0.000 K	Enter

- **Control Setup**

		(Model 340 front panel button) Control Setup
Loop:	**1** Control Setup	Enter
Enable:	**ON**	Enter
Power Up:	**ON**	Enter
Setup Unit:	TEMP K	Enter
Htr Ω:	**49**	49 Enter
Control Mode:	Manual PID	Enter
Filter:	OFF	Enter
		Save Screen
		<MORE>
Loop:	**1** Control Limits	Enter
Temp:	**350 K**	350 Enter
+slope:	0.0%	Enter
- slope:	0.0%	Enter
Max Htr I:	1.00 A	Enter
Max Range:	49 W	Enter
		Save Screen
		<MORE>
		Control Setup
Loop:	**2** Control Setup	^ Enter
Enable:	**ON**	^ Enter
Power Up:	**ON**	Enter
Setup Unit:	TEMP K	Enter
Control Mode:	Manual PID	Enter
Filter:	OFF	Enter
		Save Screen
		<MORE>
Loop:	**2** Control Limits	Enter
Temp:	**350 K**	350 Enter
+slope:	0.0%	Enter
- slope:	0.0%	Enter
		Save Screen, Save Screen

5. **Start up only the Model 340 software driver program** and display the virtual front panel. The channels should be assigned as follows:
   Control = A
   Sample = B

6. Set up Loop 1 Domains.
   - Close the Model 340 software front panel.
   - Select menu item: Utilities -> Domain File Name and input a file name. A suggested format is: **75014L1A.ini** to indicate **L**oop **1**, set **A**. Change the last letter for variations such as a set of domains with shorter settle times when temperature accuracy is not as important. Note that this temperature control domain file will be located in the Windows directory.
   - Select menu item: Utilities -> Domains and input the data from Table 4-16.

Table 4-16. Model 340 Software Loop 1 Domain settings for the 75014 CCRSM

Domain #	Begin T [K]	End T [K]	P	I	D	Htr Power (range)	Slew rate [K/min]	First: Wait Time [min]	Second: F/C/V	Third: Wait Time [min]
1	0	14	0	0	0	0	20	5	* < 0.05	10
2	14	21	40	0	0	5	20	3	* < 0.05	6
3	21	29	50	0	0	5	20	5	* < 0.05	10
4	29	49	60	0	0	5	20	10	* < 0.1	20
5	49	351	100	0	0	5	20	20	* < 0.1	40
6	351	1000	0	0	0	0	100	0	none	0

* Function (of Function/Condition/Value): **Sample drift** [K/min]

7. Set up Loop 2 Domains.
   - Select menu item: Loop 2 and make sure the Lock Set Point item is checked (select it if it is not checked). This causes the set points of the two temperature control loops to be the same at all times.
     √ Lock Set Point
   - Select menu item: Loop 2 -> Domain File Name and input a file name. A suggested format is: **75014L2A.ini** to indicate **L**oop **2**, set **A**. Change the last letter for variations such as a set of domains with shorter settle times when temperature accuracy is not as important. Note that this temperature control domain file will be located in the Windows directory.
   - Select menu item: Loop 2 -> Domains and input the data from Table 4-17. Note that locking the set point causes the wait times and conditions for Loop 2 to be ignored, but they should be entered anyway.

Table 4-17. Model 340 Software Loop 2 Domain settings for the 75014 CCRSM

Domain #	Begin T [K]	End T [K]	P	I	D	Htr Power (range)	Slew rate [K/min]	First: Wait Time [min]	Second: F/C/V	Third: Wait Time [min]
1	0	14	10	20	0	1	20	5	* < 0.05	10
2	14	21	5	20	0	1	20	3	* < 0.05	6
3	21	29	10	20	0	1	20	5	* < 0.05	10
4	29	49	20	18	0	1	20	10	* < 0.1	20
5	49	351	40	15	10	1	20	20	* < 0.1	40
6	351	1000	0	0	0	0	100	0	none	0

* Function (of Function/Condition/Value): **Sample drift** [K/min]

8. Close the Model 340 software front panel.
9. Select menu item: File > Save As… and enter a file name. A suggested format is: "**75014_S1.34c**" used here to mean the **75014 S**ample insert number **1**. A unique name must be used if more than one Sample Insert, each with its own calibrated sensor, will be used. If more than one sample insert will be used they can be numbered for identification.The .34c extension indicates that this is a Model 340 configuration file.
10. For each additional sample insert, do the following:
    - Step 3, Exit the Model 340 software program.
    - Step 4, Input Setup, Input B portion only.
    - Step 5, Start up Model 340 software program and check Control and Sample channels.
    - Step 8.
    - Step 9.
11. Check that the configuration files were saved. Select menu item: File -> Load. A dialog box appears with a list of Model 340 configuration files (.34c extensions). Click Cancel, or select a configuration file to load and click OK. This step is performed as part of normal sample module operation in section 4.2.3.3 Verify Temperature Controller Setup.
12. Exit the Model 340 software program.

4.2.1.8 Power Booster Installation

The Loop 2 heater output of the Model 340 can be only 1 V and 0.1 A for a maximum of 1 W into a 100 Ω heater. A Kepco Model PAT 40-0.5 programmable dc power supply is used to boost the output power to a maximum of 20 W into an 80 Ω heater. The second loop heater in the OmniPlex has a resistance of 78 Ω plus the resistance of the wiring, so the maximum Loop 2 heater power is about 20 W.

1. Connect coaxial BNC cable from Power Booster **Heater Input** on (**PB-5**) to Model 340 **ANALOG OUT 2** (**G-15**).
2. If possible, cap Model 340 **ANALOG OUT 1** (**G-14**) BNC bulkhead so it will not be used by mistake.
3. Plug the power cord from the Power Booster socket (**PB-1**) into an available socket in the power strip.
4. Plug the Heater Output Cable (PN 673-405) dual banana plug into Power Booster sockets (**PB-2, 3**) with the ground tab side in the middle of the three banana sockets (**PB-3**).
5. Plug the Heater Output Cable (PN 673-405) single banana plug into the third Power Booster banana socket (**PB-4**).
6. Pass the other end of the Heater Output Cable (PN 673-405) through a wiring port in the instrument console and connect the 2-pin circular connector end to the OmniPlex Loop 2 heater socket (**OP-8**).

Table 4-18. Power Booster Connections and Connection Designations (PB-n)

Power Booster				Cable	
PB-	**Socket**	**Term.**	**Use**	**Connection to**	**Pin**
PB-1	**Input**	**1**	Input power: Hot (black)	electrical	**H**
	power	**2**	Input power: Neutral (white)	power	**N**
	cord	**3**	Input power: Ground (green)	outlet	**G**
PB-2	**Heater**	**6**	Heater output V+ to power booster terminal (6) +e	(**OP-8**) OmniPlex	**B**
PB-3	**output**	**5**	Heater output V– to power booster terminal (6) –e	Loop 2 heater	**A**
PB-4	**cable**	**4**	Heater output cable shield to PB terminal (4) –e	(# 263316B8)	**-**
PB-5	**Htr input**	**14**	V+ from Model 340 controller to PB terminal (14) R_R	(**G-15**) Model 340 coax	**center**
	cable	**7**	V– from Model 340 controller to power booster terminal (7) +e	Analog out 2	**shield**
	none	**11**	Programming resistor,	none	**-**
		12	two 47.5 kΩ resistors in parallel		**-**

4.2.1.9 Removal, Storage and Shipping

Removal of the 75014 CCRSM from an electromagnet platform:

1. Remove Sample Insert from OmniPlex and plug sample well.
2. Remove the Gaussmeter probe from between the electromagnet poles. Store in a safe place where the Gaussmeter probe will not be damaged.
3. Back out the electromagnet poles.
4. Use a 5/16" hex key to remove the 3/8"-16 bolts holding the base plate to the top of the electromagnet stand (EM4) or to the saddle plates (EM7 or EM12).
5. The OmniPlex cryostat (with base plate still attached) is now free of the electromagnet platform and may be removed. Pull the base plate forward. Be careful not to hit the sample module tail on anything.

Storage:

1. Store vertically on a stand.
2. Short term (less than one month) storage on a horizontal surface is also possible. Long term horizontal storage might result in sagging of the copper sample well within the OmniPlex tail. Take the OmniPlex cryostat to a table and lay on its side with the Expander (heavy) down against the table. One end of the base plate will also rest on the table and the tail will stick out and up at an angle.

Shipping:

1. Set OmniPlex on a solid, clean table with the expander lying down against the table surface.

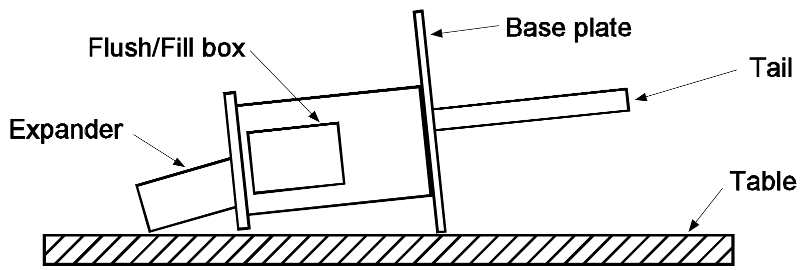


Figure 4-25. OmniPlex Orientation on a Horizontal Surface

2. **Remove Tail Vacuum Shroud**. Use a 5/32" hex wrench to remove the (6) #10-24 x 5/8" SHC screws. Put the screws in a small ziploc bag and set aside as they will be used to secure the shipping tail. Wrap/package the tail vacuum shroud with the O-ring for shipping.
3. **Remove Tail Radiation Shield**. Use a 7/64" hex wrench to remove the (6) #6-32 x 3/8" SHC screws. Put the screws in a small ziploc bag. Carefully peel back any tape holding superinsulation to the tail radiation shield so it can be reused on reassembly. Carefully remove the tail radiation shield. Wrap/package the tail radiation shield with the screws for shipping.
4. **Attach shipping tail.** Find the white PVC shipping tail which should have been kept with the packing materials for the 75014 CCRSM. The shipping tail should have foam wraps inside. These should slip over the sample well tail (with a screwing motion) and compress enough when inserted into the shipping tail to support the sample well tail during shipping. Secure the shipping tail using the (6) #10-24 x 5/8" SHC screws removed from the tail vacuum shroud.
5. **Remove base plate**. Hang the base plate end over the edge of the table. Use a 3/16" hex wrench to remove the (3) #1/4"- 28 SHC screws and washers. Remove the base plate and return the screws and washers to the holes in the bottom of the vacuum shroud**. Finger tighten ONLY** or the screws will bottom out in these blind tapped holes and the threads will be damaged.
6. **Package 75014 CCRSM for shipping**. The Flush/Fill unit ships attached to the vacuum shroud. Use the original OmniPlex shipping container or build a suitable replacement. The unit may be shipped in horizontal or vertical orientation.

4.2.2 Sample Mounting with the Model 75014 CCRSM

Mount samples by following the Model 75013 SCSM sample mounting instructions given in Section 4.2.2 with the following exceptions:

1. The sample mounting portion of the Model 75014 Sample Insert is permanently attached, not removable like the Sample Card used in the Model 75013 SCSM.
2. The sample mounts in the center of a sapphire mounting plate centered between solder posts. Glue the sapphire mounting plate to the G-10 plate with rubber cement. Normally, it should not be removed.The solder posts around the sapphire mounting plate are not numbered, but are laid out in the same pattern and orientation as the numbered triaxial bulkhead connectors on the Sample Insert junction box (see Figures 4-19 or 4-20). The figure on the cover of the junction box shows connections to two common sample geometries (van der Pauw square and 1-3-3-1 Hall bar).
3. There is no sample identification space on the Model 75014 Sample Insert sample mounting plate. If desired, attach a removable note to the Sample Insert junction box with the sample identification and other relevant information.

4.2.3 Operation of the Model 75014 CCRSM

This section provides instructions for the APD Omniplex™ Top Loading Exchange Gas Cryostat. This module is designed for more sophisticated temperature control.

4.2.3.1 Sample Insert Insertion

Use the procedure below in loading the Sample Insert to avoid contamination or condensation from air.

Sample Insert Style A (see Figure 4-19).

1. Clean Sample Insert of any dust or dirt accumulated on its surface. Verify that the Sample Insert is completely dry.
2. Ready the Sample Insert, loosen the compression fitting at top of cryostat, remove Sample Well Plug, and carefully insert the Sample Insert about half way. Tighten the compression fitting.
3. Press the valve button on the Flush/Fill unit 2 or 3 times. This will remove any air from the sample well and backfill with helium gas. Any air in the sample well will freeze if the temperature is below about 65 K.
4. When the temperature controller reads ≈150 K (–123 °C), slowly push the Sample Insert into the cryostat until slot in header mates with alignment pin.
5. Set rotation stage to zero degrees so sample is perpendicular to the applied magnetic field.

Sample Insert Style B (see Figure 4-20).

1. Clean Sample Insert of any dust or dirt accumulated on its surface. Verify that the Sample Insert is completely dry.
2. Ready the Sample Insert, remove Sample Well Plug, and carefully insert the Sample Insert.
3. Twist Sample Insert junction box in the rotation stage to fully engage the bayonett lock.
4. Press valve button on Flush/Fill unit 2 or 3 times. This removes any air from the sample well and backfills with helium gas. Any air in the sample well freezes if the temperature is below about 65 K.
5. Set rotation stage to zero degrees so sample is perpendicular to the applied magnetic field.

4.2.3.2 Sample Insert Cable Connections

The 4 or 6 triaxial sample cables should already have a protective sleeve plus a short section of spiral cable wrap and a tie down clamp near the sample end. Bolt the tie down clamp into the right rear bolt hole on top of the saddles. This strain relieves the cables, but positions them close to the sample well where they will be attached to the Sample Insert.

4.2.3.3 Verify Temperature Controller Setup

The temperature controller must be set up for the Sample Module in use. If no temperature controller configuration file exists, create one (see Section 4.2.1.7). Note that there is no indication of the current configuration (unlike the Field Control driver program).

1. Start the Model 340 software driver program on the computer and load the appropriate configuration file. To do this, select the menu item: File -> Load. A dialog box will appear with a list of configuration files (.34c extensions). Select one and click on OK. The Model 340 will be configured, but there is no indication of the current configuration.
2. Open the Front Panel and check that the input channels are reading properly and assigned as follows:
   Control = A
   Sample = B

4.2.3.4 Vacuum Pump Out Procedure

The customer must supply a vacuum pump to evacuate the sample module to a pressure of 100 Pa (0.1 torr) or lower prior to initial operation. Vacuum pressure gauging must be provided or added to the OmniPlex. The OmniPlex can be removed and taken to a vacuum pumping station for pumpout.

Pumpout of the vacuum jacket may be required only every few months if the OmniPlex is kept cold and the lowest possible temperatures are not required. Pumpout of the vacuum space can be performed during operation of the closed cycle refrigerator (CCR) if a turbo, turbomolecular, cryo, diffusion or other very low ultimate pressure (10^{-5} Pa or 10^{-7} torr) dry vacuum pump is used. Pumping during operation might be necessary for long term (several days) operation to the lowest possible temperatures or for repeated ramping from low to high temperature limits.

Initial Pumpout Procedure (starting from atmospheric pressure):

1. The OmniPlex should be at room temperature for initial vacuum pumpout.
2. Connect vacuum line to Vacuum Valve on OmniPlex Vacuum Pumpout Port (**OP 2**), but **do not open the vacuum valve** yet. The vacuum valve is one of the following two styles:
   a. **Seal-off plug valve**, Cryolab Model SV9-084-5W1 on a KF-25 flange. Remove the retainer ring from inside the vacuum valve body. Push the Cryolab valve operator onto the seal-off valve body and tighten in place with a 1-3/16" (30.2 mm) wrench kept in the OmniPlex tool box. The vacuum hose provided is 13 mm (1/2 inch) ID with KF-16 flange connections. Connect the vacuum hose between the valve operator and the vacuum pump.
   b. **Diaphragm valve** with large black knob and KF-25 flanges. The vacuum hose provided is 25 mm (1 inch) ID with KF-25 flange connections. Connect the vacuum hose between the valve operator and the vacuum pump.
3. Open the vacuum valve:
   a. **Cryolab plug valve**. Push the Cryolab valve handle in and turn clockwise to screw into the plug. Pull out on the handle to remove the valve plug.
   b. **Diaphragm valve**. Turn the large black knob counter clockwise all the way to fully open the valve.
4. Start the vacuum pump and pump out the OmniPlex vacuum space to a pressure less than 1.3 Pa (or 10 millitorr or 10 microns). If using a mechanical vacuum pump which can backstream oil, pump the minimum time necessary to achieve this pressure. Dry pumps can be run longer and the vacuum will be cleaner if the system is pumped for a day or overnight.
5. Close the vacuum valve:
   a. **Cryolab plug valve**. Push in Cryolab valve operator handle to insert valve plug. Rotate handle counter clockwise to unscrew handle from plug. Pull handle back out. Turn off vacuum pump and vent vacuum hose. If desired, remove valve operator from valve and replace retainer ring and dust cap.
   b. **Diaphragm valve**. Turn the large black knob clockwise all the way to fully close the valve. Turn off the vacuum pump and vent the vacuum hose. If desired, remove the vacuum hose.
6. Monitor the pressure on the vacuum gauge. The pressure should rise slowly and level off at a pressure less than about 13 Pa (or 0.1 torr or 100 microns). If the pressure rises rapidly above this pressure level, a leak or contamination may exist. Test the system for leaks to isolate the cause of the problem, and repair it. If everything appears normal, proceed to the next step.

NOTE: Dry vacuum pumping can continue until no longer desired, but if using a mechanical pump stop pumping before starting the CCR compressor.

Vacuum Cleanup Procedure (starting with vacuum):

1. The OmniPlex can be at any temperature for vacuum cleanup, but a dry vacuum pump with low base pressure is required if the OmniPlex CCR is operating.
2. Connect the vacuum hose between the vacuum pump and the vacuum valve on the OmniPlex (OP 2).

3. Start vacuum pump and pump out vacuum line to a pressure less than 1.3 Pa (or 10 millitorr or 10 microns).
4. Open the vacuum valve:
   a. **Cryolab plug valve**. Push the Cryolab valve handle in and turn clockwise to screw into the plug. Pull out on the handle to remove the valve plug.
   b. **Diaphragm valve**. Turn the large black knob counter clockwise all the way to fully open the valve.
5. Pump out the OmniPlex vacuum space to a pressure less than 1.3 Pa (or 10 millitorr or 10 microns). If using a mechanical vacuum pump which can backstream oil, pump the minimum time necessary to achieve this pressure. Dry pumps can be run longer and the vacuum will be cleaner if the system is pumped for a day or overnight.
6. Close the vacuum valve:
   a. **Cryolab plug valve**. Push in the Cryolab valve operator handle to insert the valve plug. Rotate the handle counter clockwise to unscrew the handle from the plug. Pull the handle back out. Turn off the vacuum pump and vent the vacuum hose. If desired, remove the valve operator from the valve and replace the retainer ring and dust cap.
   b. **Diaphragm valve**. Turn the large black knob clockwise all the way to fully close the valve. Turn off the vacuum pump and vent the vacuum hose. If desired, remove the vacuum hose.
7. Monitor the pressure on the vacuum gauge. The pressure should rise slowly and level off at a pressure less than about 13 Pa (or 0.1 torr or 100 microns). If the pressure rises rapidly above this pressure level, a leak or contamination may exist. Test the system for leaks to isolate the cause of the problem, and repair it. If everything appears normal, proceed to the next step.

NOTE: Dry vacuum pumping can continue until no longer desired, but if using a mechanical pump stop pumping before starting the CCR compressor.

4.2.3.5 Cool Down

1. Optional: Start the Chart Recorder function on the computer:
   - Maximize the Model 340 software program.
   - Select the menu item: Timing-> Log Time. Set the log time to 5 seconds.
   - Select the menu item: Utilities -> Chart Recorder. Select the following items to plot:
     - Sample temperature
     - Control temperature
   - In the plot window, select the menu item: File -> Log…, name the log file and click OK.
2. Start the APD compressor.
3. Verify that the water flow rate is at least 3.0 liters/minute (0.8 gpm).
4. During cooldown, check for condensation on the outside of the OmniPlex tail. Condensation indicates that the vacuum is not good enough and the vacuum pumpout must be repeated.
5. The cooldown to 15 K should take about 1 to 2 hours.
6. Close the Chart Recorder log file when the cooldown is complete.

4.2.3.6 Temperature Control Parameters

Choosing temperature control parameters always requires a compromise between the desires for rapid temperature changes and good stability and accuracy with little temperature overshoot or oscillation.

The temperature control domain parameters suggested in the section on setting up the Model 340 were chosen for slow, controlled temperature changes with little overshoot or oscillation. If faster temperature changes are desired, first try setting the second wait times in the Domains to zero. Additional optimization can be performed by following the procedures described in the Model 340 User's Manual.

4.2.3.7 Sample Insert Removal

Use the procedure below to remove a cold Sample Insert from the Model 75014 CCRSM.

Sample Insert Style A (see Figure 4-19).

1. Unplug the triaxial BNC cables from the Sample Insert junction box. Leave 10-pin circular connector in place to monitor temperature.
2. Loosen sample well compression fitting at top of cryostat.

3. Move Sample Insert up slowly about 1 foot, stop, and tighten compression fitting.
4. Watch Sample Temperature on Model 330 Temperature Controller. When temperature reaches ≈100 K (–173 °C), pull Sample Insert up some more. Watch for frost on newly exposed portion of Sample Insert to disappear. **CAUTION:** Do not force Sample Insert through a frozen seal.
5. Continue to slowly pull Sample Insert upwards in 6 inch increments. As Sample Insert moves upwards, cold sections of tube may freeze seals. If a tightness or stiffness is felt when withdrawing probe, simply pause a minute or so to allow probe to warm before continuing to withdraw. Several minutes may be required for this process.
6. When temperature reaches ≈273 K (0 °C), disconnect connector at top of Sample Insert.
7. Ready Sample Well Plug, loosen compression fitting, remove Sample Insert, and place Sample Well Plug in.
8. Press the Flush Fill valve button 2 or 3 times to remove the gas (possibly contaminated with air) from the Sample Well, and refill the sample well with helium. Any air in this space may freeze.

Sample Insert Style B (see Figure 4-20).

1. Unplug the triaxial BNC cables from the Sample Insert junction box. If desired, leave 10-pin circular connector in place to monitor temperature.
2. Twist Sample Insert junction box in the rotation stage to release the bayonett lock.
3. Remove the Sample Insert quickly from the OmniPlex sample well.
4. Insert the sample well plug and make sure it seals tightly.
5. Press the Flush Fill valve button 2 or 3 times to remove the gas (possibly contaminated with air) from the sample well.
6. Wait until the Sample Insert is dry before removing or mounting samples. Blow dry with a hot air gun, if desired, but do not overheat.

4.2.4 Service and Maintenance for the Model 75014 CCRSM

4.2.4.1 Leakage Resistance and Shielding

Measurement of very high resistance samples (>10 MΩ) requires very high resistance between all combinations of signal, guard and ground. The following procedure is possible only with measurement instrumentation that drives the guards around the signal lines (-HVWR or -LVWR).

1. Measure the resistance of the Sample Insert without any sample mounted. If necessary, first clean the sample mounting area with isopropyl alcohol and demineralized water, then blow dry with warm air from a heat gun. Install the Sample Insert in the OmniPlex sample well. Measure the resistance (R14,23) in high resistance mode using the Resistance software program.
2. The resistance should be significantly greater than the specified maximum accurately measurable resistance of the measurement system. Note that a leakage resistance of 100 times the maximum sample resistance would lead to a 1% measurement error.
3. If the resistance is low, check the resistance between signal and guard and between guard and ground. A convenient place to do this is at the connectors on the junction box. Likely places to look for shorts are a) the connections between the coaxial cable and the bulkhead connectors, b) the connections to the solder posts, and c) the region between the solder posts. Look for stray wires or improperly cleaned connections.

4.2.4.2 Guide Disk Repair

If the guide disk on the bottom end of Sample Insert falls off, re-epoxy or screw it back on.

4.2.4.3 Sapphire sample plate replacement

Clean sapphire plate and G-10 sample mounting plate region between the solder posts. If the original sapphire plate is cracked or damaged, order a replacement (Lake Shore part number 672-210) or make a similar sample mounting plate from sapphire. Apply a small amount of rubber cement to the rougher side, center between the solder posts, and press down so the rubber cement fills the gap between the sapphire plate and the G-10. Allow to dry, then remove any excess rubber cement.

4.2.4.4 Incorrect Temperature Readings

Check the temperature controller setup for proper sensor type and calibration curve.

Check electrical connections and cables.

Check that the GaAlAs diode temperature sensor on the Sample Insert is epoxied to the back of the sample mounting plate. If the diode temperature sensor has detatched, epoxy it back in place using a very small amount of epoxy - the epoxy should not form a fillet on the sides.

If necessary, replace the temperature sensor. Contact Lake Shore to order a replacement and for replacement instructions.

4.2.4.5 Insufficient Heating

Check the heater resistances at the connectors on the OmniPlex and verify that they are correct. A burned out Loop 1 heater (on the cold end of the expander) can be replaced in the field, but will require removal of the tail and vacuum shroud. Contact Lake Shore service for instructions and replacement parts. A burned out Loop 2 heater (sample well) can be replaced in the field more easily. Refer to instructions for Loop 2 Heater Replacement.

Check cables back to the temperature controller and power booster.

Verify output from the temperature controller and power booster.

4.2.4.6 Loop 2 Heater Replacement

Order a replacement heater (Lake Shore part number 673-245 or Minco Products part number H7A10W28).

Remove the tail vacuum shroud and tail radiation shield from the OmniPlex. Be careful to remove tape holding the reflective mylar to the radiation shield flange before removing the radiation shield. Follow directions in sections on initial assembly or packing for shipment.

Unsolder old heater leads. Unscrew nut and remove old heater.

If the indium foil gasket must be replaced, make a new one from a piece of indium foil (0.005 inches thick) included with the sample mounting accessories.

Place the new heater over the screw stud and onto the indium foil gasket. Add lock washer and nut, then tighten. Wait one hour for indium to creep, then retighten.

Solder leads and insulate with Teflon or Kynar heat shrink tubing.

Make sure all leads are secured and will not contact the radiation shield.

Replace tail radiation shield and the tape holding the reflective mylar in place.

Replace the tail vaccum shroud.

Follow vacuum pumpout procedure.

4.2.4.7 Problems with OmniPlex, Compressor, Hoses, or Expander

Refer to the APD manual for the OmniPlex.

4.3 MODEL 75016 OSM - OVEN SAMPLE MODULE

The Model 75016 Oven Sample Module (75016 OSM) 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 two heater circuits powered by a temperature controller. An assembly overview is shown in Figure 4-27. The 75016 OSM consists of the following components:

- Oven Body (see Figure 4-28 and Table 4-19):
  - Rotation Stage.
  - Flush/Fill Unit.
  - Mounting Base Plate.
- Sample Insert (see Figure 4-29).
- Power Booster for a Model 340 Loop 2 Heater Output.

Also required for operation of the Model 75014 CCRSM, but not provided:

- Model 750TC Temperature Controller option.
- Vacuum pump.

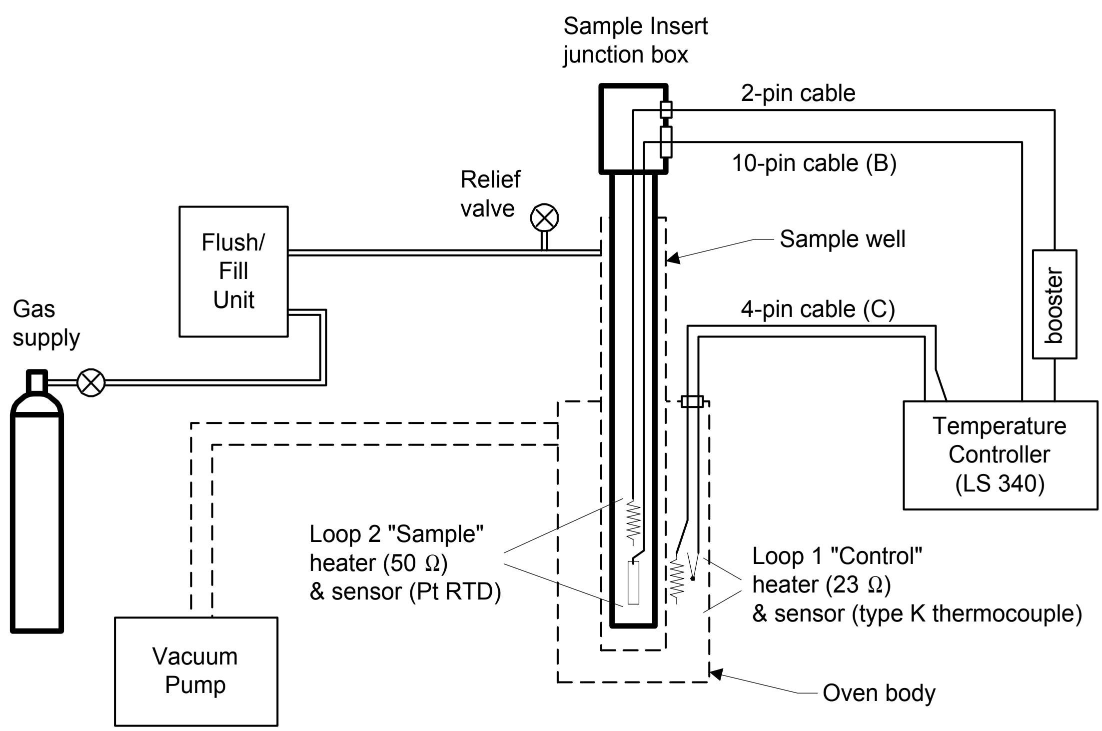


Figure 4-26. Model 75016 OSM Operational Schematic.
The electromagnet and measurement systems are not shown.

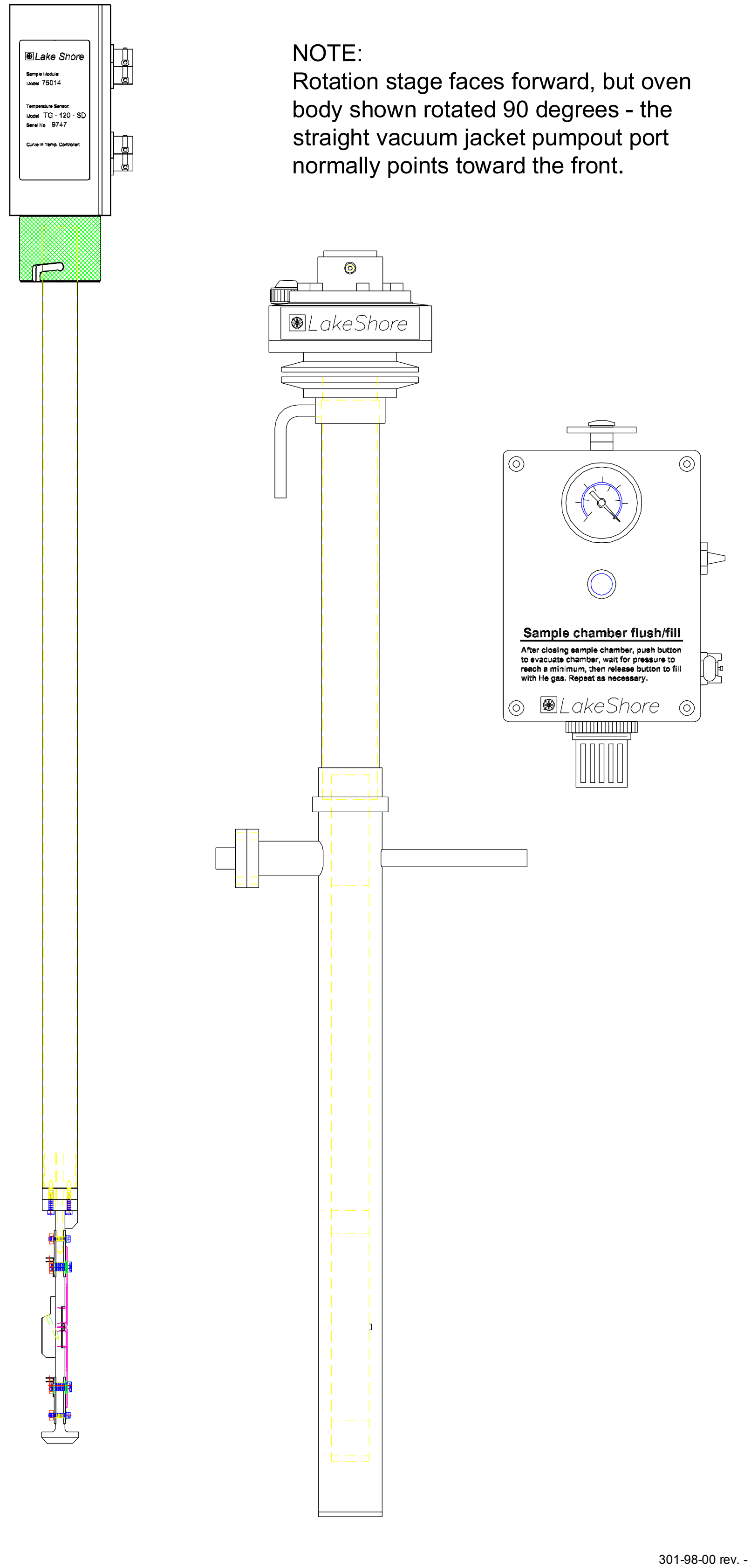


Figure 4-27. Model 75016 OSM Assembly Overview. View from front of electromagnet.

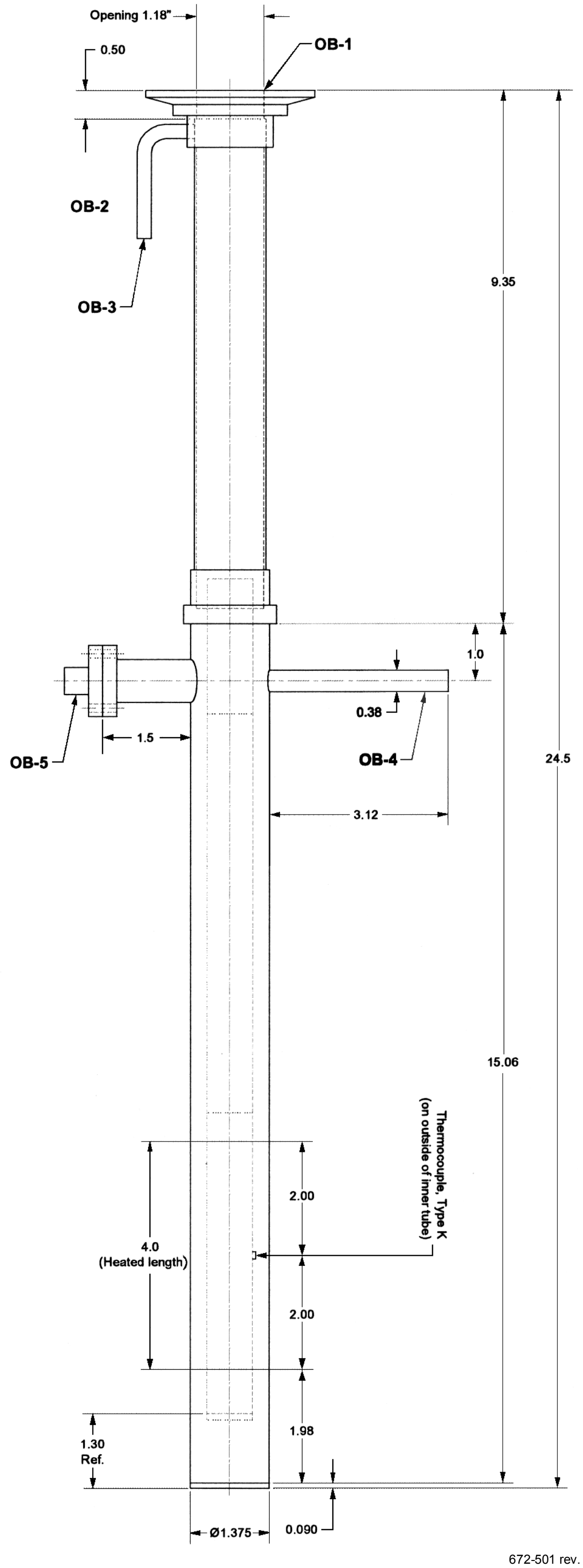


Figure 4-28. Oven body for the Model 75016 OSM

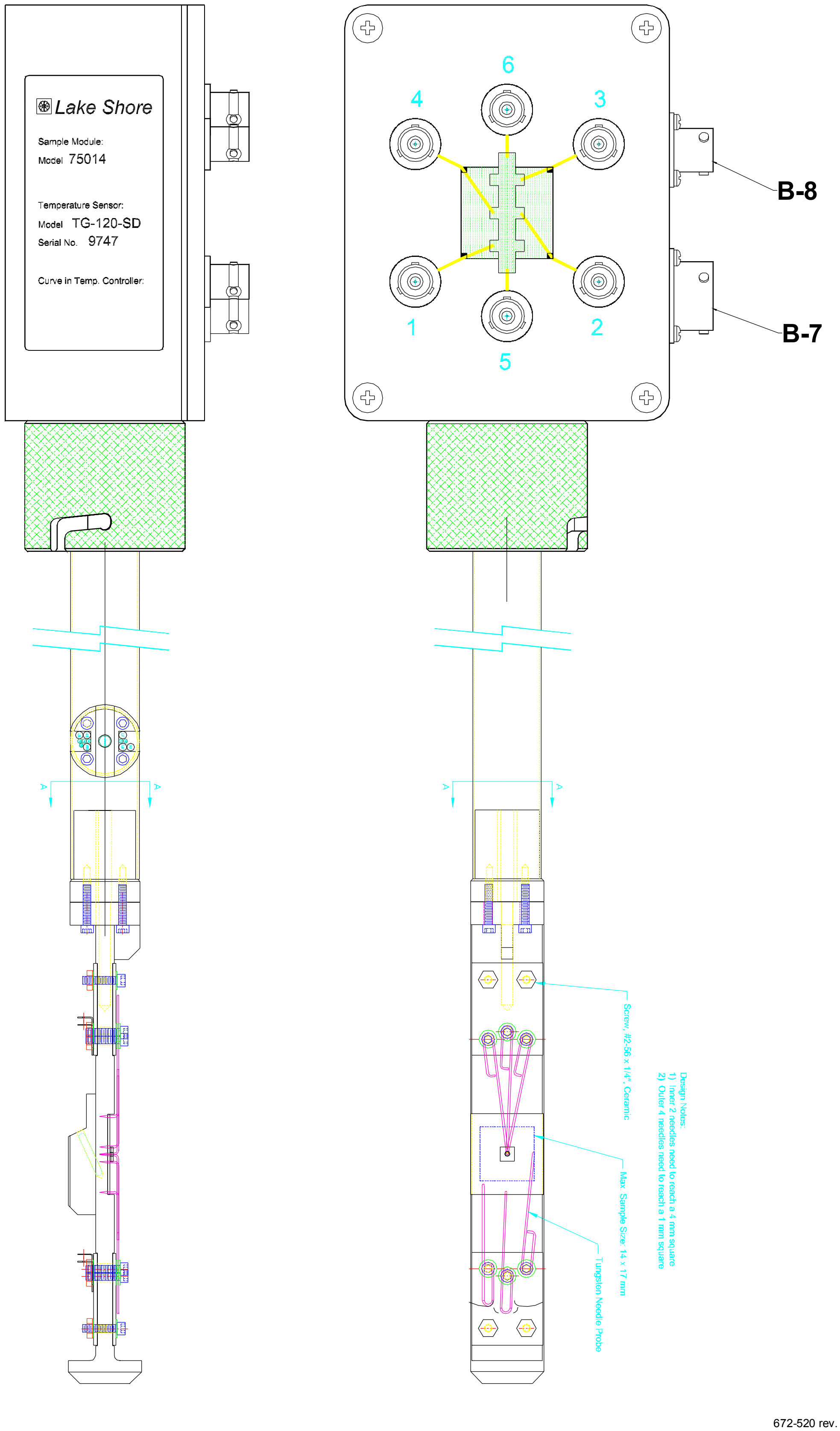


Figure 4-29. Model 75016 OSM Sample Insert

Table 4-19. 75016 OSM Oven Body Connection Point and Interface Designations.
The locations of the connections listed below are shown in Figure 4-28.

OB-	Oven Body
1	Sample well access port, NW-50 flange, 19.1 mm (0.75 inch) clear bore
2	Sample well relief valve, 28 kPa (4 psig) cracking pressure
3	Sample well exchange gas inlet, Swagelok for 6.35 mm (1/4 inch) OD tube
4	Vacuum pumpout port, 9.52 mm (3/8 inch) OD tube
5	Loop 1 temperature sensor and heater (23 Ω), 4-pin circular connector (RED), see Table 4-21

Table 4-20. Sample Connection Wiring for the 75016 OSM Sample Insert.
The wire resistance is measured from the connector on the junction box to the needle probe.

Connector	Pin	Use	Wire R [Ω]
B-1	**1**	Sample connection # 1	2.5
B-2	**2**	Sample connection # 2	2.5
B-3	**3**	Sample connection # 3	2.5
B-4	**4**	Sample connection # 4	2.5
B-5	**5**	Sample connection # 5, I+ for Hall bars	2.5
B-6	**6**	Sample connection # 6, I– for Hall bars	2.5
B-7	**A**	V– Sample temperature sensor output voltage (Channel **B**)	8
	B	V+ Sample temperature sensor output voltage (Channel **B**)	8
	C	I– Sample temperature sensor excitation current (Channel **B**)	8
	J	I+ Sample temperature sensor excitation current (Channel **B**)	8
	D	I+ Heater (Loop 2), 50 Ω	8
	E	I– Heater (Loop 2)	8
	G	unused	
	H		
	F		
	K		
B-8		unused	

Table 4-21. Wiring of 75016 OSM Loop 1 Cable (LSCI PN 653-216).
Connects oven body 4-pin connector for Loop 1 heater and temperature sensor (OB-5) to the Model 340.

Connection	Pin	Use	Connection	Pin
OB-5	**A**	I+ Heater (Loop 1), 23 Ω	(**G-5**) on Model 340	**Hi**
	B	I– Heater (Loop 1)	(**G-6**) on Model 340	**Lo**
	C	+ Type K thermocouple, Yellow (Channel **C**)	(**G-8**) on Model 340, C+ terminal	**+**
	D	– Type K thermocouple, Red (Channel **C**)	(**G-8**) on Model 340, C– terminal	**–**

4.3.1 Setting Up the Model 75016 OSM

Setup must be performed in the following cases:

1. Initial setup following shipping or long term storage.
2. Quick setup following sample module exchange in the electromagnet.

The 75016 OSM can be removed from an electromagnet and stored on a stand without detatching many of the connections, so Case 2 is simpler and often does not require all the steps in the initial setup. Table 4-22 lists the steps required for setup. The table gives an overview and also can be used as a checklist.

Table 4-22. Model 75016 OSM Setup Steps.
Reference refers to the relevant section in this manual.
An asterisk (*) indicates the procedure is not always required.

Initial	Quick	Description	Reference	
1		Unpacking and Assembly	4.3.1.1	
2	1	Oven Installation in the Electromagnet	4.3.1.2	
3	2	Sample Well Helium Purge Gas Connection	4.3.1.3	
4	3	Gaussmeter Probe Installation and Orientation	4.3.1.4	
5	4	Check oven connections	Table 4-21	
6	5*	Rotation Stage Alignment	4.3.1.5	
7	6*	Temperature Controller Setup	4.3.1.6	
8		Power Booster Installation	4.3.1.7	

4.3.1.1 Unpacking and Assembly

1. **Unpack sample module**. Ships in a long cardboard box. Set oven assembly on a clean table. Save packaging in case future shipping is required.
2. Assemble mounting collar on the oven neck. When the oven is held vertically, the vacuum pumpout tube and rotation stage name plate should face forward. The two bolts holding the two halves of the mounting collar should face toward the rear.

4.3.1.2 Oven Installation in the Electromagnet

The Model 75016 OSM mounts on top of an electromagnet. Below are directions for mounting to different magnet systems.

1. **Install the base plate**. The U-shaped cutout in the base plate must be large enough for the oven neck.
   • **EM4 base plate only** (672-106)**:** The base plate attaches to the top of the electromagnet stand with two side plates in between.
   • **EM7 base plate only** (672-141)**:** The base plate attaches directly to the top of the electromagnet stand.
2. Install the six 3/8"-16 × 1.5" socket head cap screws (654-123) with 3/8" nylon washers (654-148) through the top of the Base Plate.
3. Back out magnet poles to allow plenty of clearance for the oven tail. Make sure the path is clear between the location of the 75016 OSM and the magnet stand.
4. Carry the 75016 OSM to the magnet and set in a vertical position so the mounting collar rests on top of the base plate. Be careful not to hit the oven tail on anything.
5. Use a 3/16" hex wrench to attach the mounting collar to the base plate using (2) #1/4"- 20 × 3/4" SHC screws (674-202).
6. Loosen the mounting collar and raise or lower the oven body so the center of the sample mounting space is at the center of the magnet poles. As seen in , the center of the sample mounting space is 51 mm (2 inches) up from the bottom of the oven body.
7. Tighten the mounting collar, making sure the collar is square with the rotation stage.

4.3.1.3 Sample Well Helium Purge Gas Connection

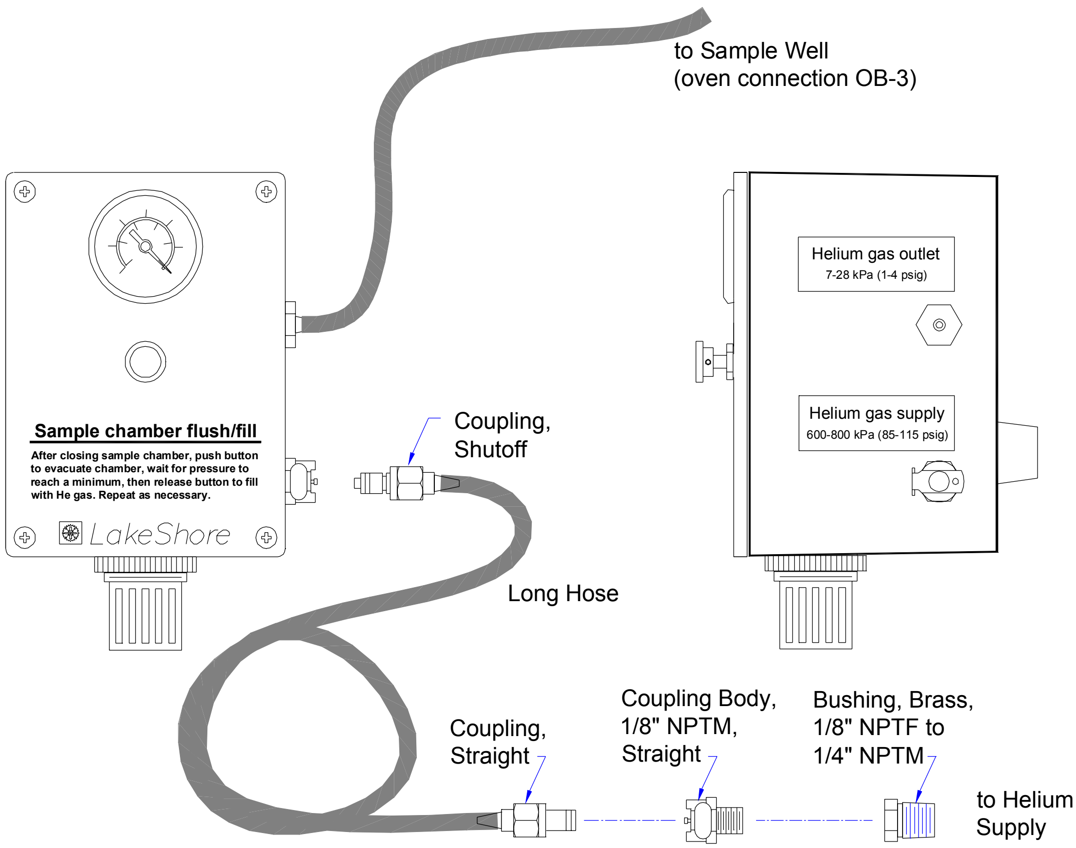


Figure 4-30. Sample Chamber Flush/Fill Unit

The helium exchange gas sample environment requires a source of He gas (standard grade) with delivery pressure of 600-800 kPa (85-115 psig). The customer supplies the helium gas source. A urethane hose 3 m (10 ft.) long and 1/8" ID connects to the Flush/Fill unit. The other end fits a 1/8" barb fitting. Use a 1/8" barb fitting with 1/8" and 1/4" NPTM fittings or a quick disconnect to connect to the helium gas source.

1. Mount the Flush/Fill unit in a convenient location.
2. Attach one end of the 60 cm (24") piece of urethane tubing by pushing onto the Helium Gas Outlet hose barb on the side of the Flush/Fill unit.
3. Install the other end of the urethane hose in the 1/4" ID Swagelok fitting on the sample well manifold.
4. Remove the 0.75 psig relief valve on the sample well manifold and replace with a Relief Valve, 4 psig, 1/4" NPTM (602-611). Use Teflon tape to seal the threads. The 0.75 psig relief valve can be used in house, but is not needed on the 75014 CCRSM.
5. Insert the connector end of the long urethane supply hose into the supply inlet port in the side of the Flush/Fill unit.
6. Chain a high pressure helium gas cylinder within reach of the supply hose. The pressure regulator must be capable of supplying helium gas at a regulated gauge pressure of 600-800 kPa (85-115 psi).
7. Connect the free end of the Flush/Fill supply hose to the pressure regulator on the helium cylinder. A 1/8" NPTM hose barb (672-274) is supplied along with a 1/8"NPTF to 1/4"NPTM adapter bushing (209-045), but we more commonly use quick connect fittings in house.
8. Verify that the sample well plug is in place.
9. Set the helium cylinder regulator pressure in the proper 600-800 kPa (85-115 psi) range and open any valves to supply helium to the Flush/Fill unit.

10. Listen for any leaks or hoses popping off. Check for slow leaks by closing the main helium supply tank valve and watching the regulator supply pressure gauge. The pressure should not drop more than 1000 kPa (145 psi) within 10 minutes and is more typically one tenth this leak down rate. Correct any leakage problems and open the main supply valve.
11. Get a balloon and stretch over the Relief Valve on the sample well manifold.
12. Push the valve button on the front of the Flush/Fill unit and check that the pressure drops to about –25 mm Hg (–80 kPa).
13. Release the valve button. The sample well should fill with helium gas until the pressure gauge is pegged. If the balloon fills with gas, the sample well pressure regulator sticking out from the bottom of the Flush/Fill box is set too high. Otherwise, use this regulator to increase the sample well pressure until the balloon just begins to fill, then back off about 1/4 turn.
14. Briefly press the valve button and try to achieve a sample well pressure of –5 mm Hg (–15 kPa). If this pressure can be achieved and the sample well does not refill and pressurize with helium gas, then the sample well regulator is not set high enough. Adjust the regulator setting until a stable pressure of –5 mm Hg is not possible after releasing the valve button, but the balloon does not fill.
15. The Flush/Fill unit is now ready for loading of the Sample Insert.

4.3.1.4 Gaussmeter Probe Installation and Orientation

Operation of the Model 75014 CCRSM requires a Gaussmeter Probe (Figure 4-5) and Gaussmeter Probe Holder (Figure 4-6).

CAUTION: Exercise care when handling the Gaussmeter Probe. The tip is very fragile. Any excess force can alter the calibration or cause the sensor to break. Broken sensors are not repairable.

WARNING: If electromagnet has been moved and not yet powered to full current, the magnet coils may shift the first time the electromagnet is energized, allowing the Gaussmeter probe holder to fall out and possibly damaging the Gaussmeter probe. After moving the electromagnet, *manually* run the electromagnet to full current before installing the Gausmeter probe holder.

1. The gap between the tail of the oven and the right hand electromagnet pole face should be 3-6 mm (1/8 to 1/4 inch). The gap on the left side can be smaller. Lock the electromagnet poles in place. **NOTE**: The Gaussmeter probe tip is to be located between oven tail and the right hand electromagnet pole face.
2. Insert Gaussmeter probe holder between the coils of the electromagnet (see Figure 4-6). Note that the Probe Mounting Hole can be above or below the threaded rod, as desired. Turn the two knurled endpieces to wedge the assembly in place. Do not overtighten or the threaded rod will bend and buckle.
3. Rotate the mounting block on the threaded rod until it is aligned near the right hand pole face (when viewed from the front of the electromagnet).
4. Tighten the front screw to lock the mounting block against the threaded rod. Do not overtighten. **CAUTION:** Exercise care when handling the Gaussmeter probe because the sensor mounted in the tip is fragile. Stressing the probe tip may alter the sensor calibration. Any excess force can easily break the sensor. Broken sensors are not repairable.
5. Insert Gaussmeter probe through Probe Mounting with the Snowflake pattern facing to the *left*. The Top Screw must clamp onto the large diameter portion of the probe handle.
6. Locate Gaussmeter probe 2-3 mm away from the right side of the oven tail and with the tip parallel to the electromagnet pole face. The oven surface becomes hot to the touch, so direct contact with the Gaussmeter probe is not recommended. The magnetic fields very close to the pole face can be nonuniform, so placement of the tip directly against the electromagnet pole face is not recommended. The location of the mounting block along the threaded rod might require adjustment.
7. Move probe holder assembly forward or backward to position the sensitive portion of probe tip over the center of the electromagnet pole face. The knurled endpieces might need loosened to allow movement, then re-tightened. Verify the probe is straight and properly oriented with snowflake pattern facing to the left so the wide side of the probe tip is parallel to the electromagnet pole face. Adjust as necessary.

CAUTION: A Gaussmeter Probe reversed in orientation reverses the sign of readings (i.e. a positive magnetic field reads as a negative field). Correct sign of readings is critical to magnetic field control! If unsure of correct orientation, use procedure below:

1. With the magnet power supply OFF, place the Gaussmeter probe in the electromagnet noting the orientation of the Lake Shore Snowflake symbol.
2. Turn the power supply ON in MANUAL mode. Manually set a positive current of a few amperes corresponding to approximately +0.05 tesla (+500 gauss).
3. Read the front panel display of the Model 450 and ensure the field reading is positive. If the field reading is negative, reverse the orientation of the Gaussmeter probe.
4. When done, reduce current to zero and turn OFF power supply.

4.3.1.5 Rotation Stage Alignment

The rotation stage ships mounted on the oven sample well access port (OB-1). Alignment is normally not required unless the rotation stage is removed or rotated for some reason.

Accurate Hall effect measurements require that the sample be perpendicular to the magnetic flux density (field). The rough alignment procedure involves physical alignment of the rotation stage relative to the pole faces, a difficult task to perform accurately and which does not take into account any misalignment contributed by the interface to the Sample Insert or by the Sample Insert itself. The fine alignment procedure involves electrical measurements and is both more accurate and more time consuming.

Below are instructions to install and align the rotation stage. Read the entire procedure before proceeding.

Installation of the rotation stage

1. Start with the plug in the quick connect on top of the rotation stage (i.e. no Sample Insert loaded).
2. Fully loosen the KF-50 quick flange clamp below the rotation stage and open it wide enough to allow rotation of the stage, but do not remove the clamp.

Rough orientation of the rotation stage

The Lake Shore nameplate on the rotation stage should face toward the front of the magnet. The rotation stage should orient the sample perpendicular to the magnetic field and facing the right magnet pole for accurate Hall effect measurements.

1. Orient the rotation stage assembly so the Lake Shore nameplate faces forwards.
2. Check orientation relative to the pole faces - the sides of the rotation stage should be parallel to the pole faces - and tighten the clamp. Exact alignment is not easy as the path between the rotation stage and the poles is not clear.

Fine alignment of the rotation stage

1. Mount a sample with a large Hall coefficient on the Sample Insert. The medium resistivity boron doped silicon sample supplied with the system is a good choice if it can be tested near room temperature.
2. Insert Sample Insert into sample well. Face junction box to the right (usual orientation) and lock in place.
3. Connect triaxial input cables to the junction box on the Sample Insert.
4. Start the Hall System Software program.
5. Activate the Resistance software program, select the menu: Sample Definition, and set up the appropriate sample type for a measurement with the following parameters:
   - Hall Resistance
   - Current reversal OFF (not selected)
   - Two geometries OFF (not selected)
   - Settle time = 120 seconds (adjust as needed)
   - Excitation current of +100 uA is suggested for the medium resistivity (~10.5 Ω·cm) silicon sample near room temperature
6. Activate the Field Control program. Select the menu: Edit -> Properties and note the maximum magnetic field achievable. Select the menu: Run -> Go To Field and input a field near the maximum to get the largest signal.
7. Verify that the rotation stage is set at 0 degrees rotation.
8. Take a measurement (click on the green TAM button). Repeat as necessary to display the Hall voltage.

9. Rotate the stage about zero to find the orientation where the absolute value of the Hall voltage is maximized. This is the offset angle, Ao. The Hall voltage is displayed on the front panel of the voltmeter. If the voltmeter front panel can not be seen easily, activate the Voltmeter software program, display the front panel, and rotate the monitor for easy viewing. If the signal is too small to locate the maximal orientation accurately the following corrective actions are suggested:
   a) increase the excitation current,
   b) increase the magnetic flux density, or
   c) use a different sample with smaller sheet charge density.
10. If the offset angle, Ao, is significant - more than a few degrees - rotate the sample stage by the following process:
    a. Set the rotation stage to zero degrees. If desired, use an Allen key to tighten the knob and prevent rotation.
    b. Loosen the KF-50 clamp and rotate the stage and sample insert to maximize the Hall voltage reading (absolute value).
    c. Tighten the KF-50 clamp, being careful not to let the stage rotate during clamping.
    d. Go back to the previous step (15).
11. Record the offset angle, Ao, and note on the Sample Insert. Hall effect measurements using this Sample Insert should be made with the rotation stage set to the offset angle Ao, rather than set to zero. Note that if more than one sample insert is used with this sample module, Ao can change with the sample insert, so each one should be tested.
12. Return the magnetic flux density to zero using the Field Control program menu: Run -> Go To Field.
13. Exit the Hall program when finished.

4.3.1.6 Temperature Controller Setup

The Model 750TC Option adds a Model 340 and is required for operation of the 75016 OSM. This procedure configures the Model 340 inputs for one thermocouple (type K) inside the oven jacket, one platinum resistor (PT-103) at the sample location on the Sample Insert, and two loop temperature control.

A schematic of the control system is shown in Figure 4-26. Temperature sensor and heater physical locations are shown in Figures 4-28 and 4-29.

The first control loop consists of a temperature sensor and heater attached inside of the oven body, on the outside of the sample well tube.

The sample is located near the bottom of the sample well and is separated from the sample well walls by helium exchange gas. A temperature sensor mounted directly to the sample insert provides a much more accurate measure of the actual sample temperature. The standard platinum resistor curve can be significantly in error far from the freezing point of water. To reduce the error, the platinum sensor can be individually calibrated as a function of temperature and the calibration curve loaded into the temperature controller and selected for use.

The heater for the second control loop is located in the Sample Insert sample mounting platform. The temperature sensor on the sample insert is used to control the second loop heater. Refer to the Model 340 manual for further information on dual control loop theory and operation.

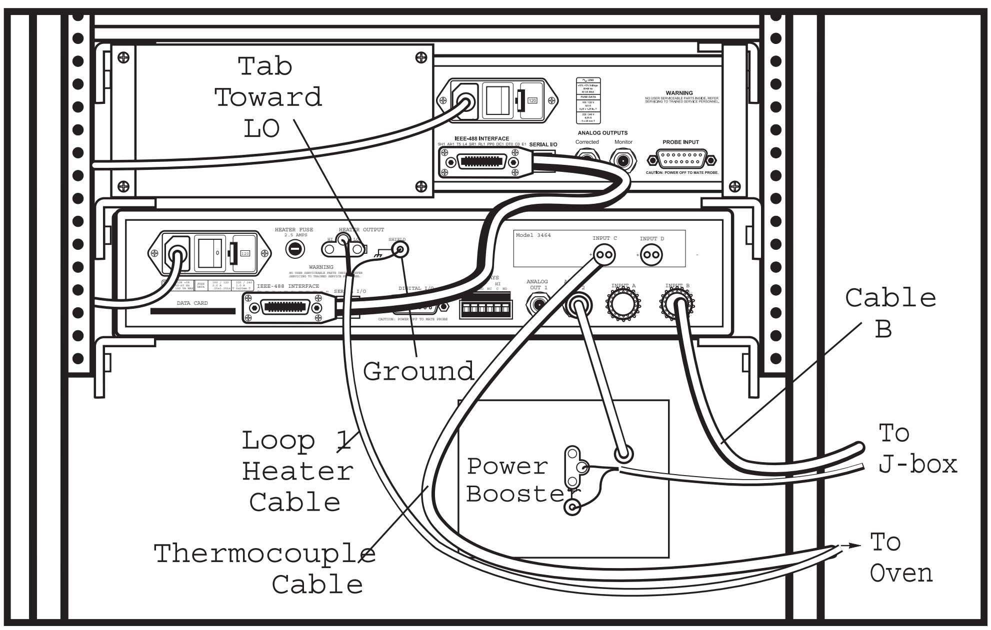


Figure 4-31. Typical Model 340 Connections to the Model 75016 OSM

Table 4-23. Connection List for Model 340 to Model 75016 OSM

#	CONNECTION	FROM	TO
1	Auxiliary input cable, 655-451 (see Table 4-24)	( ) cable 6-pin circular connector **A** NOT CONNECTED (**G-17**) cable 6-pin circular connector **B** to Model 340 Channel **B** (**PB-2**) Cable dual banana connector to Power Booster Output (**PB-3**) Cable single banana connector to Power Booster Shield	(**B-7**) Junction box of Sample Insert, 10-pin circular connector socket (marked BLUE)
2	Loop 1 Control Cable, 653-216	(**G-8**) Yellow wire to Channel **C+** and Red wire to Channel **C-** (**G-5, 6**) Cable dual banana connector to Model 340 Heater Output, gnd tab to LO (**G-7**) Cable single banana connector to Model 340 Heater Output SHIELD	(**OB-5**) 4-pin pin circular connector socket pointing to the rear of the oven (marked RED)
3	Power Booster Coaxial/BNC Heater Input Cable	(**PB-4**) Power Booster Input	(**G-15**) Model 340 Analog Out 2

Table 4-24. Cable 655-451 Wiring. Connects 75016 Sample Insert 10-pin connector (B-7) to Model 340

Connection	Pin	Use	Connection	Pin
B-7	**A**	V– Sample temperature sensor output voltage (Channel **B**)	(**G-17**) on Model 340	**2**
	B	V+ Sample temperature sensor output voltage (Channel **B**)		**4**
	C	I– Sample temperature sensor excitation current (Channel **B**)		**1**
	J	I+ Sample temperature sensor excitation current (Channel **B**)		**5**
	D	I+ Heater (Loop 2), 50 Ω	(**PB-2**) Power	**Hi**
	E	I– Heater (Loop 2)	Booster Output	**Lo**
	G	V– Temperature sensor output voltage (Channel **A**)	(NOT USED)	**2**
	H	V+ Temperature sensor output voltage (Channel **A**)		**4**
	F	I– Temperature sensor excitation current (Channel **A**)		**1**
	K	I+ Temperature sensor excitation current (Channel **A**)		**5**

Following is the setup procedure:

1. Connect all cables listed in Table 4-23. (See Figure 4-31.)
2. **For Quick setup only**: Skip the remainder of this section and proceed directly to Section 4.3.3.3 Verify Temperature Controller Setup. To determine if a quick setup is possible, check if a configuration file already exists. Use either Windows Explore and look in the Windows directory, or start the Model 340 program and select the menu item: File -> Load. Typical file names relevant to this sample module might look like "75016_S1.34c". Note that some work can be saved by first loading a configuration file similar to one to be set up.
3. Exit any programs using the Model 340. The Model 340 must be in LOCAL mode to change settings through the front panel.
4. Set up the Model 340 through the front panel as specified in the procedure below. For further information, refer to the Model 340 User's Manual and the software driver help files.
   For setup of a Model 330, refer to the Model 330 User's Manual.

• **Input Setup**		(Model 340 front panel button)
		Input Setup
Input:	**A**	Enter
Enable:	**OFF**	^ Enter
		Save Screen
Input:	**B**	^ Enter
Enable:	**ON**	^ Enter
Type:	**Plat. 100/500**	^ Enter (500 Ω range to reach 800 K)
Curve:	**4 PT-100**	^ Enter
(or calibration curve, if calibrated)		
		Save Screen
Input:	**C**	^ Enter
Enable:	**ON**	^ Enter
Type:	**Thermocouple**	^ Enter
Room Comp:	**ON**	Enter
Curve:	**6 TYPE K**	^ Enter
		Save Screen
Input:	**D**	^ Enter
Enable:	**OFF**	^ Enter
		Save Screen, Save Screen
• **Display Format**		(Model 340 front panel button)
		Display Format
Input Displays:	**2**	^ Enter
Display 1:	C TEMP K	Enter
Display 2:	B TEMP K	Enter
		Save Screen
		Display Format
		<MORE>
Control Loops:	**BOTH**	^ Enter
Heat Display:	**POWER**	^ Enter
		Save Screen
• **Interface**		(Model 340 front panel button)
		Interface
IEEE-488		
Terminator:	CR LF	Enter
EOI:	ON	Enter
Address:	**14**	Enter
		Save Screen
• **Analog Outputs**		(Model 340 front panel button)
		Analog Outputs
1:		Enter
Mode:	OFF	Enter
Bipolar:	OFF	Enter
		Save Screen
2:		^ Enter
Mode:	**LOOP**	^ Enter
Bipolar:	OFF	Enter
		Save Screen, Save Screen

- **Loop 1**

		(Model 340 front panel button)
		Loop 1
		Control Channel
Loop 1 Channel:	**C**	Enter
		Loop 1
		Setpoint
Setpoint:	0.000 K	Enter

- **Loop 2**

		(Model 340 front panel button)
		Loop 2
		Control Channel
Loop 2 Channel:	**B**	^ Enter
		Loop 2
		Setpoint
Setpoint:	0.000 K	Enter

- **Control Setup**

		(Model 340 front panel button)
		Control Setup
Loop:	**1** Control Setup	Enter
Enable:	**ON**	Enter
Power Up:	OFF	Enter
Setup Unit:	TEMP K	Enter
Htr Ω:	**25**	25 Enter
Control Mode:	Manual PID	Enter
Filter:	OFF	Enter
		Save Screen
		<MORE>
Loop:	**1** Control Limits	Enter
Temp:	**800 K**	800 Enter
+slope:	0.0%	Enter
- slope:	0.0%	Enter
Max Htr I:	2.00 A	2 Enter
Max Range:	92 W	Enter
		Save Screen
		<MORE>
		Control Setup
Loop:	**2** Control Setup	^ Enter
Enable:	**ON**	^ Enter
Power Up:	OFF	Enter
Setup Unit:	TEMP K	Enter
Control Mode:	Manual PID	Enter
Filter:	OFF	Enter
		Save Screen
		<MORE>
Loop:	**2** Control Limits	Enter
Temp:	**800 K**	800 Enter
+slope:	0.0%	Enter
- slope:	0.0%	Enter
		Save Screen, Save Screen

5. **Start up only the Model 340 software program** and display the virtual front panel. The channels should be assigned as follows:
   Control = C
   Sample = B

6. Set up Loop 1 Domains.
   - Close the Model 340 software front panel.
   - Select menu item: Utilities -> Domain File Name and input a file name. A suggested format is: **75016L1A.ini** to indicate **L**oop **1**, set **A**. Change the last letter for variations such as a set of domains with shorter settle times when temperature accuracy is not as important. Note that this temperature control domain file will be located in the Windows directory.
   - Select menu item: Utilities -> Domains and input the data from Table 4-25.

Table 4-25. Model 340 Software Loop 1 Domain settings for the 75016 OSM

Domain #	Begin T [K]	End T [K]	P	I	D	Htr Power (range)	Slew rate [K/min]	First: Wait Time [min]	Second: F/C/V	Third: Wait Time [min]
1	0	300	0	0	0	0	20	5	* < 0.1	10
2	300	800	100	50	0	5	20	5	* < 0.1	10
3	800	1000	0	0	0	0	100	0	none	0

* Function (of Function/Condition/Value): **Sample drift** [K/min]

7. Set up Loop 2 Domains.
   - Select menu item: Loop 2 and make sure the Lock Set Point item is checked (select it if it is not checked). This causes the set points of the two temperature control loops to be the same at all times.
     √ Lock Set Point
   - Select menu item: Loop 2 -> Domain File Name and input a file name. A suggested format is: **75016L2A.ini** to indicate **L**oop **2**, set **A**. Change the last letter for variations such as a set of domains with shorter settle times when temperature accuracy is not as important. Note that this temperature control domain file will be located in the Windows directory.
   - Select menu item: Loop 2 -> Domains and input the data from Table 4-26. Note that locking the set point causes the wait times and conditions for Loop 2 to be ignored, but they should be entered anyway.

Table 4-26. Model 340 Software Loop 2 Domain settings for the 75016 OSM

Domain #	Begin T [K]	End T [K]	P	I	D	Htr Power (range)	Slew rate [K/min]	First: Wait Time [min]	Second: F/C/V	Third: Wait Time [min]
1	0	300	100	50	10	1	20	5	* < 0.1	10
2	300	800	100	50	10	1	20	5	* < 0.1	10
6	800	1000	0	0	0	0	100	0	none	0

* Function (of Function/Condition/Value): **Sample drift** [K/min]

8. Close the Model 340 software front panel.
9. Select menu item: File > Save As… and enter a file name. A suggested format is: "**75016_S1.34c**" used here to mean the **75016 S**ample insert number **1**. A unique name must be used if more than one Sample Insert, each with its own calibrated platinum sensor, will be used. If more than one sample insert will be used they can be numbered for identification.The .34c extension indicates that this is a Model 340 temperature controller configuration file.
10. For each additional sample insert, do the following:
    - Step 3, Exit the Model 340 software program.
    - Step 4, Input Setup, Input B portion only.
    - Step 5, Start up Model 340 software program and check Control and Sample channels.
    - Step 8.
    - Step 9.
11. Check that the configuration files were saved. Select menu item: File -> Load. A dialog box appears with a list of Model 340 configuration files (.34c extensions). Click Cancel, or select a configuration file to load and click OK. This step is performed as part of normal sample module operation in Section 4.3.3.3 Verify Temperature Controller Setup.
12. Exit the Model 340 software program.

4.3.1.7 Power Booster Installation

The Loop 2 heater output of the Model 340 can be only 1 V and 0.1 A for a maximum of 1 W into a 100 Ω heater. A Kepco Model PAT 40-0.5 programmable dc power supply is used to boost the output power to a maximum of 20 W into an 80 Ω heater. The second loop heater in the oven has a resistance of 50 Ω plus the resistance of the wiring, so the maximum Loop 2 heater power is about 12 W.

1. Connect coaxial BNC cable from Power Booster Heater Input on (PB-5) to Model 340 ANALOG OUT 2 (G-15).
2. If possible, cap Model 340 ANALOG OUT 1 (G-14) BNC bulkhead so it will not be used by mistake.
3. Plug the power cord from the Power Booster socket (PB-1) into an available socket in the power strip.
4. Plug the Auxiliary Input Cable (PN 655-451) dual banana plug into Power Booster sockets (PB-2, 3) with the ground tab side in the middle of the three banana sockets (PB-3).
5. Plug the Auxiliary Input Cable (PN 655-451) single banana plug into the third Power Booster banana socket (PB-4).
6. Pass the other end of the Auxiliary Input Cable (PN 655-451) through a wiring port in the instrument console. The 10-pin connector on the other end will later connect to the junction box on the Sample Insert.

Table 4-27. Power Booster Connections and Connection Designations (PB-n)

Power Booster				Cable	
PB-	**Socket**	**Term.**	**Use**	**Connection to**	**Pin**
PB-1	**Input**	**1**	Input power: Hot (black)	electrical	**H**
	power	**2**	Input power: Neutral (white)	power	**N**
	cord	**3**	Input power: Ground (green)	outlet	**G**
PB-2	**Heater**	**6**	Heater output V+ to power booster terminal (6) +e	(**B-7**) OmniPlex	**B**
PB-3	**output**	**5**	Heater output V- to power booster terminal (6) -e	Loop 2 heater	**A**
PB-4	**cable**	**4**	Heater output cable shield to PB terminal (4) -e	On sample insert	**-**
PB-5	**Htr input**	**14**	V+ from Model 340 controller to PB terminal (14) R_R	(**G-15**) Model 340 coax	**center**
	cable	**7**	V- from Model 340 controller to power booster terminal (7) +e	Analog out 2	**shield**
	none	**11**	Programming resistor,	none	**-**
		12	two 47.5 kΩ resistors in parallel		**-**

4.3.1.8 Removal, Storage and Shipping

Removal of the 75016 OSM from an electromagnet platform:

1. Exit from all computer programs.
2. Remove Sample Insert from oven and plug sample well.
3. Remove the Gaussmeter probe from between the electromagnet poles. Store in a safe place where the Gaussmeter probe will not be damaged.
4. Back out the electromagnet poles.
5. Use a 5/16" hex key to remove the 3/8"-16 bolts holding the base plate to the top of the electromagnet stand (EM4) or to the saddle plates (EM7 or EM12).
6. The oven (with base plate still attached) is now free of the electromagnet platform and may be removed. Pull the base plate forward. Be careful not to hit the sample module tail on anything.

Storage:

1. Store vertically on a stand.
2. Short term (less than one month) storage on a horizontal surface is also possible. Long term horizontal storage might result in sagging of the sample well within the oven tail.

Shipping:

1. **Remove base plate**. Use a 3/16" hex wrench to remove the (3) #1/4"- 28 SHC screws and washers. Remove the base plate and return the screws and washers to the holes in the bottom of the collar.
2. **Package 75016 OSM for shipping**. The Flush/Fill unit ships detatched. Use the original shipping container or build a suitable replacement. The unit may be shipped in horizontal or vertical orientation.

4.3.2 Sample Mounting with the Model 75016 OSM

Mount samples by following the Model 75013 SCSM Prober Sample Card sample mounting instructions given in Section 4.1.2.2 with the following exceptions:

1. The sample mounting portion of the Model 75016 Sample Insert is permanently attached, not removable like the Prober Sample Card used in the Model 75013 SCSM.
2. The sample mounts in the center of a sapphire mounting plate centered between solder posts. Glue the sapphire mounting plate to the G-10 plate with rubber cement. Normally, it should not be removed.The solder posts around the sapphire mounting plate are not numbered, but are laid out in the same pattern and orientation as the numbered triaxial bulkhead connectors on the Sample Insert junction box (see Figure 4-29). The figure on the cover of the junction box shows connections to two common sample geometries (van der Pauw square and 1-3-3-1 Hall bar).
3. There is no sample identification space on the Model 75016 Sample Insert sample mounting plate. If desired, attach a removable note to the Sample Insert junction box with the sample identification and other relevant information.

4.3.3 Operation of the Model 75016 OSM

This section provides instructions for the APD Omniplex™ Top Loading Exchange Gas Cryostat. This module is designed for more sophisticated temperature control.

4.3.3.1 Sample Insert Insertion

Use the procedure below in loading the Sample Insert to avoid contamination or condensation from air.

1. Clean Sample Insert of any dust or dirt accumulated on its surface. Verify that the Sample Insert is dry.
2. Ready the Sample Insert, remove Sample Well Plug, and carefully insert the Sample Insert.
3. Twist Sample Insert junction box in the rotation stage to fully engage the bayonett lock.
4. Press valve button on Flush/Fill unit 2 or 3 times. This removes any air from the sample well and backfills with helium gas. Any air remaining in the sample well will drop to the bottom of the sample well, near the sample, if a lighter purge gas such as helium is used.

5. Set rotation stage to zero degrees so sample is perpendicular to the applied magnetic field.

4.3.3.2 Sample Insert Cable Connections

The 4 or 6 triaxial sample cables should already have a protective sleeve plus a short section of spiral cable wrap and a tie down clamp near the sample end. Bolt the tie down clamp into the right rear bolt hole on top of the saddles. This strain relieves the cables, but positions them close to the sample well where they will be attached to the Sample Insert.

4.3.3.3 Verify Temperature Controller Setup

The temperature controller must be set up for the Sample Module in use. If no temperature controller configuration file exists, create one (see section 4.3.1.6). Note that there is no indication of the current configuration (unlike the Field Control driver program).

1. Start the Model 340 softwqare driver program on the computer and load the appropriate configuration file. To do this, select the menu item: File -> Load. A dialog box will appear with a list of configuration files (.34c extensions). Select one and click on OK. The Model 340 will be configured, but there is no indication of the current configuration.
2. Open the Front Panel and check that the input channels are reading properly and assigned as follows:
   Control = C
   Sample = B

4.3.3.4 Vacuum Pump Out Procedure

The customer must supply a vacuum pump to evacuate the sample module to a pressure of 0.1 Pa ($7x10^{-4}$ torr) or lower prior to initial operation. Vacuum pressure gauging must be provided or added to the oven. The oven must be pumped continuously during operation.

1. The oven should be at room temperature for initial vacuum pumpout.
2. Connect vacuum line to the oven Vacuum Pumpout Port (**OB-4**).
3. The other end of the vacuum line has a KF-25 flange attached. Connect the flanged end to a vacuum pump.
4. Start the vacuum pump and pump out the oven vacuum space to a pressure less than 1 Pa ($7x10^{-3}$ torr). If using a mechanical vacuum pump which can backstream oil, a trap must be used. Dry pumps can be run longer and the vacuum will be cleaner.

4.3.3.5 Temperature Control Parameters

Choosing temperature control parameters always requires a compromise between the desires for rapid temperature changes and good stability and accuracy with little temperature overshoot or oscillation.

The temperature control domain parameters suggested in the section on setting up the Model 340 temperature controller were chosen for slow, controlled temperature changes with little overshoot or oscillation. If faster temperature changes are desired, first try setting the second wait times in the Domains to zero. Additional optimization can be performed by following the procedures described in the Model 340 User's Manual.

4.3.3.6 Sample Insert Removal

Use the procedure below to remove a Sample Insert from the Model 75016 OSM.

1. Wait until the Sample Insert temperature is below 350 K before removal.
2. Unplug the triaxial BNC cables from the Sample Insert junction box. If desired, leave 10-pin circular connector in place to monitor temperature.
3. Twist Sample Insert junction box in the rotation stage to release the bayonett lock.
4. Remove the Sample Insert from the oven sample well.
5. Insert the sample well plug and make sure it seals tightly.
6. Press the Flush Fill valve button 2 or 3 times to remove the gas (possibly contaminated with air) from the sample well.

4.3.4 Service and Maintenance for the Model 75016 OSM

4.3.4.1 Leakage Resistance and Shielding

Measurement of very high resistance samples (>10 MΩ) requires very high resistance between all combinations of signal, guard and ground. The following procedure is possible only with measurement instrumentation that drives the guards around the signal lines (-HVWR or -LVWR).

1. Measure the resistance of the Sample Insert without any sample mounted. If necessary, first clean the sample mounting area with isopropyl alcohol and demineralized water, then blow dry with warm air from a heat gun. Install the Sample Insert in the oven sample well. Measure the resistance (R14,23) in high resistance mode using the Resistance software program.
2. The resistance should be significantly greater than the specified maximum accurately measurable resistance of the measurement system. Note that a leakage resistance of 100 times the maximum sample resistance would lead to a 1% measurement error.
3. If the resistance is low, check the resistance between signal and guard and between guard and ground. A convenient place to do this is at the connectors on the junction box. Likely places to look for shorts are a) the connections between the coaxial cable and the bulkhead connectors, b) the connections to the solder posts, and c) the region between the solder posts. Look for stray wires or improperly cleaned connections.

4.3.4.2 Needle Probe Replacement

Contact Lake Shore for replacement needle probes (Lake Shore P/N 673-207) and bending instructions.

4.3.4.3 Sapphire sample plate replacement

Clean sapphire plate and copper sample mounting plate region between the needle probes. If the original sapphire plate is cracked or damaged, order a replacement (Lake Shore part number 672-528) or make a similar sample mounting plate from sapphire. Hold the sapphire plate in place with two wires tied around the sample mounting plate. The wires must lay in the edge grooves or they will rub against the sides of the sample well and break.

4.3.4.4 Incorrect Temperature Readings

Check the temperature controller setup for proper sensor type and calibration curve.

Check electrical connections and cables.

Check that the platinum temperature sensor on the Sample Insert is firmly attached to the back of the sample mounting plate. If the temperature sensor has detatched, paste it back in place using a very small amount of ceramic paste.

If necessary, replace the temperature sensor. Contact Lake Shore to order a replacement and for replacement instructions.

4.3.4.5 Insufficient Heating

Check the heater resistances at the connectors on the oven body and Sample Insert junction box and verify that they are correct. A burned out Loop 1 heater (in the oven body) must be replaced at the factory. Contact Lake Shore to schedule service. A burned out Loop 2 heater (Sample Insert) can be replaced in the field. Refer to instructions for Loop 2 Heater Replacement.

Check cables back to the temperature controller and power booster.

Verify output from the temperature controller and power booster.

4.3.4.6 Loop 2 Heater Replacement

Order a replacement heater (Lake Shore part number 672-529).

Remove the copper sample mounting platform from the end of the Sample Insert tube by removing the four #4-40 screws.

Separate the sample mounting platform from the tube, exposing the end of the heater.

Detatch old heater leads and remove the heater.

Spot weld or braze the new heater to the lead wires and insulate with fiberglass tubing rated to at least 850 K.

Insert the new heater in the hole in the sample mounting platform.

Screw the sample mounting platform back onto the end of the Sample Insert tube. The sample space must face in the same direction as the cover of the junction box.

4.4 MODEL 9500 FCSM – FLOW CRYOSTAT SAMPLE MODULE

The Model 9500 Flow Cryostat Sample Module (9500 FCSM) 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 liquid helium taken from the surrounding dewar against two heater circuits powered by a temperature controller. An assembly overview is shown in Figure 4-17. The 9500 FCSM consists of the following components:

- Liquid helium dewar.
- Superconducting magnet.
- Flow cryostat (see Figure 4-17 and Table 4-10).
- Sample Insert (see Figures 4-19 and 4-20).
- Vacuum pump.

Optional additional equipment:

- Liquid helium transfer line.

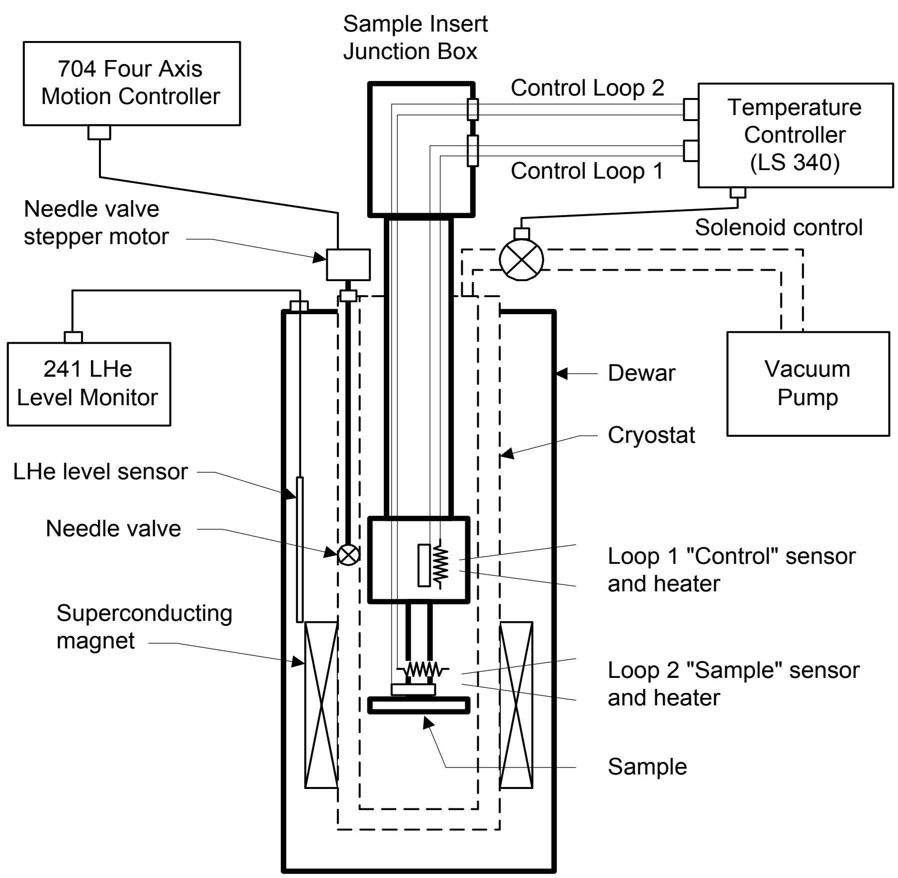


Figure 4-32. Model 9500 FCSM Operational Schematic.
The magnet power supply and measurement systems are not shown.

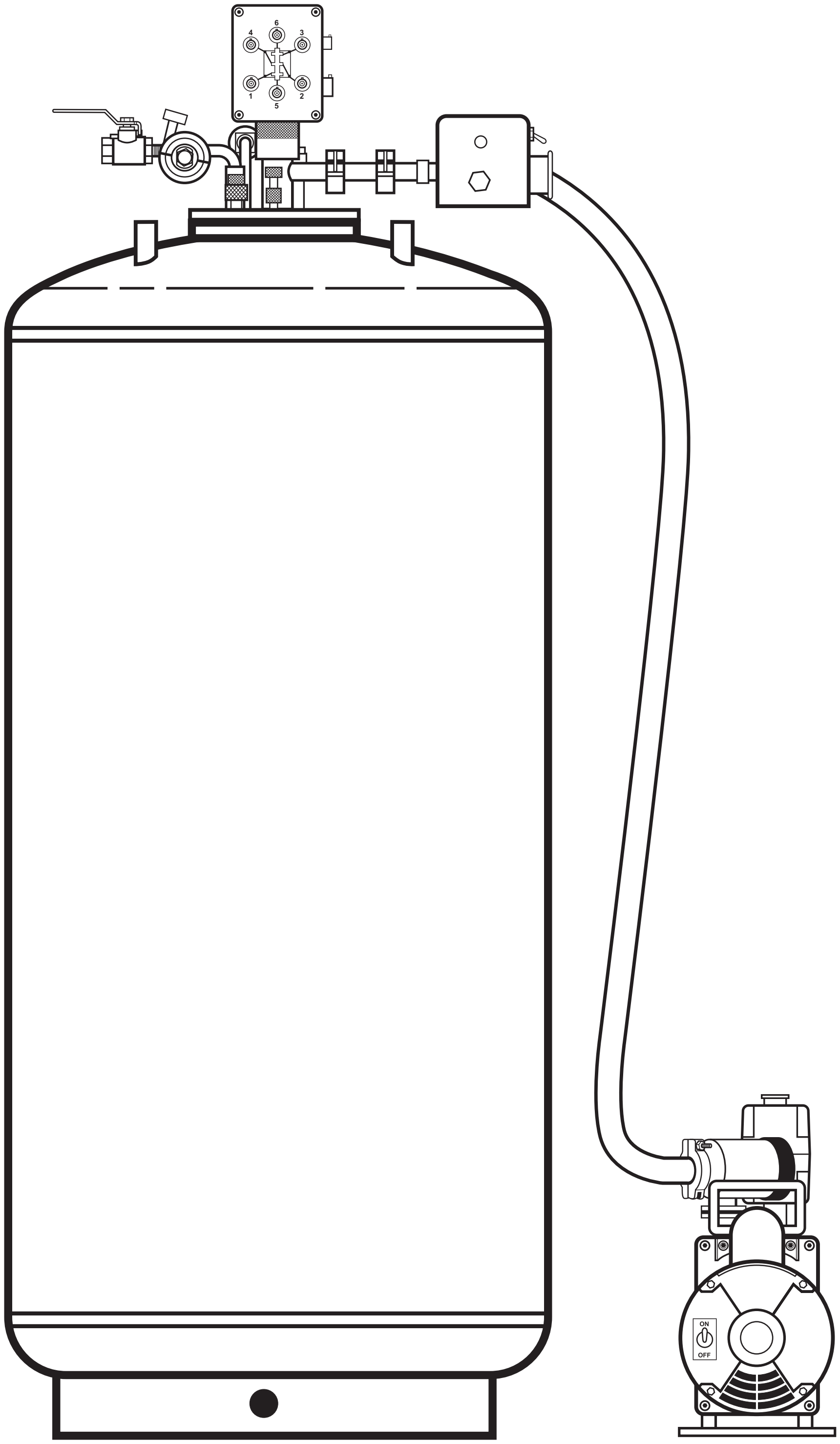


Figure 4-33. Model 9500 FCSM Assembly Overview.
The cryostat, magnet, and sample insert are shown mounted inside the dewar.

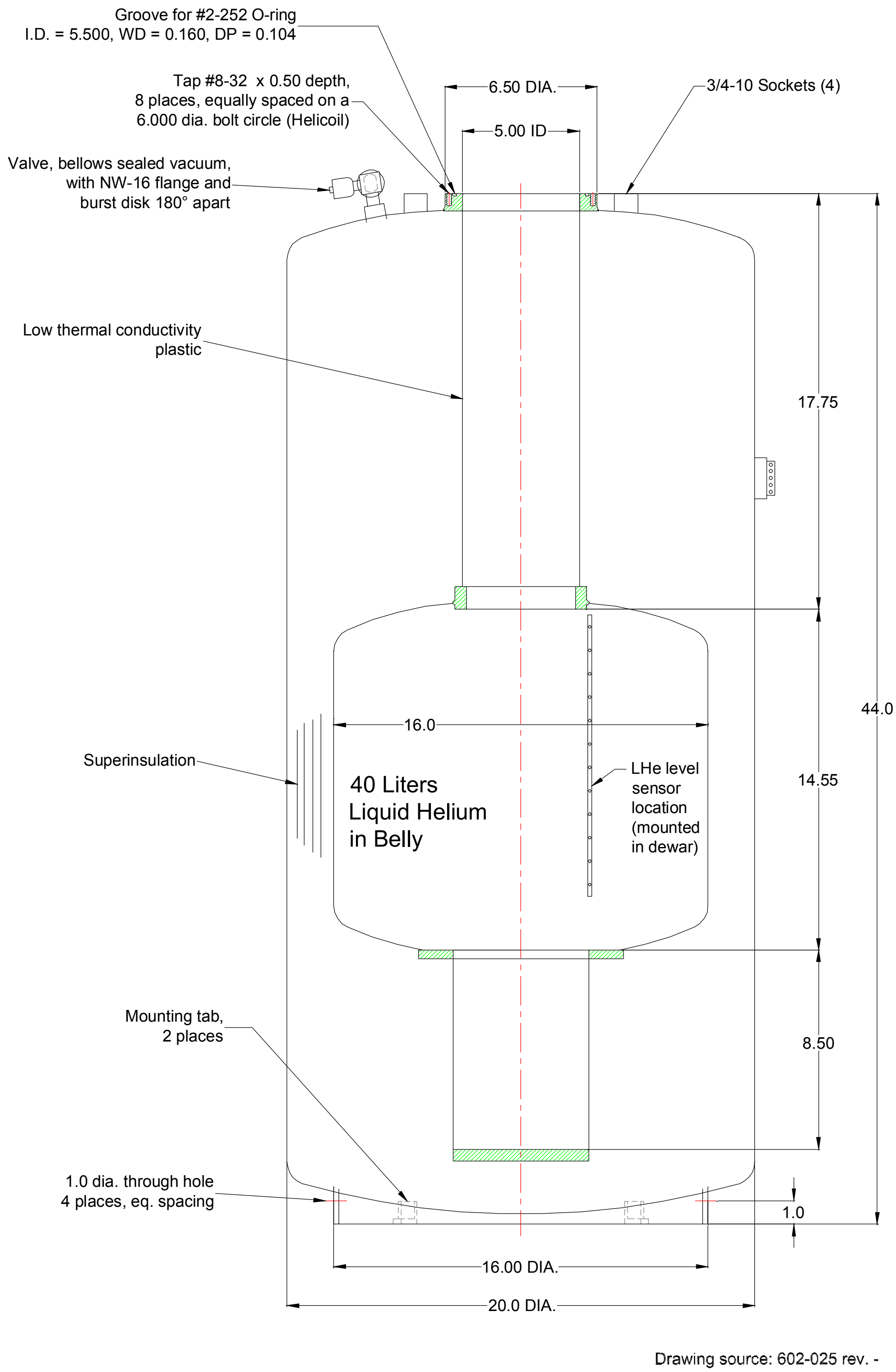


Figure 4-34. Standard LHe dewar for the Model 9500 FCSM.
A liquid nitrogen shielded dewar is also available.

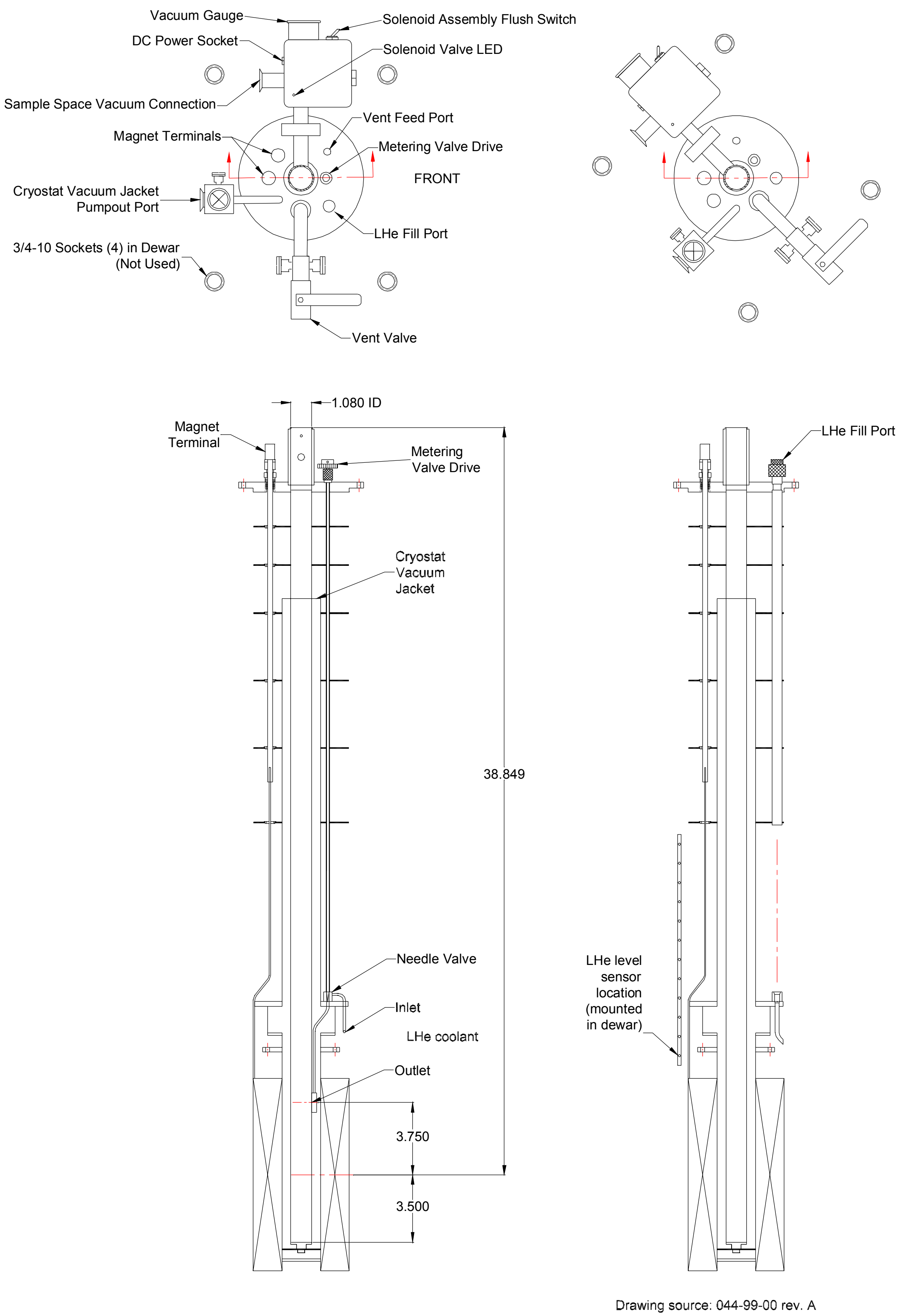


Figure 4-35. Cryostat and Magnet for the Model 9500 FCSM

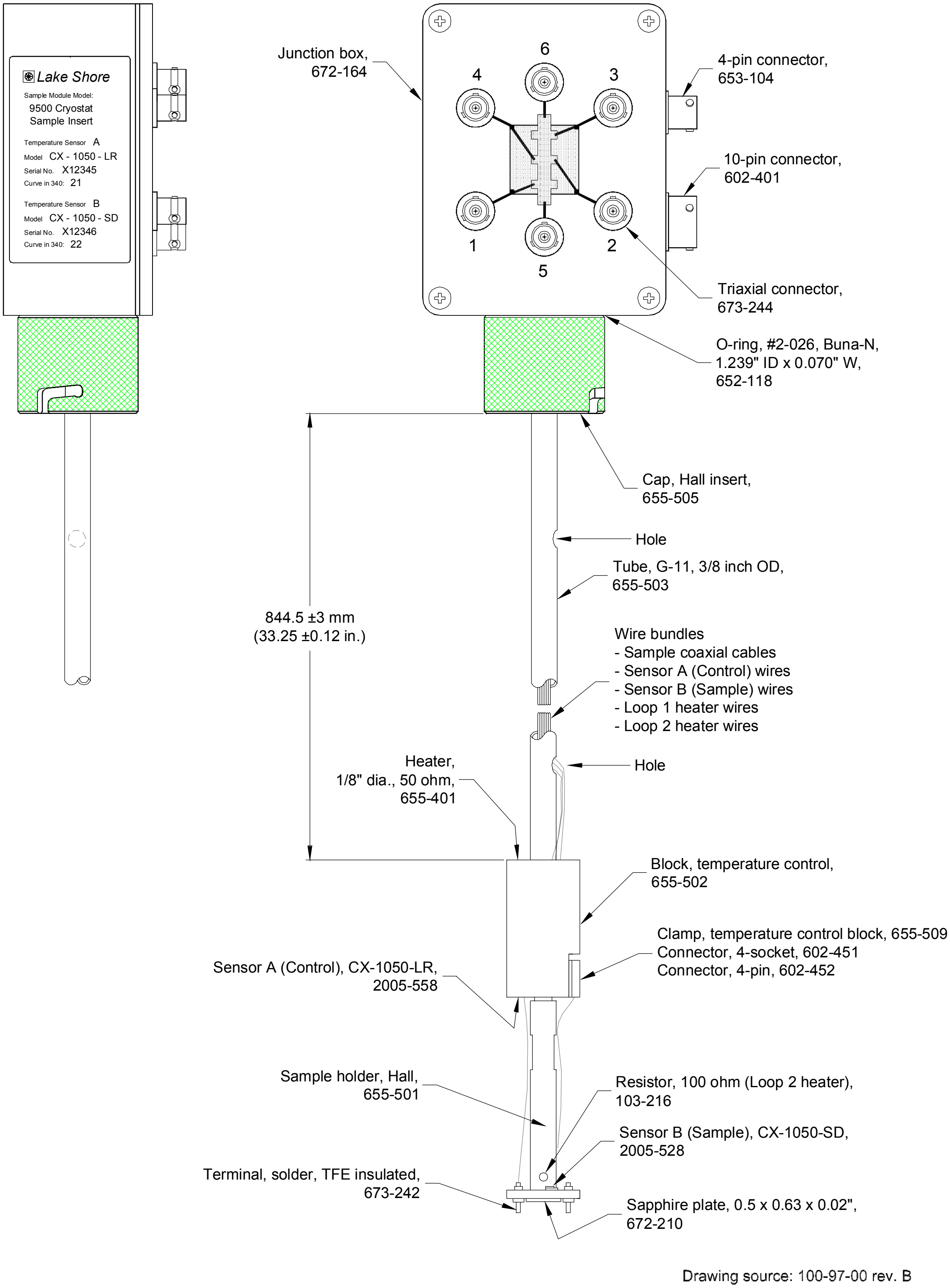


Figure 4-36. Model 9500 FCSM Sample Insert

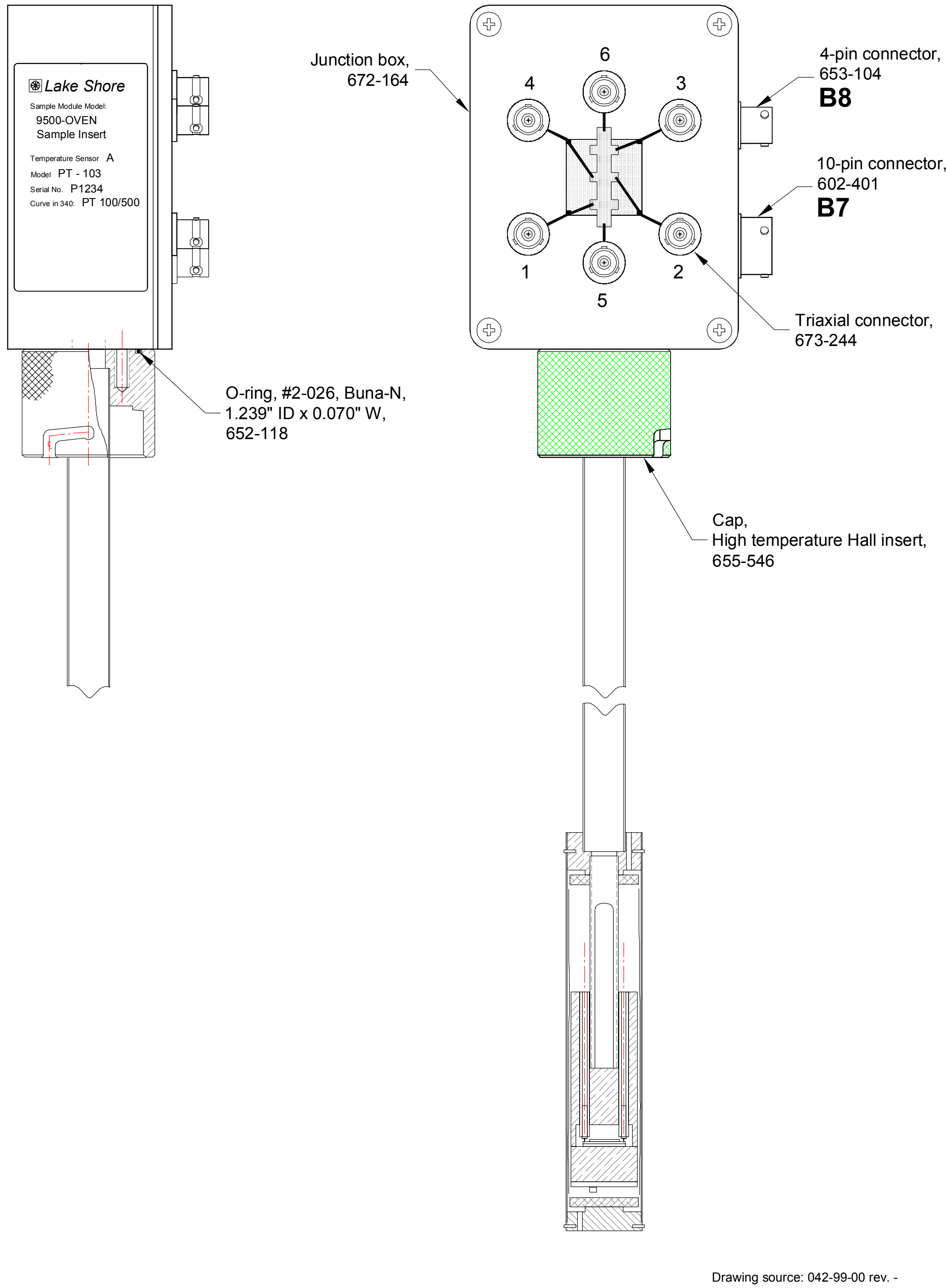


Figure 4-37. Model 9500-OVEN - OFCSM Sample Insert

Table 4-28. Flow Cryostat Connection Point and Interface Designations
The locations of the connections listed below are shown in Figure 4-18.

FC-		Flow Cryostat
	1	Sample space access port, 2-pin bayonette, 27.4 mm (1.08 inch) clear bore
	2	Sample space vacuum pumpout port, NW-25 flange
	3	Flush switch
	4	Liquid helium fill port
	5	Liquid helium level sensor connector on dewar
	6	Dewar pumpout valve
	7	Dewar vent valve
	8	Dewar vent relief valve

Table 4-29. Sample Connection Wiring for the 9500 FCSM Sample Insert
The wire resistance is measured from the connector on the junction box to the sample contact post.

Connector	Pin	Use	Wire R [Ω]
B-1	**1**	Sample connection # 1	30
B-2	**2**	Sample connection # 2	30
B-3	**3**	Sample connection # 3	30
B-4	**4**	Sample connection # 4	30
B-5	**5**	Sample connection # 5, I+ for Hall bars	30
B-6	**6**	Sample connection # 6, I- for Hall bars	30
B-7	**A**	"Sensor" temperature sensor (Channel **B**), V-	8
	B	"Sensor" temperature sensor (Channel **B**), V+	8
	C	"Sensor" temperature sensor (Channel **B**), I-	8
	J	"Sensor" temperature sensor (Channel **B**), I+	8
	D	Heater, 50 Ω, 1 A, in temperature control block (Loop 1), I+	8
	E	Heater, 50 Ω, 1 A, in temperature control block (Loop 1), I-	8
	G	"Control" temperature sensor (Channel **A**), V-	8
	H	"Control" temperature sensor (Channel **A**), V+	8
	F	"Control" temperature sensor (Channel **A**), I-	8
	K	"Control" temperature sensor (Channel **A**), I+	8
B-8	**A**	Heater, 100 Ω, 0.1 A, near sample (Loop 2), I+	8
	B	Heater, 100 Ω, 0.1 A, near sample (Loop 2), I-	8
	C	unused	
	D		

Table 4-30. Sample Connection Wiring for the 9500-OVEN OFCSM Sample Insert.
The wire resistance is measured from the connector on the junction box to the sample contact post.

Connector	Pin	Use	Wire R [Ω]
B-1	**1**	Sample connection # 1	30
B-2	**2**	Sample connection # 2	30
B-3	**3**	Sample connection # 3	30
B-4	**4**	Sample connection # 4	30
B-5	**5**	Sample connection # 5, I+ for Hall bars	30
B-6	**6**	Sample connection # 6, I– for Hall bars	30
B-7	**A**	unused	8
	B		8
	C		8
	J		8
	D	Heater, 50 Ω, 1 A, in temperature control block (Loop 1), I+	8
	E	Heater, 50 Ω, 1 A, in temperature control block (Loop 1), I–	8
	G	Temperature sensor (Channel **A**), V–	8
	H	Temperature sensor (Channel **A**), V+	8
	F	Temperature sensor (Channel **A**), I–	8
	K	Temperature sensor (Channel **A**), I+	8
B-8	**A**	unused	8
	B		8
	C		
	D		

4.4.1 Setting Up the Model 9500 FCSM

Setup must be performed in the following cases:

1. Initial setup following shipping, long term storage, or when switching from an electromagnet-based sample module (7500 series).
2. Quick setup after switching sample inserts.

The 9500 FCSM is normally not removed from the superconducting magnet installed in the dewar and can be left set up. Switching to a different sample insert requires a partial, or quick setup because each sample insert contains two calibrated temperature senstors. Table 4-31 lists the steps required for setup. The table gives an overview and also can be used as a checklist.

Table 4-31. Model 9500 FCSM or 9500-OVEN OFCSM Setup Steps

Reference refers to the relevant section in this manual. An asterisk (*) indicates the procedure is not always required.

Initial	Quick	Description	Reference
1		Unpacking and Assembly	**4.4.1.1**
2		Dewar Vacuum Pump Out Procedure	**4.4.1.2**
3	**1**	Model 241 Liquid Helium Level Monitor Connections	**4.4.1.3**
4	**2**	Set Up Model 704 Four Axis Motor Controller	**4.4.1.4**
5	**3**	FIELD CALIBRATION	**4.4.1.5**
6	**4**	Check connections to the 9500 FCSM	Table 4-28
7	**5***	Temperature Controller Setup for the 9500 FCSM Sample Insert or Temperature Controller Setup for the 9500-OVEN OFCSM Sample Insert	**4.4.1.6** or **4.4.1.7**

4.4.1.1 Unpacking and Assembly

Refer to instructions in Chapter 3.

4.4.1.2 Dewar Vacuum Pump Out Procedure

The mechanical vacuum pump supplied with the 9500 can be used to evacuate the dewar to a pressure of 100 Pa (0.1 torr) or lower prior to initial operation. Vacuum pressure gauging must be provided, if required. Other vacuum pumping stations can also be used for pumpout.

Pumpout of the vacuum jacket may be required only every few months if the dewar is kept cold. Pumpout is best performed when the dewar is at room temperature inside and out.

Initial Pumpout Procedure (starting from atmospheric pressure):

1. The dewar should be at room temperature for initial vacuum pumpout.
2. Connect vacuum line to Vacuum Valve on Dewar Vacuum Pumpout Port (FC-2).
3. Open the Dewar Vacuum Valve.
4. Start the vacuum pump and pump out the dewar vacuum space to a pressure <1.3 Pa (or 10 millitorr or 10 microns). If using a mechanical vacuum pump which can backstream oil, pump the minimum time necessary to achieve this pressure. Dry pumps can be run longer and the vacuum will be cleaner if the system is pumped for a day or overnight.
5. Close the vacuum valve.

Vacuum Cleanup Procedure (starting with vacuum):

1. The dewar should be at room temperature and already have a fairly good vacuum.
2. Connect vacuum line to Vacuum Valve on Dewar Vacuum Pumpout Port (FC-2), but **do not open the vacuum valve yet**.
3. Start vacuum pump and pump out vacuum line to a pressure <1.3 Pa (or 10 millitorr or 10 microns).
4. Open the Dewar Vacuum Valve.
5. Start the vacuum pump and pump out the dewar vacuum space to a pressure less than 1.3 Pa (or 10 millitorr or 10 microns). If using a mechanical vacuum pump which can backstream oil, pump the minimum time necessary to achieve this pressure. Dry pumps can be run longer and the vacuum will be cleaner if the system is pumped for a day or overnight.
6. Close the vacuum valve.

4.4.1.3 Model 241 Liquid Helium Level Monitor Connections

The liquid helium level monitor must be connected to the liquid helium level sensor installed in the dewar. The level monitor is set up at Lake Shore for operation with this level sensor, so calibration should not be necessary. Refer to the 241 manual for additional instructions. The Model 241 Level Monitor uses a superconductive liquid level sensor; dewar temperature >10 K interrupts level readings.

NOTE: The Model 241 liquid helium level monitor is set up to read a level sensor with an 11 inch active length. See the Model 241 Liquid Helium Level Monitor User's Manual for instructions if this has not been done already.

1. Locate the cable with a 4-pin connector on one end and a DB-9 connector on the other end. Plug the DB-9 connector into the Model 241 DB-9 port (Figure 4-38). Plug the 4-pin connector into the 4-pin output on the superconducting magnet dewar (see Figure 4-34).
2. Plug the power adapter cable into an AC outlet. Plug the other end into the Model 241 +12 VDC power port (Figure 4-38).
3. Turn on the power switch on the back of the instrument.

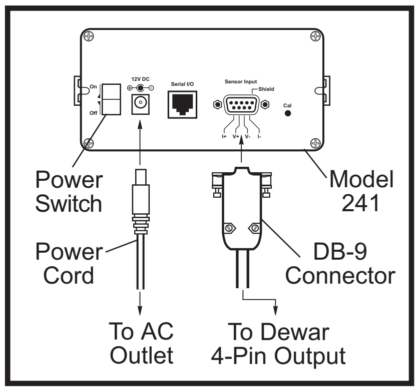


Figure 4-38. Model 241 Liquid Helium Level Monitor Connections

4.4.1.4 Set Up Model 704 Four Axis Motor Controller

Connect between the 704 and the stepper motor on the cryostat. The stepper motor controls the needle valve used to regulate the flow of liquid helium coolant allowed into the sample space.

1. Connect terminal block to input B on the back of the 704.
2. Connect RS-232 communications from the computer to the jack on the back of the 704.

4.4.1.4.1 Communication Via RS-232 and Hyperterminal

To open a connection with the Model 704 directly, click **Start > Programs > Accessories > Hyperterminal** on the Windows 95 Taskbar. Then double click the Model 704 icon. After the terminal window appears, press the spacebar twice to receive a # sign response. Terminal settings are Com Port 1, 9600 baud, 8 bits, 1 stop bit, no parity.

Table 4-32. RS-232 Command List

ESC	**Abort/Terminate**
@	**Soft Stop**
Ann	**Motor Selection:** **A0** = Motor A **A16** = Motor B **A8** = Motor C **A24** = Motor D
A129	**Read Input/Output Status:** Response = the sum of the following: **DATA:** **CAUSE:** 1 High input on Port 1 2 High input on Port 2 4 High input on Port 3 8 Output 1 ON 16 Output 2 ON 32 High if moving 64 Trip Point passed 128 Direction Level: High if "-"
Enn	**Motor On/Off:** **E0** = motor phases off **E12** = motor phases on, limit switches enabled
Innnn	**Initial Velocity** (steps/second)
Knnnn	**Ramp Slope** (**0** = no ramp, larger numbers mean slower ramps)
M	**Move** at constant speed
Onnnn	**Set Origin:** Set current position to nn, **O0** sets current position = 0
S	**Store** parameters as defaults
T	**Trip Point** (not used)
+nnnn	**Positive Step:** move nnnn steps in the positive direction
-nnnn	**Negative Step:** move nnnn steps in the negative direction
Vnnnn	**Slew Velocity** (steps/second)
Wnnnn	**Wait** nnnn milliseconds
X	**Examine Parameters** (format: K=kk, I=ii, V=vv, T=tt)
Z	**Display Position**

4.4.1.4.2 Normal Initial Setup

To restore the Model 704 to its correct initial state before running the 4-Axis software, power-up the controller, start the Model 704 Hyperterminal session, then type the following commands (terminate lines with carriage returns, *italics indicates response*):

<spacebar> #

E0

A16

V100

I400

K8

O0

E12

X *K=8, I=400, V=100, T=0*

Z *0*

+10 *Motor moves 10 steps in positive direction*

Z *10*

-10 *Motor moves 10 steps in negative direction*

Z *0*

4.4.1.4.3 Sample of Typical Operation

E0		*turn motor phases off*
A0		*switch to channel A*
E12		*turn motor phases on*
O0		*set current location to 0*
V1000		*set velocity to 1000(for channel A)*
K8		*set ramp to 8*
+1000		*move 1000 steps in the positive direction*
A129		*check limits*
	3	*indicates Channel A selection and both limit inputs are high, or inactive (0 + 2 + 1 = 3)*
Z		*request current position*
	1000	*response*
E0		*turn motor phases off*
A16		*change to channel B*
E12		*turn motor phases on*
O0		*set current location to 0*
V400		*set velocity to 400*
K4		*set ramp to 4 (a faster acceleration than K = 8)*
-550		*move 550 steps in the negative direction*
A129		*check limits*
	18	*indicates channel B selection and low limit activation (16 + 2 + 0 = 18)*
Z		*request current position*
	-327	*response (current position = -327, indicates where limit switch tripped)*
W2000		*wait 2 seconds*
E0		*turn motor phases off*
A0		*switch to channel A*
E12		*turn motor phases on*
O1000		*set current position to 1000 (= position of channel A)*
V1000		*set velocity to 1000 (= velocity for channel A)*
K8		*set ramp to 8 (= ramp for channel A)*
+500		*move 500 steps in the positive direction*
A129		*check limits*
	3	*indicates Channel A selection and both limit inputs are high, or inactive (0 + 2 + 1 = 3)*
Z		*request position*
	1500	*response*

NOTES:

1. Always turn off motor phases before switching channels to avoid damaging motor windings and switching relays.
2. Keep track of the position of each channel and reset the position (along with velocity, acceleration, initial velocity, etc.) each time you change channels.
3. Activate limit switches for channel X by bringing inputs X1 or X2 to ground (g1). Limits are active only for the currently selected channel. A +5V output is provided so that optical or other logic-based limit detectors can be used as well as a simple switch. Input X1 is the negative limit for channel X, while input X2 is the positive. If a limit input is brought low, the motor stops moving and holds at the current position. Check status of limit switches with the A129 command. If the limit inputs are both high, then the least significant bits of the response to A129 will be ones. (i.e., 3, 7, 19, etc., depending on the status of the more significant bits.) If the low limit is activated, then the one's bit = 0 (i.e., 2, 6, 18, etc.) If the high limit is activated, then the two's bit = 0 (i.e., 1, 5, 17, etc.). These are easy to check from a programming standpoint with bit arithmetic.

4.4.1.4.4 Automatic Valve Control

The Model 9300 flow cryostat is equipped with automatic valve control for both the flow control (needle) valve (Paragraph 6.2.1) and the sample space evacuation (solenoid) valves (Paragraph 6.2.2).

4.4.1.4.5 Flow Control Valve

Proper operation of the flow control valve depends on correctly initializing the valve controller. The following procedure explains how to initialize the flow control valve.

1. Power up the system and start the Virtual Temperature Control software. (This can be started directly or by starting the Hall experiment.)
2. Click the **FourAxis** button on the Windows task bar to bring up the Motion Controller software.
3. Select the **Front Panel** menu.
4. Be sure that Motor 2 is active. Click the **Motor Off** radio button.
5. Manually tighten the needle valve as far as possible. The valve stem turns clockwise to tighten, but the motor shaft turns counter-clockwise.
6. Click the **Motor On** radio button.
7. Click inside the **Move To** edit box and type -20. Then click on the **Move** button.
8. Click the **Set Origin** button. The current position should read **0**.
9. Close the front panel and minimize, but do not exit, the FourAxis software.

NOTE: The Model 704 motion controller remembers its current position as long as it remains powered up. It should not be necessary to repeat this procedure unless the power is switched off. Upon power-up, the Model 704 starts up with its current position set to 0. Simply returning the flow control valve to 0 before powering down preserves the current setting.

Set the flow control valve position directly through either the FourAxis or the Virtual Model 340 front panel. In the latter case, type the desired setting into the **Flow Valve** edit box, followed by the **Tab** key. Valve settings are given in steps; there are 400 steps per valve stem rotation.

The Virtual Model 340 software uses the **Domains** settings for automatic control over the flow control valve settings. Each temperature domain has two fields for entering flow control valve positions: **During Ramp** and **After Ramp**. The **During Ramp** setting controls the valve position while the temperature setpoint is changing during a temperature ramp and until the first wait time has elapsed. The **After Ramp** setting controls the valve setting after the first wait time has elapsed. Access temperature domains using the **Utilities > Enter Domain Information** menu item in the Virtual Model 340 software.

NOTE: Temperature domains are either ascending or descending. The starting temperature of a descending domain is higher than its ending temperature, and *vice versa* for an ascending domain. It is common in a descending domain to open the flow control valve wide during the ramp, and then open it only slightly after the ramp. It is also common to open the solenoid valve during a descending ramp and close it afterward. This allows rapid cool-down followed by temperature control with minimal power and helium consumption.

4.4.1.4.6 Sample Space Evacuation Valve

The sample space needs to be evacuated to facilitate rapid cool-down and to reach temperatures below 4.2 K. The space is evacuated by opening a relay-controlled solenoid valve using either the Model 340 or Virtual Model 340 software.

Model 340: To toggle the position of the solenoid valve from the Model 340 software, click the valve button on the toolbar. Also access the two Model 340 relays through the **Utilities->Relay Settings** menu item. The **Low Relay** controls the solenoid; the **High Relay** is unassigned.

VIRTUAL Model 340: Control the solenoid valve from the Virtual Model 340 front panel by clicking the **Sample Space Valve** radio buttons: **Open**, **Closed**, and **Auto**. The **Auto** setting allows the valve to be controlled automatically through the temperature domains. As with the flow control valve, the sample space valve has two settings for each domain, one for during and after a ramp.

4.4.1.5 FIELD CALIBRATION

Configure the Model 620/622 Magnet Power Supply as directed in Chapter 3.

4.4.1.6 Temperature Controller Setup for the 9500 FCSM Sample Insert

This procedure configures the Model 340 inputs for two calibrated Cernox temperature sensors on the 9500 Sample Insert, and two loop temperature control.

A schematic of the control system is shown in Figure 4-32. Temperature sensor and heater physical locations are shown in Figure 4-36.

The first control loop consists of a temperature sensor and heater inside the temperature control block of the 9500 sample insert.

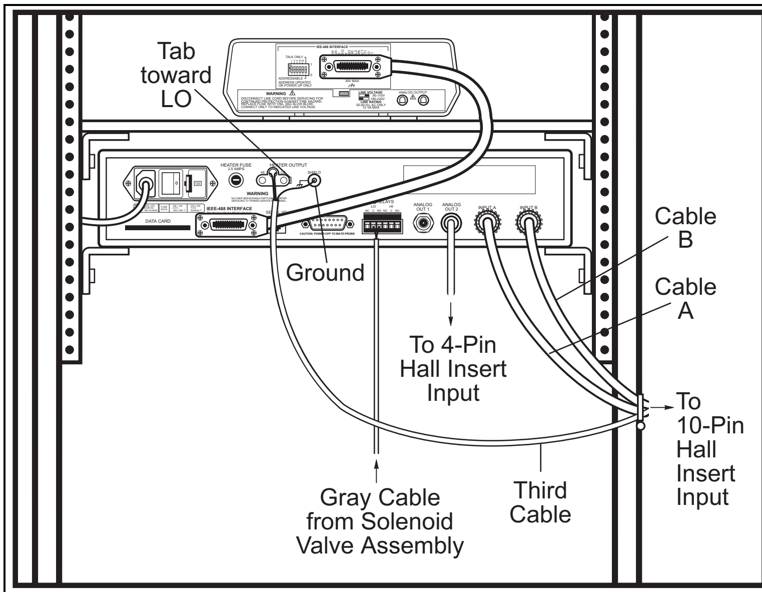


Figure 4-39. Typical Model 340
Connections to the Model 9500 FCSM.

The sample is located on the end of the 9500 sample insert with the loop 2 heater nearby. Many temperature sensors experience unacceptably large reading errors when operated in high magnetic fields at low temperatures. For this reason Cernox temperature sensors are used to monitor the temperature. The disadvantage is that each Cernox resistor must be individually calibrated as a function of temperature and the proper calibration curve must be loaded into the temperature controller and selected for use.

Refer to the Model 340 manual for further information on dual control loop theory and operation.

Following is the setup procedure:

1. Connect all cables listed in Table 4-33 (see Figure 4-24).
2. For Quick setup only: Skip the remainder of this section and proceed directly to Section 4.2.3.3. To determine if a quick setup is possible, check if a configuration file already exists. Use either Windows Explore and look in the IDEAHALL directory, or start the Model 340 program and select the menu item: File -> Load. Typical file names relevant to this sample module might look like "9500_S1.34c". Note that some work can be saved by first loading a configuration file similar to one to be set up.
3. Exit any programs using the Model 340. The Model 340 must be in LOCAL mode to change settings through the front panel.

Table 4-33. Connection List for Model 340 to Model 9500 CCRSM

#	CONNECTION	FROM	TO
1	Auxiliary input cable, 655-451 (see Table 4-34)	(**G-16**) cable 6-pin circular connector **A** to Model 340 Channel **A** (**G-17**) cable 6-pin circular connector **B** to Model 340 Channel **B** (**G-5, 6**) Cable dual banana connector to Model 340 Heater Output, gnd tab to LO (**G-7**) Cable single banana connector to Model 340 Heater Output SHIELD	(**B-7**) Junction box of Sample Insert, 10-pin circular connector socket
2	455-450 Cable, 4-pin circular connector to coaxial BNC	(**B-8**) Junction box of Sample Insert, 4-pin circular connector socket	(**G-15**) Model 340 Analog Out 2
3	Cable from cryostat to block connector	(**FC-8**) Sample space vacuum valve	(**G-13**) Model 340 Relay Out **LO**

Table 4-34. Cable 655-451 Wiring. Connects 9500 Sample Insert 10-pin connector (B-7) to Model 340

Connection	Pin	Use	Connection	Pin
B-7	**A**	V- temperature sensor output voltage (Channel **B**)	(**G-17**) on Model 340	**2**
	B	V+ temperature sensor output voltage (Channel **B**)		**4**
	C	I- temperature sensor excitation current (Channel **B**)		**1**
	J	I+ temperature sensor excitation current (Channel **B**)		**5**
	D	I+ Heater, 50 Ω	(**G-5, 6**) on Model 340	**Hi**
	E	I- Heater		**Lo**
	G	V- temperature sensor output voltage (Channel **A**)	(NOT USED)	**2**
	H	V+ temperature sensor output voltage (Channel **A**)		**4**
	F	I- temperature sensor excitation current (Channel **A**)		**1**
	K	I+ temperature sensor excitation current (Channel **A**)		**5**

4. Set up the Model 340 through the front panel as specified in the procedure below. For further information, refer to the Model 340 User's Manual and the Model 340 software help files. (For setup of a Model 330, refer to the Model 330 User's Manual.)

- **Input Setup**

		(Model 340 front panel button)
		Input Setup
Input:	**A**	Enter
Enable:	**ON**	^ Enter
Type:	**Cernox**	^ Enter
Curve:	**21 CX-1050-LR**	^ Enter
(Curve number is typical; match the sensor serial number to the calibration curve)		
		Save Screen
Input:	**B**	^ Enter
Enable:	**ON**	^ Enter
Type:	**Cernox**	^ Enter
Curve:	**22 CX-1050-SD**	^ Enter
(Curve number is typical; match the sensor serial number to the calibration curve)		
		Save Screen, Save Screen

- **Display Format**

		(Model 340 front panel button)
		Display Format
Input Displays:	**2**	^ Enter
Display 1:	A TEMP K	Enter
Display 2:	B TEMP K	Enter
		Save Screen
		Display Format
		<MORE>
Control Loops:	**BOTH**	^ Enter
Heat Display:	**POWER**	^ Enter
		Save Screen

- **Interface**

		(Model 340 front panel button)
		Interface
IEEE-488		
Terminator:	CR LF	Enter
EOI:	ON	Enter
Address:	**14**	Enter
		Save Screen

- **Analog Outputs**

		(Model 340 front panel button)
		Analog Outputs
1:		Enter
Mode:	OFF	Enter
Bipolar:	OFF	Enter
		Save Screen
2:		^ Enter
Mode:	**LOOP**	^ Enter
Bipolar:	OFF	Enter
		Save Screen, Save Screen

- **Loop 1**

		(Model 340 front panel button)
		Loop 1
		Control Channel
Loop 1 Channel:	**A**	Enter
		Loop 1
		Setpoint
Setpoint:	0.000 K	Enter

- **Loop 2**

		(Model 340 front panel button)
		Loop 2
		Control Channel
Loop 2 Channel:	**B**	^ Enter
		Loop 2
		Setpoint
Setpoint:	0.000 K	Enter

- **Control Setup**

		(Model 340 front panel button)
		Control Setup
Loop:	**1** Control Setup	Enter
Enable:	**ON**	Enter
Power Up:	OFF	Enter
Setup Unit:	TEMP K	Enter
Htr Ω:	**50**	50 Enter
Control Mode:	Manual PID	Enter
Filter:	OFF	Enter
		Save Screen
		<MORE>
Loop:	**1** Control Limits	Enter
Temp:	**400 K**	400 Enter
+slope:	0.0%	Enter
- slope:	0.0%	Enter
Max Htr I:	1.00 A	Enter
Max Range:	50 W	Enter
		Save Screen
		<MORE>
		Control Setup
Loop:	**2** Control Setup	^ Enter
Enable:	**ON**	^ Enter
Power Up:	OFF	Enter
Setup Unit:	TEMP K	Enter
Control Mode:	Manual PID	Enter
Filter:	OFF	Enter
		Save Screen
		<MORE>
Loop:	**2** Control Limits	Enter
Temp:	**400 K**	400 Enter
+slope:	0.0%	Enter
- slope:	0.0%	Enter
		Save Screen, Save Screen

Table 4-35. Model 340 Software Domain settings for the 9500 FCSM when temp. setpoint is *increasing*

	Domain #						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Begin T [K]	0	2	6	12	50	120	310
End T [K]	2	6	12	50	120	310	400
Ramp Rate [K/min]	3	3	3	10	15	15	10
Loop 1 Heater Power (range)	0	3	4	4	5	5	5
Loop 2 Heater Power (range)	1	1	1	1	1	1	1
Sample Space Valve During Ramp	√	√					
Sample Space Valve After Ramp	√	√					
Needle Valve Setting During Ramp	0	20	20	20	20	20	5
Needle Valve Setting After Ramp	0	20	20	20	20	20	5
Loop 1 P	0	0	300	500	500	300	300
Loop 1 I	0	0	0	0	0	100	100
Loop 1 D	0	0	2	5	5	25	20
Loop 2 P	40	40	60	60	150	400	400
Loop 2 I	300	600	330	330	330	300	300
Loop 2 D	1	1	5	5	10	50	50
First: Wait Time [min]	5	4	5	2	2	2	3
Second: Function, Relationship, Value	*<0.01	*<0.01	*<0.01	*<0.01	*<0.01	*<0.01	*<0.01
Third: Wait Time [min]	2		2	2	2	2	3

* Function: Sample Drift

5. **Start up only the CryoModel 340 software driver program** and display the virtual front panel. The channels should be assigned as follows:
   Control = A
   Sample = B
6. Select menu item: Utilities -> Domain File Name and input a file name. A suggested format is: **9500TC_A.ini** to indicate **9500 T**emperature **C**ontrol, set **A**. Change the last letter for variations such as a set of domains with shorter settle times when temperature accuracy is not as important. Note that this temperature control domain file will be located in the Windows directory.
7. Select menu item: Utilities -> Domains and input the data from Table 4-35 and Table 4-36.
8. Select menu item: Loop 2 and make sure the Lock Set Point item is checked (select it if it is not checked). This causes the set points of the two temperature control loops to be the same at all times.
   √ Lock Set Point
9. Close the CryoModel 340 software front panel.
10. Select menu item: File > Save As… and enter a file name. A suggested format is: "**9500_S1.34c**" used here to mean the **9500 S**ample insert number **1**. A unique name must be used if more than one Sample Insert, each with its own calibrated sensors, will be used. If more than one sample insert will be used they can be numbered for identification.The .34c extension indicates that this is a Model 340 temperature controller configuration file.

11. For each additional sample insert, do the following:
    - Step 3, Exit the Model 340 software program.
    - Step 4, Input Setup.
    - Step 5, Start up CryoModel 340 software program and check Control and Sample channels.
    - Step 8.
    - Step 9.
12. Check that the configuration files were saved. Select menu item: File -> Load. A dialog box appears with a list of Cryo340 configuration files (.34c extensions). Click Cancel, or select a configuration file to load and click OK. This step is performed as part of normal sample module operation in section 4.2.3.3 Verify Temperature Controller Setup.
13. Exit the CryoModel 340 software program.

Table 4-36. Model 340 Software Domain settings for the 9500 FCSM when temp. setpoint is *decreasing*

	Domain #						
	8	**9**	**10**	**11**	**12**	**13**	**14**
Begin T [K]	2	6	12	50	120	310	400
End T [K]	0	2	6	12	50	120	310
Ramp Rate [K/min]	3	3	3	10	13	13	15
Loop 1 Heater Power (range)	0	3	4	4	4	5	5
Loop 2 Heater Power (range)	1	1	1	1	1	1	1
Sample Space Valve During Ramp	√	√	√	√	√	√	√
Sample Space Valve After Ramp	√	√	√				
Needle Valve Setting During Ramp	0	20	300	300	200	150	100
Needle Valve Setting After Ramp	0	20	20	20	20	20	5
Loop 1 P	0	0	300	500	500	300	300
Loop 1 I	0	0	0	0	0	100	100
Loop 1 D	0	0	2	5	5	25	25
Loop 2 P	40	40	60	60	150	400	400
Loop 2 I	300	600	330	330	330	300	300
Loop 2 D	1	1	5	5	10	50	50
First: Wait Time [min]	5	2	2	1	3	4	4
Second: Function, Relationship, Value	*<0.01	*<0.01	*<0.01	*<0.01	*<0.01	*<0.01	*<0.01
Third: Wait Time [min]	2	1	1	1	2	2	3

* Function: Sample Drift

4.4.1.7 Temperature Controller Setup for the 9500-OVEN OFCSM Sample Insert

This procedure configures the Model 340 inputs for one platinum temperature sensor on the 9500-OVEN Sample Insert, and one loop temperature control.

A schematic of the control system is shown in Figure 4-32. Temperature sensor and heater physical locations are shown in Figure 4-36.

The sample is located on the end of the 9500-OVEN sample insert with the heater nearby. Many temperature sensors experience unacceptably large reading errors when operated in high magnetic fields at low temperatures. For this reason operation at high magnetic fields is not recommended below 100 K.

Refer to the Model 340 manual for further information on control theory and operation.

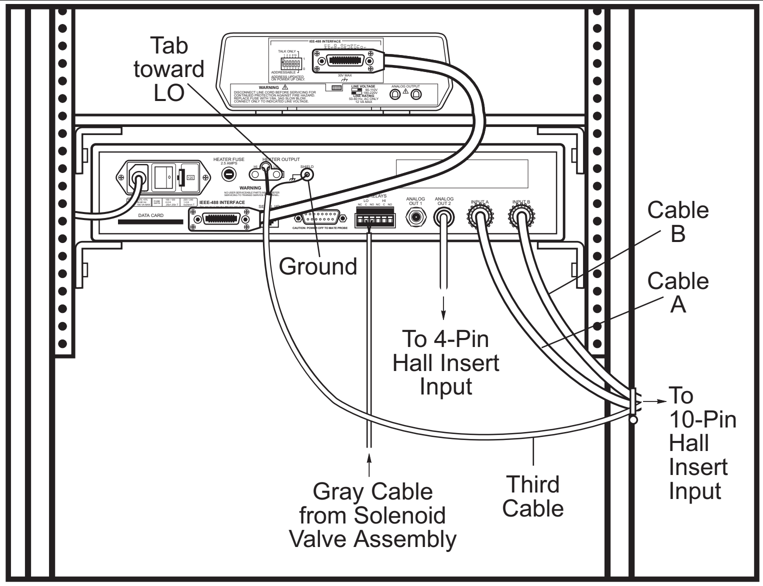


Figure 4-40. Typical Model 340 Connections to the Model 9500-OVEN OFCSM.

Following is the setup procedure:

1. Connect all cables listed in Table 4-37 (see Figure 4-24).
2. For Quick setup only: Skip the remainder of this section and proceed directly to Section 4.2.3.3. To determine if a quick setup is possible, check if a configuration file already exists. Use either Windows Explore and look in the IDEAHALL directory, or start the Model 340 program and select the menu item: File -> Load. Typical file names relevant to this sample module might look like "9500_OV1.34c". Note that some work can be saved by first loading a configuration file similar to one to be set up.
3. Exit any programs using the Model 340. The Model 340 must be in LOCAL mode to change settings through the front panel.

Table 4-37. Connection List for Model 340 to Model 9500-OVEN OFCSM

#	CONNECTION	FROM	TO
1	Auxiliary input cable, 655-451 (see Table 4-38)	(**G-16**) cable 6-pin circular connector **A** to Model 340 Channel **A** (**G-17**) cable 6-pin circular connector **B** to Model 340 Channel **B** (**G-5, 6**) Cable dual banana connector to Model 340 Heater Output, gnd tab to LO (**G-7**) Cable single banana connector to Model 340 Heater Output SHIELD	(**B-7**) Junction box of Sample Insert, 10-pin circular connector socket
2	Loop 2 Heater Output Cable: 4-pin circular connector to coaxial BNC (PN 655-450)	(**B-8**) Junction box of Sample Insert, 4-pin circular connector socket	(**G-15**) Model 340 Analog Out 2 (coaxial BNC)
3	Cable from cryostat to block connector	(**FC-8**) Sample space vacuum valve	(**G-13**) Model 340 Relay Out **LO**

Table 4-38. Cable 655-451 Wiring. Connects 9500 Sample Insert 10-pin connector (B-7) to Model 340

Connection	Pin	Use	Connection	Pin
B-7	**A**	V- temperature sensor output voltage (Channel **B**)	(**G-17**) on Model 340	**2**
	B	V+ temperature sensor output voltage (Channel **B**)		**4**
	C	I- temperature sensor excitation current (Channel **B**)		**1**
	J	I+ temperature sensor excitation current (Channel **B**)		**5**
	D	I+ Heater, 50 Ω	(**G-5, 6**) on Model 340	**Hi**
	E	I- Heater		**Lo**
	G	V- temperature sensor output voltage (Channel **A**)	(NOT USED)	**2**
	H	V+ temperature sensor output voltage (Channel **A**)		**4**
	F	I- temperature sensor excitation current (Channel **A**)		**1**
	K	I+ temperature sensor excitation current (Channel **A**)		**5**

4. Set up the Model 340 through the front panel as specified in the procedure below. For further information, refer to the Model 340 User's Manual and the Model 340 software help files. (For setup of a Model 330, refer to the Model 330 User's Manual.)

- **Input Setup**

		(Model 340 front panel button)
		Input Setup
Input:	**A**	Enter
Enable:	**ON**	^ Enter
Type:	**Plat. 100/250**	^ Enter
Curve:	**4 PT-100**	^ Enter
		Save Screen
Input:	**B**	^ Enter
Enable:	**ON**	^ Enter
Type:	**Plat. 100/250**	^ Enter
Curve:	**4 PT-100**	^ Enter
		Save Screen, Save Screen

- **Display Format**

		(Model 340 front panel button)
		Display Format
Input Displays:	**1**	^ Enter
Display 1:	A TEMP K	Enter
		Save Screen
		Display Format
		<MORE>
Control Loops:	**LOOP**	^ Enter
Large Output:	OFF	Enter
Heat Display:	**POWER**	^ Enter
		Save Screen

- **Interface**

		(Model 340 front panel button)
		Interface
IEEE-488		
Terminator:	CR LF	Enter
EOI:	ON	Enter
Address:	**14**	Enter
		Save Screen

- **Analog Outputs**

		(Model 340 front panel button)
		Analog Outputs
1:		Enter
Mode:	**OFF**	Enter
Bipolar:	**OFF**	Enter
		Save Screen
2:		^ Enter
Mode:	**OFF**	^ Enter
Bipolar:	**OFF**	Enter
		Save Screen, Save Screen

- **Loop 1**

		(Model 340 front panel button)
		Loop 1
		Control Channel
Loop 1 Channel:	**A**	Enter
		Loop 1
		Setpoint
Setpoint:	0.000 K	Enter

- **Loop 2** (not normally used)

		(Model 340 front panel button)
		Loop 2
		Control Channel
Loop 2 Channel:	**B**	^ Enter
		Loop 2
		Setpoint
Setpoint:	0.000 K	Enter

- **Control Setup**

		(Model 340 front panel button)
		Control Setup
Loop:	**1** Control Setup	Enter
Enable:	**ON**	^ Enter
Power Up:	OFF	Enter
Setup Unit:	TEMP K	Enter
Htr Ω:	**50**	50 Enter
Control Mode:	Manual PID	Enter
Filter:	OFF	Enter
		Save Screen
		<MORE>
Loop:	**1** Control Limits	Enter
Temp:	**600 K**	600 Enter
+slope:	0.0%	Enter
- slope:	0.0%	Enter
Max Htr I:	1.00 A	Enter
Max Range:	50 W	Enter
		Save Screen
		<MORE>
		Control Setup
Loop:	**2** Control Setup	^ Enter
Enable:	**OFF**	^ Enter
Power Up:	OFF	Enter
Setup Unit:	TEMP K	Enter
Control Mode:	Manual PID	Enter
Filter:	OFF	Enter
		Save Screen
		<MORE>
Loop:	**2** Control Limits	Enter
Temp:	**600 K**	600 Enter
+slope:	0.0%	Enter
- slope:	0.0%	Enter
		Save Screen, Save Screen

Table 4-39. Model 340 Software Domain settings for the 9500-OVEN OFCSM when temp. setpoint is *increasing*

	Domain #				
	1	**2**	**3**	**4**	**5**
Begin T [K]	0	60	150	300	425
End T [K]	60	150	300	425	600
Ramp Rate [K/min]	15	15	15	15	15
Loop 1 Heater Power Range	4	5	5	5	5
Loop 2 Heater Power Range	0	0	0	0	0
Sample Space Valve open During Ramp					
Sample Space Valve open After Ramp					
Needle Valve Setting During Ramp	40	30	20	10	0
Needle Valve Setting After Ramp	20	20	20	10	0
Loop 1 **P**	100	25	20	30	30
Loop 1 **I**	50	10	10	15	15
Loop 1 **D**	50	15	0	0	0
Loop 2 **P**	0	0	0	0	0
Loop 2 **I**	0	0	0	0	0
Loop 2 **D**	0	0	0	0	0
First: Wait Time [min]	4	4	10	10	10
Second: Function, Relationship, Value	* < 0.01	* < 0.01	* < 0.01	* < 0.01	* < 0.01
Third: Wait Time [min]	2	2	2	2	2

* Function: Sample Drift

5. **Start up only the CryoModel 340 software driver program** and display the virtual front panel. The channels should be assigned as follows:
   Control = A
   Sample = B
6. Select menu item: Utilities -> Domain File Name and input a file name. A suggested format is: **9500TC_A.ini** to indicate **9500 T**emperature **C**ontrol, set **A**. Change the last letter for variations such as a set of domains with shorter settle times when temperature accuracy is not as important. Note that this temperature control domain file will be located in the Windows directory.
7. Select menu item: Utilities -> Domains and input the data from Table 4-39 and Table 4-40.
8. Select menu item: Loop 2 and make sure the Lock Set Point item is checked (select it if it is not checked). This causes the set points of the two temperature control loops to be the same at all times.
   √ Lock Set Point
9. Close the CryoModel 340 software front panel.
10. Select menu item: File > Save As… and enter a file name. A suggested format is: "**9500_S1.34c**" used here to mean the **9500 S**ample insert number **1**. A unique name must be used if more than one Sample Insert, each with its own calibrated sensors, will be used. If more than one sample insert will be used they can be numbered for identification.The .34c extension indicates that this is a Model 340 temperature controller configuration file.

11. For each additional sample insert, do the following:
    - Step 3, Exit the Model 340 software program.
    - Step 4, Input Setup.
    - Step 5, Start up CryoModel 340 software program and check Control and Sample channels.
    - Step 8.
    - Step 9.
12. Check that the configuration files were saved. Select menu item: File -> Load. A dialog box appears with a list of Cryo340 configuration files (.34c extensions). Click Cancel, or select a configuration file to load and click OK. This step is performed as part of normal sample module operation in section 4.2.3.3 Verify Temperature Controller Setup.
13. Exit the Cryo340 software program.

Table 4-40. Model 340 Software Domain settings for the 9500-OVEN OFCSM when temp. setpoint is *decreasing*

	Domain #				
	6	**7**	**8**	**9**	**10**
Begin T [K]	60	150	300	425	600
End T [K]	0	60	150	300	425
Ramp Rate [K/min]	15	15	15	15	15
Loop 1 Heater Power Range	4	5	5	5	5
Loop 2 Heater Power Range	0	0	0	0	0
Sample Space Valve open During Ramp	√	√	√	√	
Sample Space Valve open After Ramp					
Needle Valve Setting During Ramp	300	300	100	50	20
Needle Valve Setting After Ramp	20	20	20	10	0
Loop 1 **P**	100	25	20	30	30
Loop 1 **I**	50	10	10	15	15
Loop 1 **D**	50	15	0	0	0
Loop 2 **P**	0	0	0	0	0
Loop 2 **I**	0	0	0	0	0
Loop 2 **D**	0	0	0	0	0
First: Wait Time [min]	4	4	10	10	10
Second: Function, Relationship, Value	* < 0.01	* < 0.01	* < 0.01	* < 0.01	* < 0.01
Third: Wait Time [min]	2	2	2	2	2

* Function: Sample Drift

4.4.1.8 Removal, Storage and Shipping

Removal of the 9500 FCSM from the dewar:

1. None required.

Storage:

1. Store vertically in the dewar or on a stand.
2. Short term (less than one month) storage on a horizontal surface is also possible.

Shipping:

1. Package 9500 FCSM for shipping. Box upright in the dewar.

4.4.2 Sample Mounting

4.4.2.1 Sample Mounting on the Model 9500 FCSM Sample Insert

Mount samples by following the Model 75013 SCSM sample mounting instructions given in section 4.1.2 with the following exceptions:

1. The sample mounting portion of the Model 9500 FCSM Sample Insert is permanently attached, not removable like the Sample Card used in the Model 75013 SCSM.
2. The sample mounts in the center of a sapphire mounting plate centered between solder posts. Glue the sapphire mounting plate to the G-10 plate with rubber cement. Normally, it should not be removed.The solder posts around the sapphire mounting plate are not numbered, but are laid out in the same pattern and orientation as the numbered triaxial bulkhead connectors on the Sample Insert junction box (see Figures 4-19 or 4-20). The figure on the cover of the junction box shows connections to two common sample geometries (van der Pauw square and 1-3-3-1 Hall bar).
3. There is no sample identification space on the Model 9500 FCSM Sample Insert sample mounting plate. If desired, attach a removable note to the Sample Insert junction box with the sample identification and other relevant information.

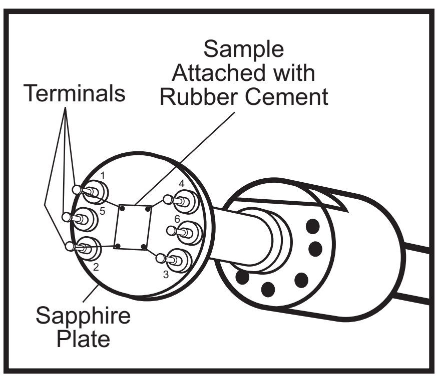


Figure 4-41. Mounting a Sample on a Model 9500 FCSM Sample Insert

4.4.2.2 Sample Mounting on the Model 9500-OVEN OFCSM Sample Insert

Mount samples in the 9500-OVEN using the following procedure:

1. Mount the sample to an alumina sample card using a thin trace of silver paint to connect each corner of the sample to a corner gold pad. Also cover the gold pads with silver paint.
2. Use more silver paint to attach the two alumina plates to the bottom of the sample card.
3. Remove the outer tube from the Sample Insert. Remove the two #2-56 screws holding the sample block to the heater block and place the sample block on a table with the scribed rectangle up.
4. Use silver paint to attach the alumina plate stack (and sample) to the sample block, aligning carefully with the scribed rectangle. Allow silver paint to dry.

5. Reattach the sample block to the heater block. Make sure the pogo pins in the heater block make contact with the gold pads on the sample card. Check connection with a voltmeter.
6. Slide outer tube over sample holder until bayonet pins slide completely into slots.

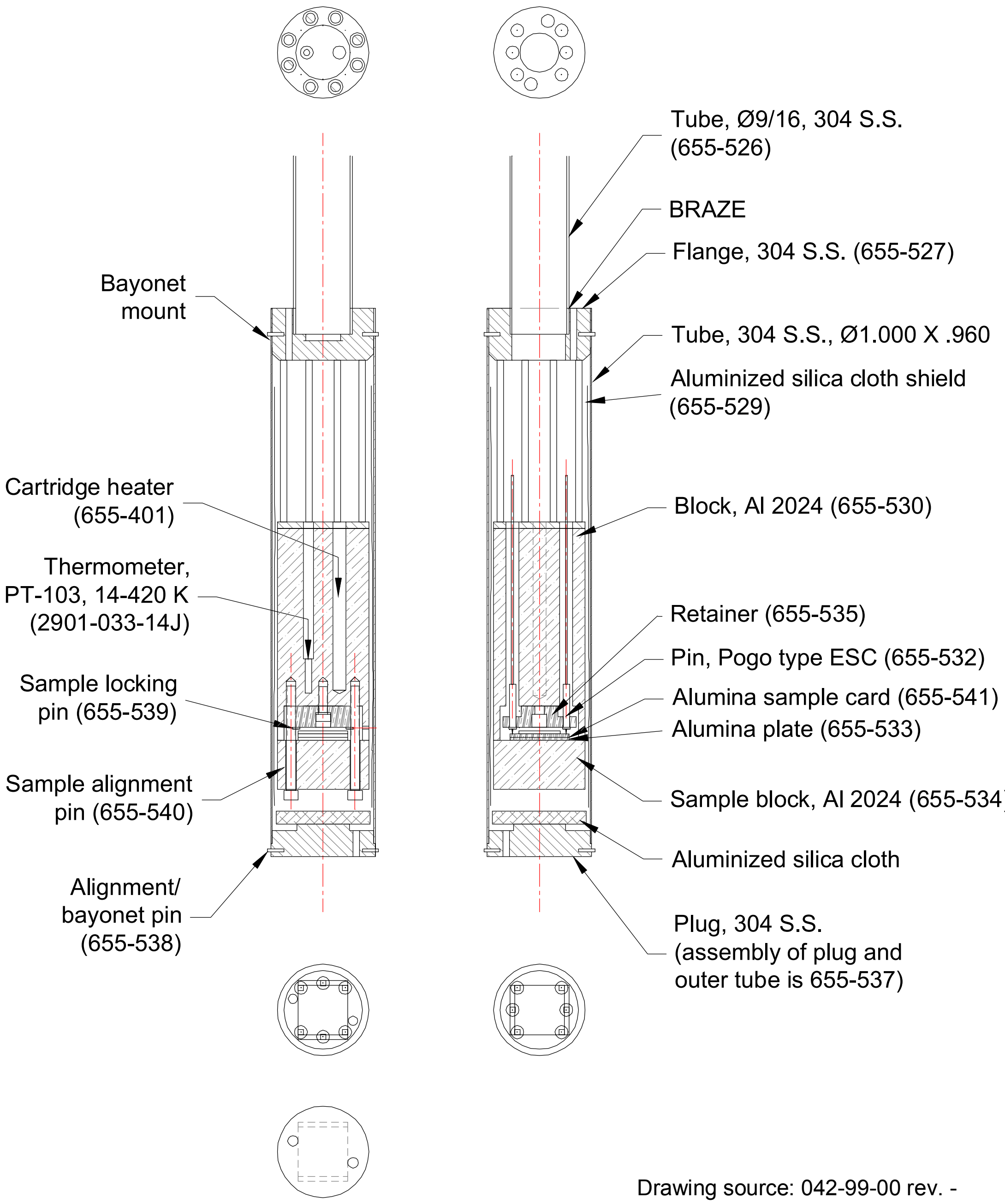


Figure 4-42. Mounting a Sample in a Model 9500-OVEN OFCSM Sample Insert

4.4.3 Operation of the Model 9500 FCSM

This section provides instructions for the APD Omniplex™ Top Loading Exchange Gas Cryostat. This module is designed for more sophisticated temperature control.

4.4.3.1 Liquid Helium Transfer to Dewar

WARNING:

- **Liquid helium and liquid nitrogen are potential asphyxiants and can cause rapid suffocation without warning. Store and use 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.**
- **Refer to Section 2.7.1 for further safety information before proceeding.**

The economical transfer of liquid helium depends upon technique. Too rapid a transfer results in excessive "blow-off" or waste of liquid. It is much more economical to pre-cool the dewar first with liquid nitrogen then cold helium vapor, than to simply vaporize liquid helium. For an efficient transfer, use one of the two following transfer procedures: Warm or Cold Dewar.

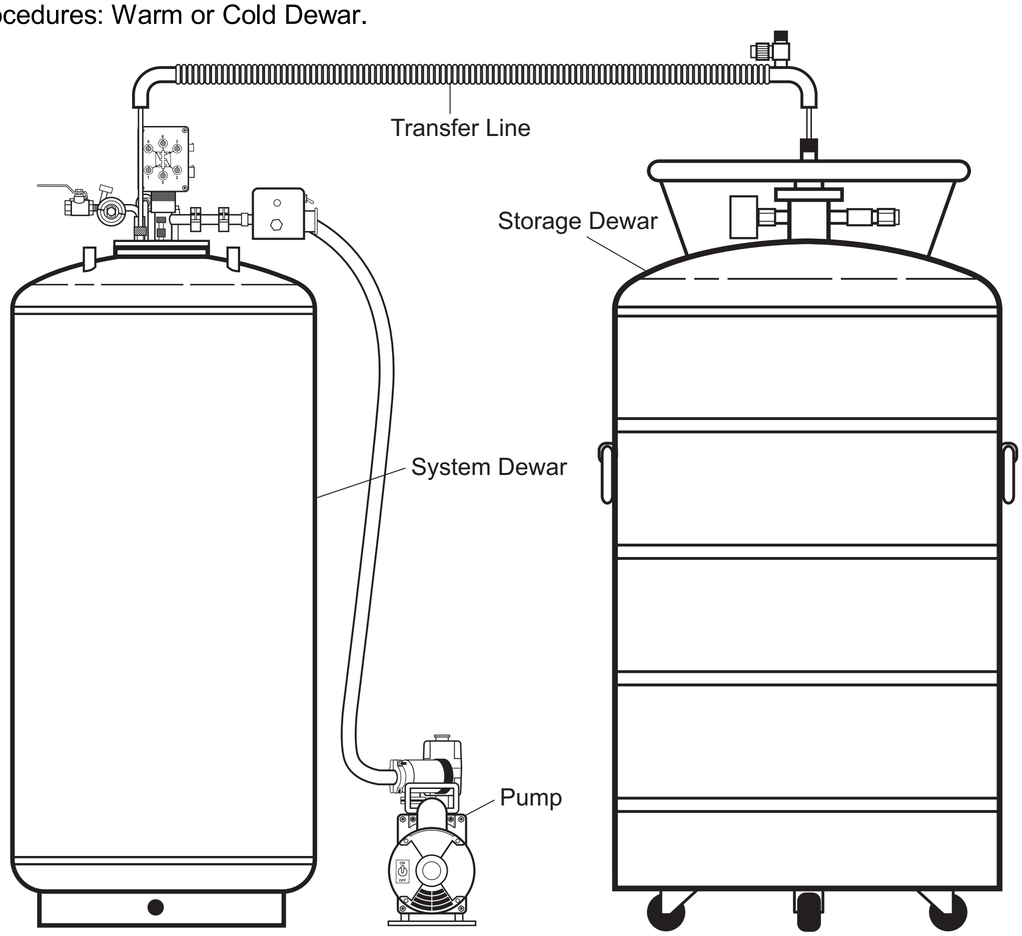


Figure 4-43. Typical Liquid Helium Filling

4.4.3.1.1 LHe Transfer to Warm Dewar

If the system is at room temperature or has **no liquid helium** in the dewar, perform the following warm transfer procedure. Please read all the steps before performing the procedure.

NOTE: Pre-cooling the dewar with liquid nitrogen is recommended if the cost of liquid helium is more important than the extra cooldown time required.

1. Open the Vent Valve to release any helium pressure in the system dewar during transfer.
2. Insert one end of transfer line into liquid helium storage dewar. Position the end of the transfer line a few inches above the dewar bottom.
   CAUTION: To prevent rapid pressure build-up, open Vent Valve and insert transfer line slowly into dewar. Venting excessive gas is usually necessary during initial transfer line insertion.
3. Remove cryostat transfer port plug and insert other end of transfer line into cryostat transfer port. Position end of transfer line a few inches above the magnet dewar bottom. Total length is 54 inches.

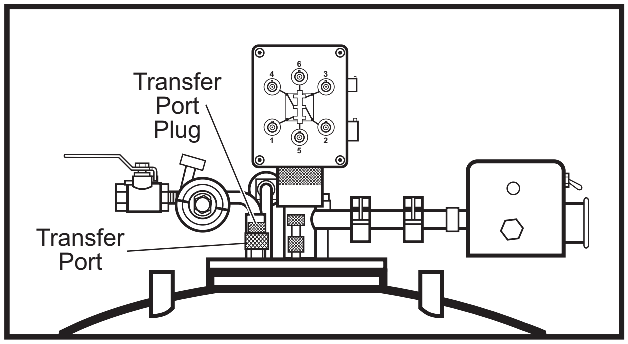


Figure 4-44. Transfer Port and Plug

4. Transfer slowly. Simply sealing/closing storage dewar and allowing transfer to proceed under ambient pressure is often sufficient for initial phase.
5. After the transfer starts, allow about 15 minutes for helium gas to totally flush the dewar. Then open the Solenoid Assembly Valve and crack open the needle valve a bit.
   NOTE: Calibrate the Model 241 liquid helium level monitor for an 11-inch probe. See the Model 241 Liquid Helium Level Monitor User's Manual for further information.
6. It takes about 2 to 3 hours to bring system temperature from room temperature to under 40 K. (Allow 4 to 6 hours for 9 tesla systems.) Since the Model 241 Level Monitor uses a superconductive probe, it makes no level readings until dewar temperature is <10 K. When temperature nears 4.2 K (or as needed), apply pressure to storage dewar to force liquid helium over. Typically, 1 to 5 psi (7 to 35 kPa) pressure is enough to transfer helium. Monitor helium level indicator and fill to desired level. The standard helium capacity is about 40 liters at a depth of 11 inches (27.9 cm). This stage requires about 15 to 30 minutes.
   NOTE: Helium transfer efficiency depends on the combined properties of the storage dewar, transfer line, and receiving dewar. Each user determines the optimum transfer characteristics for their type of storage dewar and transfer line as they relate to the 9500 System. In an efficient transfer, a 40 liter dewar requires about 75 liters for initial filling.
7. Remove both ends of transfer tube. Wear cryo-gloves when performing this operation.
   CAUTION: After a lengthy transfer, ice build-up may prevent removal of the deflection tube or immediate replacement of the transfer port plug. A gentle hot air gun can be used to warm the fill opening and melt the ice. Do *not* over-heat.
8. Firmly plug transfer port and close Vent Valve to ensure proper gas flow through vapor-cooled leads and prevent air condensation inside dewar.

4.4.3.1.2 LHe Transfer to Cold Dewar

If the system already has liquid helium in the dewar, follow the procedure below to perform a cold transfer. Read all steps before performing the procedure.

1. Open the Vent Valve to release any helium pressure in the dewar during transfer.
2. Insert one end of transfer line into liquid helium storage dewar. Position the end of the transfer line a few inches above the dewar bottom.
3. Remove the system dewar transfer port plug. Apply pressure (if required) to storage dewar while watching exposed end of transfer line. When a sputtering sound is heard and a vapor cloud forms at end of transfer line, insert it into the transfer port of the system dewar. The transfer line must be long enough to reach the

"belly" of dewar (30 inches; 76 cm), but should not extend below the existing helium level.
CAUTION: To prevent pressure build-up, open Vent Valve when inserting transfer line into dewar. Warm transfer line insertion causes existing liquid helium to boil off.

4. Set the Model 241 Level Monitor in continuous reading mode by pushing the down-arrow button.
5. Transfer and fill dewar to desired level by pressurizing storage dewar. A cold transfer takes 15 to 30 minutes to fill the dewar.
6. Remove both ends of transfer tube. Wear cryo-gloves when performing this operation.
CAUTION: After a lengthy transfer, ice build-up may prevent removal of the deflection tube or immediate replacement of the transfer port plug. A gentle hot air gun can be used to warm the fill opening and melt the ice. Do *not* over-heat.
7. Firmly plug transfer port and close Vent Valve to ensure proper gas flow through vapor-cooled leads and prevent air condensation inside system dewar.

4.4.3.2 Sample Insert Insertion

Use the procedure below in loading the Sample Insert to avoid contamination or condensation from air.

Use the procedure below to remove a cold Sample Insert from the Model 9500 FCSM.

1. Wait until the Sample Insert is dry before inserting in the cryostat. Blow dry with a hot air gun, if desired, but do not overheat.
2. Verify that the Heater is OFF. Do this by opening the Model 340 program Front Panel and clicking on the heater power level until OFF is displayed.
3. Plug the temperature control cables into the Sample Insert Junction Box 4-Pin and 10-Pin connectors.
4. Check that the red Solenoid Valve LED is **OFF**. If it is on, turn it off by doing the following: Open the Model 340 program. Click the Solenoid Valve button on the Toolbar to shut off the Solenoid Valve. **NOTE:** clicking this button toggles the valve open or closed.
5. Flip the Solenoid Assembly Flush Switch to FLUSH.
6. Remove the Sample Space Cap.
7. Insert the Sample Insert into the cryostat quickly and lock in position with the front of the junction box (side with the triaxial connectors) facing away from the LHe fill port.
8. Turn the Solenoid Assembly Flush Switch forward **away** from FLUSH.
9. Open the Model 340 program. Click the Solenoid Valve Toolbar button to turn on the Solenoid Valve on for about 5 seconds. This removes air from the sample space. Click the Solenoid Valve Toolbar button a second time to shut off the Solenoid Valve. Check that the red Solenoid Valve LED is **OFF**.
10. Verify that the red light on the solenoid valve housing is not lit, indicating that the valve is closed between the vacuum pump and the sample space.
11. In the Model 340 program, begin ramping to the desired starting temperature by following the menu: Utilities -> Ramp to Temperature, and input the temperature setpoint.

4.4.3.3 Sample Insert Cable Connections

Plug all sample cables into the Sample Insert Junction Box (#1-#6).

The 4 or 6 triaxial sample cables should already have a protective sleeve plus a short section of spiral cable wrap near the sample end. This strain relieves the cables, but additional tiedowns or restraints might be helpful.

4.4.3.4 Verify Temperature Controller Setup

The temperature controller must be set up for the Sample Module in use. If no temperature controller configuration file exists, create one (see section 4.4.1.6). Note that there is no indication of the current configuration.

1. Start the Model 340 software driver program on the computer and load the appropriate configuration file. To do this, select the menu item: File -> Load. A dialog box will appear with a list of configuration files (.34c extensions). Select one and click on OK. The Model 340 will be configured, but there is no indication of the current configuration.
2. Open the Front Panel and check that the input channels are reading properly and assigned as follows:
   Control = A
   Sample = B

4.4.3.5 Temperature Control Parameters

Choosing temperature control parameters always requires a compromise between the desires for rapid temperature changes and good stability and accuracy with little temperature overshoot or oscillation.

The temperature control domain parameters suggested in the section on setting up the Model 340 temperature controller were chosen for slow, controlled temperature changes with little overshoot or oscillation. If faster temperature changes are desired, first try setting the second wait times in the Domains to zero. Additional optimization can be performed by following the procedures described in the Model 340 User's Manual.

4.4.3.6 Cooling to Liquid Helium Temperatures

Procedure:

1. Go to 4 K setpoint.
2. Open needle valve to fill sample space with liquid helium.
3. Ramp to desired temperature. The program will close the needle valve at this time and open the Sample Space Valve to pump on the liquid helium inside.

The lowest temperatures can be held until the liquid helium in the sample space is all gone – from a few minutes to a day, depending on how much liquid was accumulated in the sample space before beginning the ramp to the final temperature.

4.4.3.7 Sample Insert Removal

Use the procedure below to remove a cold Sample Insert from the Model 9500 FCSM.

1. Check that the red Solenoid Valve LED is off. If it is on, turn it off by doing the following: Open the Model 340 program. Click the Solenoid Valve button on the Toolbar to shut off the Solenoid Valve. **NOTE:** Clicking this button toggles the valve open or closed.
2. Verify that the red light on the solenoid valve housing is not lit, indicating that the valve is closed between the vacuum pump and the sample space.
3. In the Model 340 program, check that the following menu item is checked: Loop 2 ->lock setpoint.
4. Enter 300 K as the setpoint.
5. Set the Heater Range to 5 and wait for the temperature to reach the 300 K setpoint.
6. Unplug all sample cables from the Sample Insert Junction Box (#1-#6). Do not unplug the cables connected to the 4-Pin or 10-Pin connectors used to monitor and control temperature.
7. Turn the Solenoid Assembly Flush Switch to FLUSH.
8. Twist Sample Insert junction box in the rotation stage to release the bayonett lock.
9. Withdraw the Sample Insert from the cryostat quickly. **CAUTION:** Do not touch the sample insert tube with bare hands – it might be extremely cold.
10. Replace the Sample Space Cap quickly to minimize the amount of air introduced to the sample space.
11. Turn the Solenoid Assembly Flush Switch forward **away** from FLUSH.

12. Open the Model 340 program. Click the Solenoid Valve Toolbar button to turn on the Solenoid Valve on for about 5 seconds. This removes air from the sample space. Click the Solenoid Valve Toolbar button a second time to shut off the Solenoid Valve. Check that the red Solenoid Valve LED is **OFF**.
13. Turn the Heater OFF. Do this by opening the Model 340 program Front Panel and clicking on the heater power level until OFF is displayed.
14. Unplug the temperature control cables connected to the Sample Insert Junction Box 4-Pin and 10-Pin connectors.
15. Wait until the Sample Insert is dry before removing or mounting samples. Blow dry with a hot air gun, if desired, but do not overheat.

4.4.4 Service and Maintenance for the Model 9500 FCSM

4.4.4.1 Leakage Resistance and Shielding

Measurement of very high resistance samples (>10 MΩ) requires very high resistance between all combinations of signal, guard and ground. The following procedure is possible only with measurement instrumentation that drives the guards around the signal lines (-HVWR or -LVWR).

1. Measure the resistance of the Sample Insert without any sample mounted. If necessary, first clean the sample mounting area with isopropyl alcohol and demineralized water, then blow dry with warm air from a heat gun. Install the Sample Insert in the OmniPlex sample well. Measure the resistance (R14,23) in high resistance mode using the Resistance software program.
2. The resistance should be significantly greater than the specified maximum accurately measurable resistance of the measurement system. Note that a leakage resistance of 100 times the maximum sample resistance would lead to a 1% measurement error.
3. If the resistance is low, check the resistance between signal and guard and between guard and ground. A convenient place to do this is at the connectors on the junction box. Likely places to look for shorts are a) the connections between the coaxial cable and the bulkhead connectors, b) the connections to the solder posts, and c) the region between the solder posts. Look for stray wires or improperly cleaned connections.

4.4.4.2 Sapphire sample plate replacement

Clean sapphire plate and sample mounting plate region between the solder posts. If the original sapphire plate is cracked or damaged, order a replacement (Lake Shore part number 672-210) or make a similar sample mounting plate from sapphire. Apply a small amount of rubber cement to the rougher side, center between the solder posts, and press down so the rubber cement fills the gap between the sapphire plate and the metal surface. Allow to dry, then remove any excess rubber cement.

4.4.4.3 Incorrect Temperature Readings

Check the temperature controller setup for proper sensor type and calibration curve.

Check electrical connections and cables.

Check that the temperature sensor on the Sample Insert is epoxied to the back of the sample mounting plate. If the temperature sensor has detatched, epoxy it back in place using a very small amount of epoxy - the epoxy should not form a fillet on the sides.

If necessary, replace the temperature sensor. Contact Lake Shore to order a replacement and for replacement instructions.

4.4.4.4 Insufficient Heating

Check the heater resistances at the connectors on the junction box and verify that they are correct. Burned out heaters can be replaced in the field. To replace Loop 1 heater, contact Lake Shore Service for instructions and replacement heater. To replace Loop 2 heater, refer to instructions for Loop 2 Heater Replacement.

Check cables back to the temperature controller and power booster.

Verify output from the temperature controller and power booster.

The highest temperatures can not be reached if the liquid helium level is near its maximum. Wait until the liquid helium level drops below 50% and try again.

If a desired setpoint can not be reached after operation in the liquid helium temperature range, the sample space might have liquid helium in the bottom. Close the needle valve (use the 4-Axis Controller program) and open the sample space valve, then wait until the liquid helium boils off before continuing the ramp to the desired temperaure

4.4.4.5 Loop 2 Heater Replacement

Order a replacement heater resistor.

Clip off old heater leads close to the resistor.

Drill out the old heater resistor.

Epoxy new heater resistor in place. Use a high temperature epoxy capable of withstanding 450 K.

Solder leads and insulate with Teflon or Kynar heat shrink tubing.

Make sure all leads are secured.

4.4.4.6 Insufficient Cooling

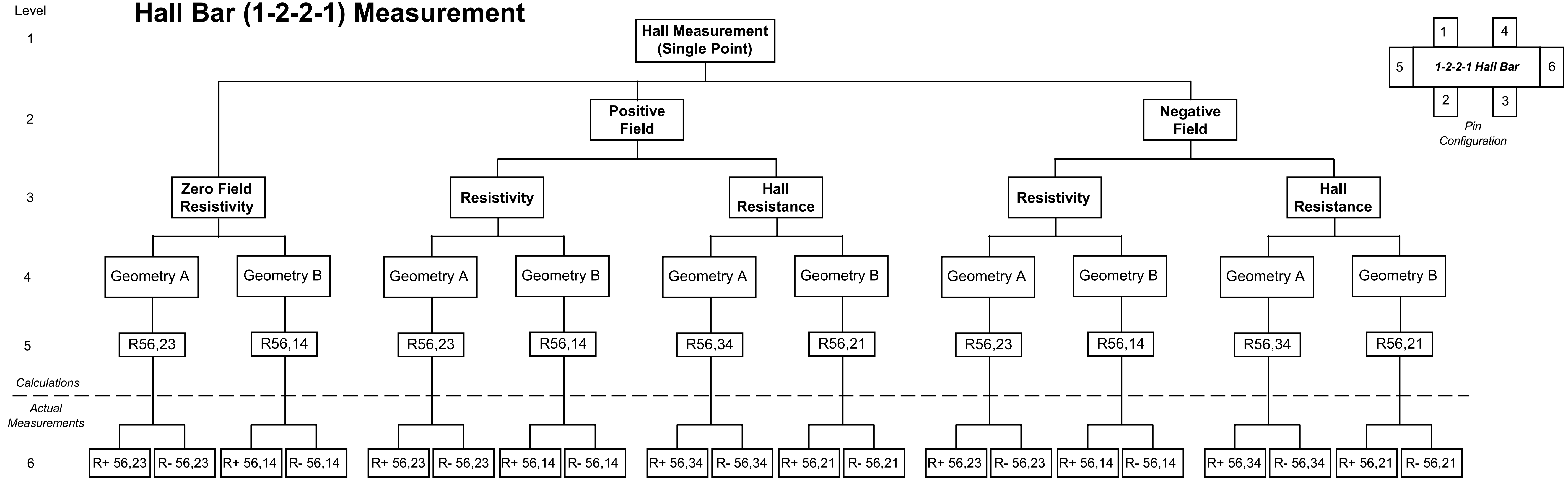
Needle valve stepper motor zero location not set properly.

Water or air frozen in the needle valve line. Warm up dewar and make sure to use vacuum pump to evacuate the sample space during cooldown.

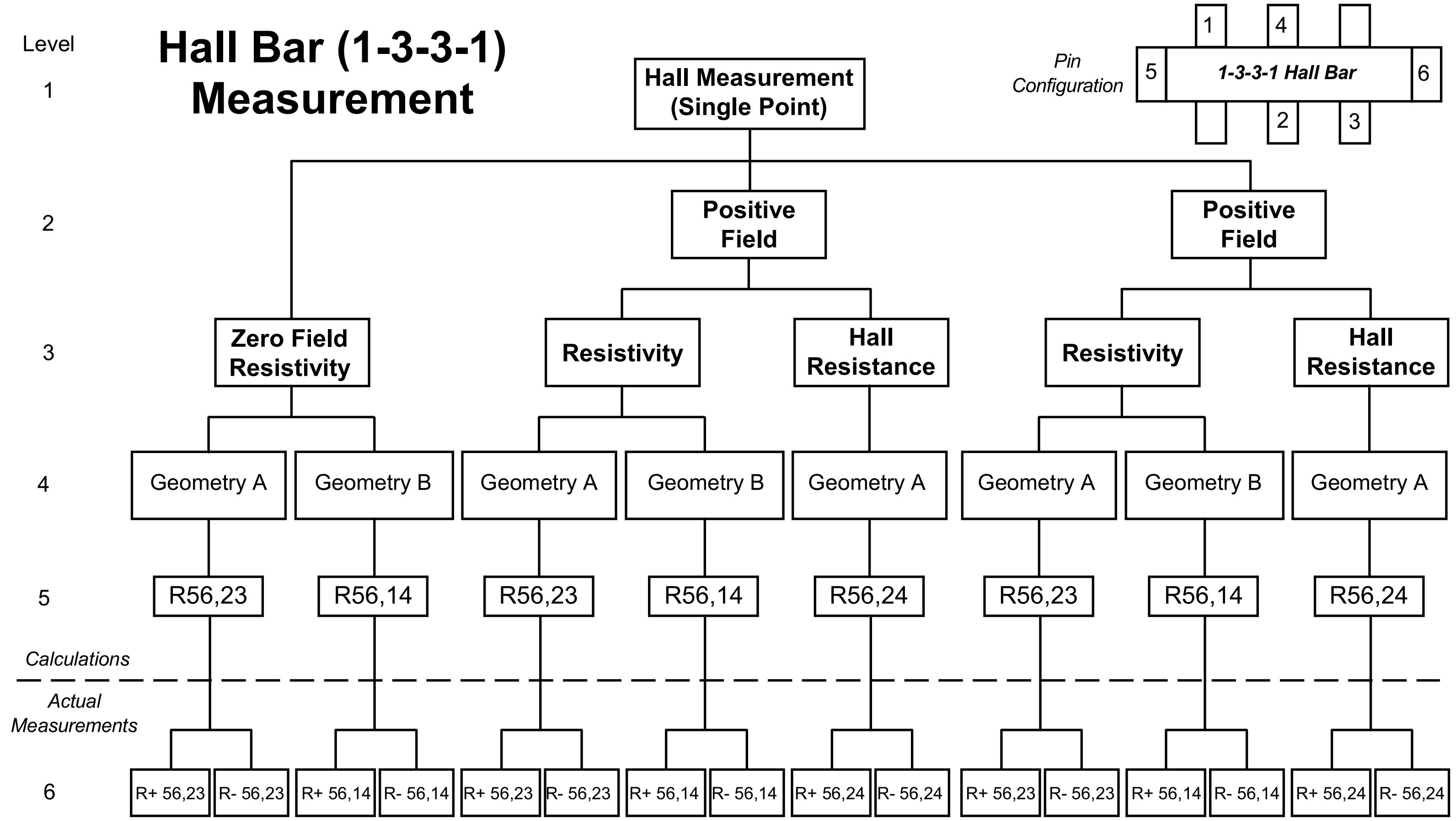
4.4.4.7 Vacuum Problems

Refer to the dewar manual or contact Lake Shore Service.

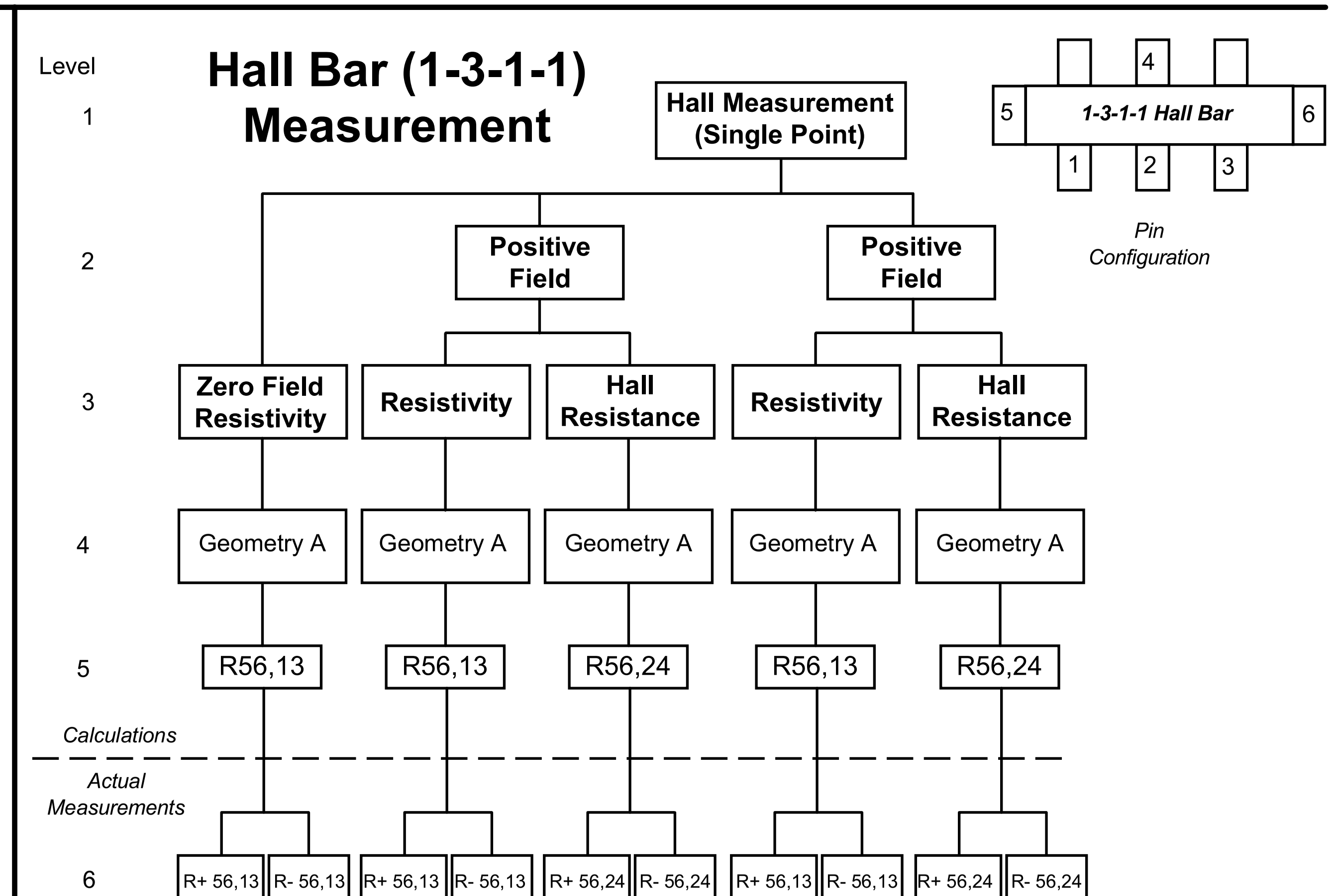
Hall Bar (1-2-2-1) Measurement

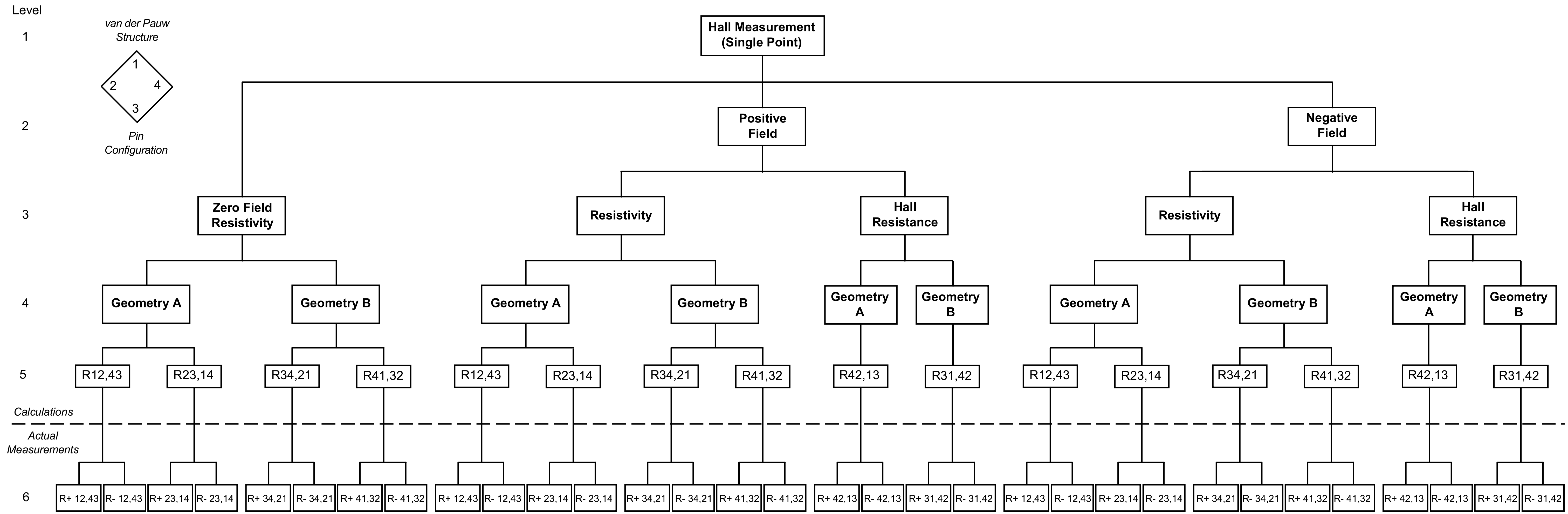


Hall Bar (1-3-3-1) Measurement



Hall Bar (1-3-1-1) Measurement





Accessing and Displaying Measurement Details

For each point in a Hall experiment, up to 32 individual resistance measurements will be made. Each van der Pauw resistivity requires 8 measurements, and the Hall resistance requires 4 measurements (with both geometric configurations selected). For a temperature dependent measurement, the zero field resistivity is measured at each temperature. The measurement sequence (for all options selected) is:

Temperature Dependent Measurement:

1. Measure zero field resistance (8 measurements).
2. Measure Hall resistance at +B (4 measurements).
3. Measure resistivity at +B (8 measurements).
4. Measure Hall resistance at -B (4 measurements).
5. Measure resistivity at -B (8 measurements).

Magnetic Field Dependent Measurements:

Measure zero field resistivity once (8 measurements) for each field:

1. Measure Hall resistance at +B (4 measurements).
2. Measure resistivity at +B (8 measurements).
3. Measure Hall resistance at -B (4 measurement).
4. Measure resistivity at -B (8 measurements).

As shown above, this can be represented as a 6-level tree. From the Hall experiment program a User can select a menu item to display details. After selecting the point of interest, the User is shown a dialog box display the information in the top level of the tree. This is the field average Hall results, density, mobility, hall coefficient.

van der Pauw Structure Single-Point Hall Measurement

CHAPTER 5

SYSTEM OPERATION

Chapter Table of Contents

Paragraph ***Title*** ***Page***

Chapter Table of Contents (Continued)

5.0 GENERAL

This chapter provides introductory information for the Lake Shore Hall Measurement Software. An introduction is provided in Paragraph 1.1, an overview of the software is provided in Paragraph 1.2, Hall measurement system interactions are detailed in Paragraph 1.3, a procedure for installing new Hall System Software is provided in Paragraph 1.4, minimum hardware requirements are detailed in Paragraph 1.5, minimum software requirements are detailed in Paragraph 1.6, and how to launch the software is described in Paragraph 1.7.

5.1 INTRODUCTION TO HALL SOFTWARE

Lake Shore is an international leader in the development of innovative measurement and control technologies. Our broad range of products includes cryogenic temperature sensors and instrumentation, magnetic measurement system products, Hall effect systems, benchtop and hand-held gaussmeters and Hall probes, electromagnets and magnet power supplies.

Lake Shore combines its established line of magnetic instrumentation and custom software with Keithley precision electronics to create an advanced Hall Effect Measurement System capable of meeting any measurement need.

Hall effect and related electronic transport measurements of bulk and thin film materials increase in importance as the demand to evaluate new materials and improve process quality increases. Such measurements are vital to characterize properties of many semiconductor materials such as Si, Ge, GaAs, GaN, AlGaAs, CdTe, HgCdTe, as well as magnetoresistors, GMR films, and high temperature superconductors. Gain additional information by taking transport Hall effect measurements as a function of magnetic flux density or temperature. Transport measurements of Hall effect and magnetoresistance are ideally suited for quality control, research and development, and production testing.

The 7500/9500 Series Hall Effect/Electronic Transport Measurement System is an advanced integrated hardware and software system designed to characterize and analyze the electronic transport properties of materials. Designed for easy and precise operation, the 7500/9500 Series System Software controls both temperature and magnetic flux density while measuring a sample material.

Fully integrated with Hall System Software, the 7500/9500 Series is easy to operate. Hall System Software controls system instrumentation throughout an experiment and determines sample resistance, resistivity, Hall coefficient, Hall mobility, carrier concentration, and current voltage characteristics.

Instrument Driver for Experimental Applications Software (IDEAS™) for Windows® is a set of Microsoft Windows-based programs for the measurement and analysis of Hall voltage, resistance, resistivity, carrier concentration and mobility, magnetoresistance, current-voltage characteristics, and contact quality, on samples with four-lead van der Pauw or six-lead Hall bar geometries.

5.1.1 Overview

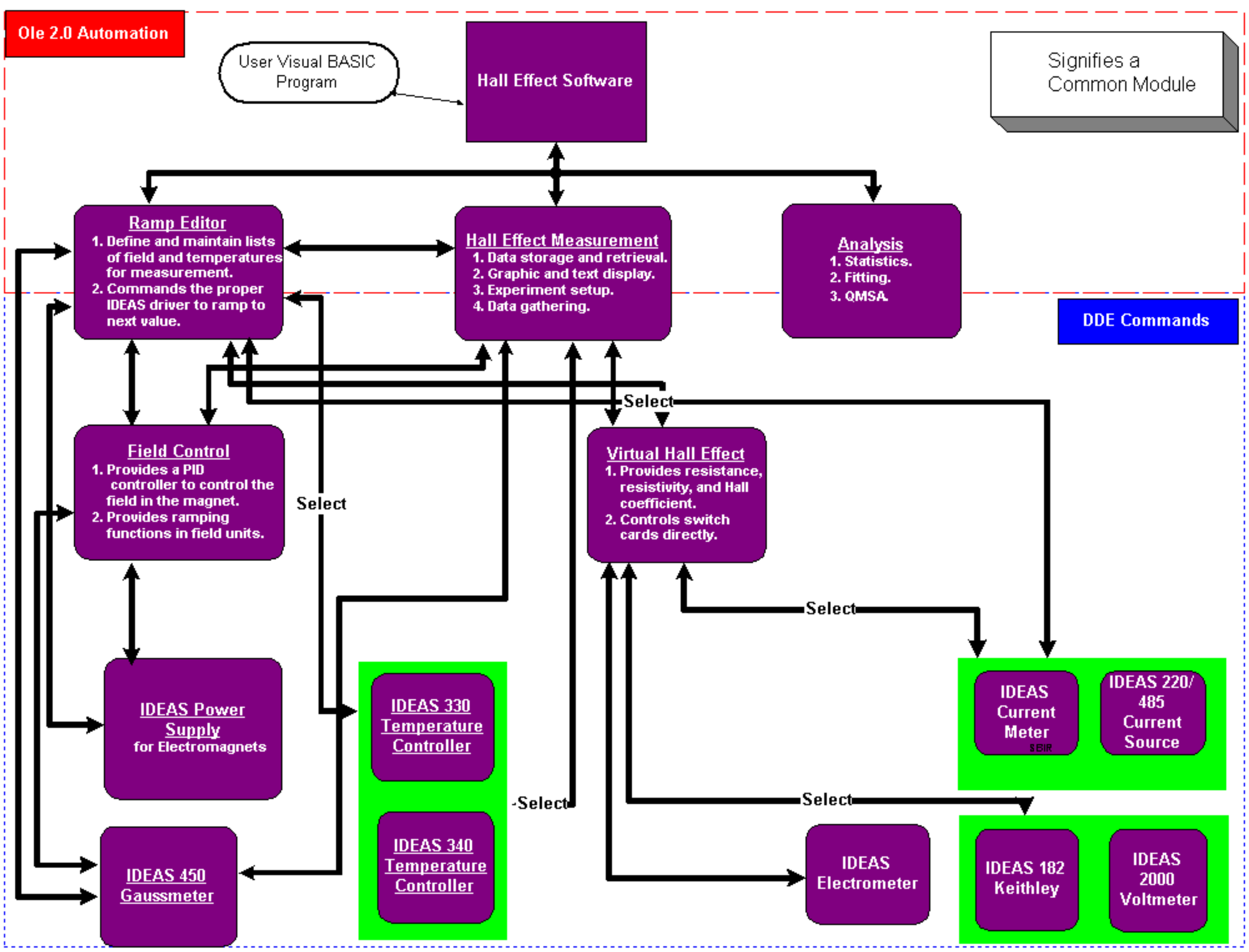
The Hall Measurement System Software is a set of Microsoft Windows-based programs for sample measurement and analysis. This software allows users to define and save sample specifications, experimental configurations, and record measurement data easily and efficiently. Users may save setup information, experimental data, and up to 64,000 characters of comment information to files, and use an output data file as a template to quickly initiate a similar set of measurements on a new sample.

Select from several standard sample geometries and contact arrangements, define magnetic flux densities and temperatures at which data is taken, and specify the measurement type and characteristics. Display or output a variety of measured and derived quantities (e.g., mobility vs. magnetic flux density or temperature).

The Hall software is designed so that the individual component programs can be used separately or as needed by higher level components of the combined program.

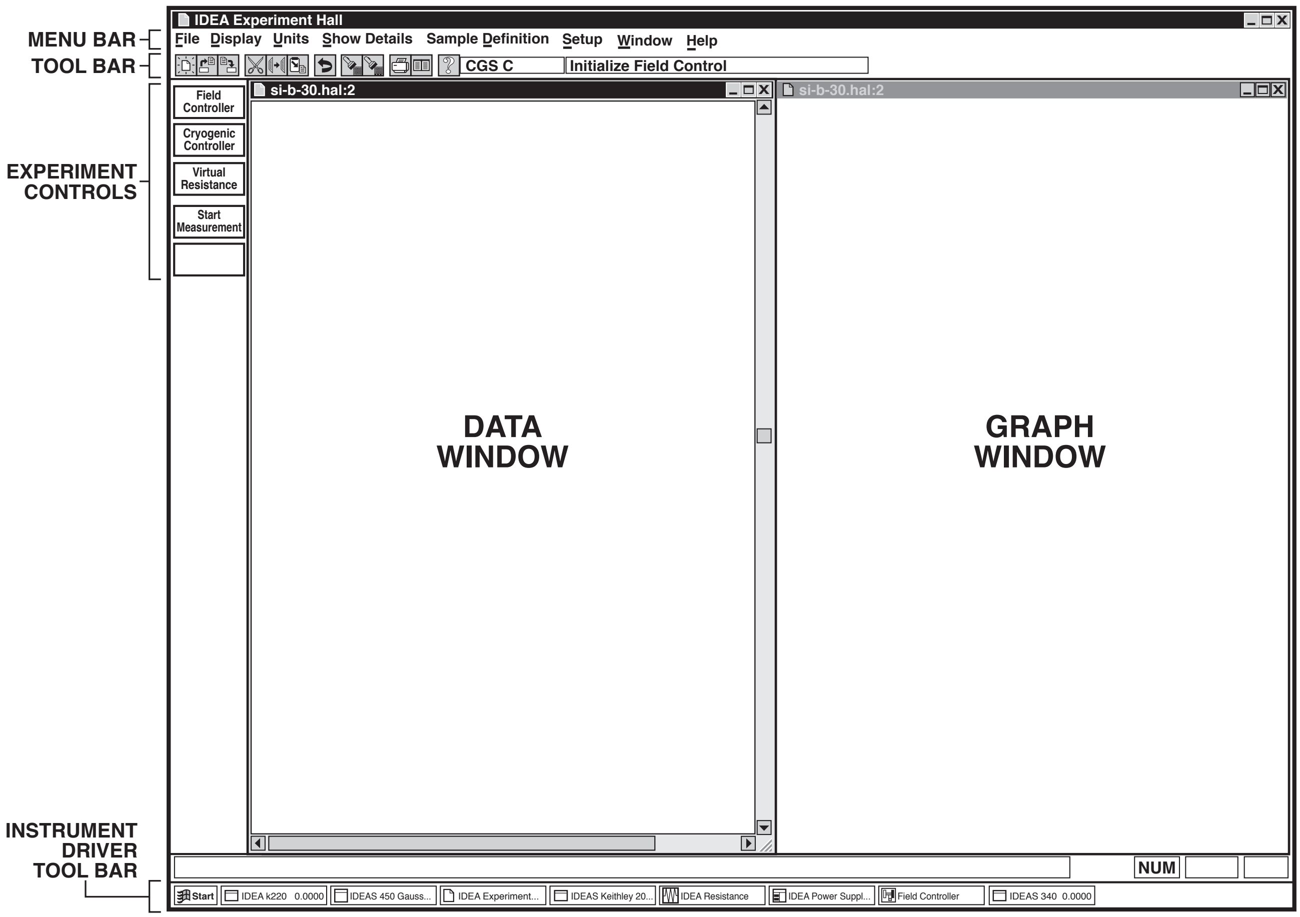
5.1.2 Hall Measurement System Interactions

Component programs of the Hall Measurement System may be used separately or as opened by higher level components of the combined program. The diagram illustrates interaction between component programs.



5.2 PROGRAM DESCRIPTION

Below is the Hall System Software Main Screen. It consists of the following elements: menu bar in Paragraph 5.1; tool bar in Paragraph 5.2; and Level 1 thru 6 Hall measurement results dialog boxes in Paragraph 5.3. The Data Window and Graph Window display only when a Hall experiment file is open.



5.2.1 Common Elements of Dialog Boxes

There are several elements that routinely appear in the Hall System Software dialog boxes. Rather than repeat them in each dialog box description, they are listed below.

5.2.1.1 Yellow Fields

A yellow field in a dialog box indicates a field that accepts scaled inputs.

The multipliers for all units except time are:	For time units, the multipliers are:
p = 10^{-12} n = 10^{-9} u = 10^{-6} m = 10^{-3} k = 10^{3} M = 10^{6}	s = seconds m = minutes h = hours

These designations are **case sensitive**; enter them exactly as indicated above. For example, to enter a maximum field of 25 kOe, type **25k**; to enter 25 MOe, type **25M**; to enter 10 minutes, type **10m**. Press tab after entering a value to advance to the next field. The displayed base units automatically change to reflect the multiplier. Enter only a value with no multiplier and the units on the right side of this text box scale appropriately.

5.2.1.2 OK Button

Either implements action of the dialog box or accepts parameters set in the dialog box and returns to the previous screen.

5.2.1.3 Cancel Button

Disregards any parameters set in the dialog box and immediately returns to the previous screen.

5.2.1.4 Help Button

Displays Help documentation for the current dialog box.

5.2.2 Menu Bar

The appearance of the menu bar depends on whether an experiment displays. If an experiment displays, the appearance of the menu bar depends on whether the Data Window or Graph Window is active.

Menu Bar with No Experiment Displayed

File Display Units Show Details Window Help

Menu Bar with Experiment Displayed, Data Window Active

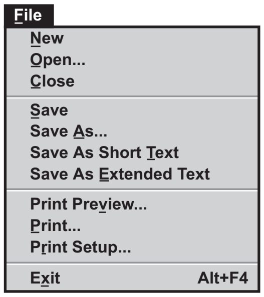
File Display Units Show Details Sample Definition Setup Window Help

Menu Bar with Experiment Displayed, Graph Window Active

File Display Units Show Details Cursor Axis Contract Select Sub Array Window Help

Availability of menu items within each menu option depends on whether an experiment displays and the type of experiment displayed.

5.2.2.1 File Menu (Always Displays)



New: Select this menu item to create a new Hall Software file with blank Data and Graph windows. After initially choosing **New**, the default Sample Definition dialog box displays (Paragraph 5.1.7). Enter the first line of the Sample ID used to generate the default file parameters, and select either a Van der Pauw or Hall Bar configuration for the experiment. After designating the Sample ID and configuration, click **OK** to display the Default File Name dialog box where users enter the name of the new Experiment Hall file, or accept the default "New.hal". The program then creates the new file with blank Data and Graph windows. **New** is available only when no Hall Software file displays.

Open: This menu item displays the **Open** dialog box where users select a previously created Hall file. Choose the drive, directory and path, file type, and file name. **Open** is available only when no Hall file displays.

Close: This menu item closes the Data and Graph windows of the experiment file. **Close** does not exit the Hall application program. To end the Hall Software application program, choose the **File/Exit** menu item or press Alt + F4. **Close** is available only when an Hall file displays.

Save: Available only if users change an active Hall file setup. If there is a change, select this function to save (or resave) changes.

Save As...: This menu item displays the **Save As** dialog box. Click **OK** to save the open Hall file contents as a standard Hall file with a different filename and a ".hal" extension appended to the filename. **Save As…** is available only when an Hall file displays.

Save As Short Text: This menu item displays the **Save As** dialog box. Click **OK** to save the open Hall Software file Data Window contents as a standard ASCII text Hall Software file, with a ".txt" extension appended to the filename. **Save As Short Text** is available only when an Hall Software file displays with the Data Window active.

Save As Extended Text: This menu item displays the **Save As** dialog box. Click **OK** to save the open Hall Software file Data window contents as an extended text Hall Software file, with a ".hal" extension appended to the filename. **Save As Extended Text** is available only when an Hall Software file displays with the Data Window active.

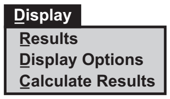
Print Preview...: This menu item displays the active Data Window in read-only format similar to how it will appear printed. **Print Preview…** is available only when an Hall Software file displays.

Print...: This menu item displays the **Print** dialog box, where users print the contents of the active data window. Specify the range to print, the print quality, and the number of copies. **Print** is available only when an Hall Software file displays.

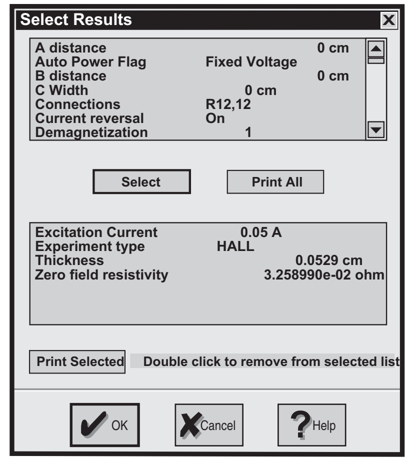
Print Setup...: This menu item displays the **Print Setup** dialog box, where users specify printing options including choice of printer, paper orientation and size, and source. **Print Setup…** is available only when an Hall Software file displays.

Exit: Select this menu item to close the open Hall Software file and exit the Experiment Hall software application. The computer prompts to save any unsaved files. Selecting this menu item is the same as pressing Alt + F4.

5.2.2.2 Display Menu (Always Displays)



5.2.2.2.1 Results (Available only with Data Window Active)



Displays the Select Results dialog box shown to the right where users select entered, measured, and calculated information to include in the experiment Data Window and Graph Window. Highlight the desired parameter(s) in the upper list box and click Select to copy them to the lower list box. Or, double click on each desired parameter in the upper list box to copy it to the lower list box. To deselect a parameter from the lower list box, double click the parameter. This menu item is available only when an Hall Software file displays with the Data Window active.

Select: Includes the highlighted result in the top list box in the lower list of results to display on the experiment data and graph. Also include results in the lower display list by double clicking on the result in the top list box. To delete a result from the lower display list, double click on it.

Print All: Outputs to the printer all results in the top list box.

Print Selected: Outputs to the printer only results in the lower list box.

After selecting all results, click **OK**, then select **Calculate Results** from the Display menu to initiate the result selections. Below is an alphabetical list of all possible results to display:

A distance: Displays the A Distance of the user-specified Hall Bar Geometry.

Auto Power Flag: The flag indicates whether current iteration was performed with fixed power or voltage. Refer to Paragraph 5.1.8.1.5.

B distance: Displays the B Distance of the user-specified Hall Bar Geometry.

C width: Displays the C Distance of the user-specified Hall Bar Geometry.

Connections: Displays the connection configuration used for current iteration, i.e., R12,34.

Current reversal: Displays whether Current Reversal was off or on during the experiment.

Demagnetization: Displays the sample Demagnetization Factor.

Density: Displays the sample density.

Display Sample ID: Displays the first eight characters of the Sample ID entered in the Sample Definition (refer to Paragraph 5.2.5).

Excitation Current: A display of the excitation current.

Experiment type: Displays the type of experiment performed. Refer to Paragraph 5.2.6.

Field measurement order: Displays user-specified measurement order (negative fields first or positive fields first).

Field reversal: Displays whether Field Reversal was off or on during the experiment.

Field settle time: Displays the user-specified field settle time.

Field step: Displays whether Field Reversal was off or on during the experiment.

Final temperature: Displays the final temperature of a temperature experiment.

Fixed Current Flag: Either in fixed current mode or in a current iteration. Refer to Paragraph 5.1.8.1.5.

Fixed Field: Displays the user-specified fixed field value for the experiment.

Fixed Power: Displays the user-specified fixed power value for the experiment. Refer to Paragraph 5.1.8.1.5.

Fixed Voltage: Displays the user-specified fixed voltage value for the experiment. Refer to Paragraph 5.1.8.1.5.

Four Wire Connections: Connection configuration used for four-wire resistance measurement, i.e., R41, 23.

Four Wire Flag: True means you were doing a four wire resistance measurement.

Hall Bar geometry: Displays the Hall bar geometry used, i.e., 1-2-2-1, 1-3-3-1, or 1-3-1-1.

Results (Continued)

Initial temperature: Displays the starting temperature of a temperature experiment.

IV Configuration: Connection configuration used in the IV measurement, i.e., R41.23.

Length: Displays the Hall Bar sample length.

Mass: Displays the sample mass entered or calculated in the Sample Definition (refer to Paragraph 5.2.5).

Max Current: Displays the maximum current reached during the experiment.

Maximum field: Displays the maximum field reached during the experiment.

Measurement geometry: Displays Geometry A, B, or both.

Min Current: Displays the minimum current reached during the experiment.

Mobility calculated with: Displays whether zero-field resistivity (B=0) or actual field (B+ or B–) resistivities were used in mobility calculation.

Molar weight: Displays the molar weight of the sample.

Number of Moles: Displays the number of Moles in the sample.

Number of Points: Displays the entered or calculated number of points in the curve

Orientation: Displays the experiment orientation: parallel or perpendicular.

P distance: Displays the P Distance of the user-specified Hall Bar Geometry.

Resistance range: Displays whether the sample resistance range was high (>100 kΩ) or low (<100 kΩ).

Sample Area: Displays the sample area.

Sample Type: Displays whether a Hall Bar or Van der Pauw sample was used in the experiment.

Settle Time: Displays the settle time used in seconds.

Temperature Control: Displays whether temperature control was off or on during the experiment.

Temperature Step: Displays the temperature increment between each data point in the curve.

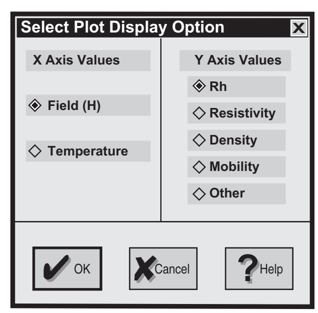
Thickness: Displays the sample thickness entered in the Sample Definition (refer to Paragraph 5.2.5).

Volume: Displays the sample volume.

Width: Displays the Hall Bar sample width.

Zero field resistivity: Displays the zero field resistivity used in mobility calculation.

5.2.2.2.2 Display Options (Available only with Graph Window Active)



Select this menu item to display the Select Plot Display Option dialog box shown to the right, where users determine which X-axis and Y-axis values to include on the graph for the currently open Hall Software file. This menu item is available only when an Hall Software file displays with the Graph Window active.

Field (H): By default, this radio button is selected when a variable field (VF) or a variable current (VC) experiment is active. The experimental field values plot along the X-axis of the graph-plot similar to the VC-Graph and VF-Graph Examples in Appendix X. Select this button for a variable temperature experiment to display a graph.

Temperature: By default, this radio button is selected when a variable temperature (VT) experiment is active. When selected, the experimental temperature values plot along the X-axis of the graph-plot.

If selected for a variable field (VF) or a variable current (VC) experiment, the displayed graph generally has little significance (due to the constancy of the temperature parameter).

Rh: Select this button to display the variance of the Hall coefficient along the Y-axis, as a function of field or temperature (as selected under X Axis Values).

Resistivity: Select this button to display the variance of resistivity along the Y-axis, as a function of field or temperature (as selected under X Axis Values).

Display Options (Continued)

Density: Select this button to display the variance of density along the Y-axis, as a function of field or temperature (as selected under X Axis Values).

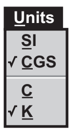
Mobility: Select this button to display the variance of mobility along the Y-axis, as a function of field or temperature (as selected under X Axis Values).

Other: Selecting this button presently results in no graph, due to the non-definition of the 'Other' parameter.

5.2.2.2.3 Calculate Results

Calculates results of an existing experiment for a different sample definition. Or leave the sample definition unchanged and simply select other appropriate results to calculate in the Select Results dialog box (Paragraph 5.1.2.1), then select Calculate Results.

5.2.2.3 Units Menu (Always Displays)



Select the experiment units of measurement from this menu. The selections appear in the Measurement System Indicator directly to the right of the Button Bar. Users may select a different system of units only when no Hall Software file displays.

SI: Selects the International System of Units which consists of these base units: meter, kilogram, second, ampere. Available only when no Hall Software file displays.

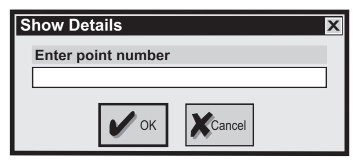
CGS: Selects a common system of units consisting of the base units centimeter, gram, and second. Available only when no Hall Software file displays.

C: Selects degrees Celsius units of temperature. Available only when no Hall Software file displays.

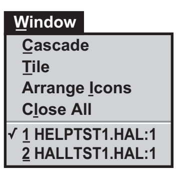
K: Selects Kelvin units of temperature. Available only when no Hall Software file displays.

5.2.2.4 Show Details Menu (Always Displays)

This menu item displays the Show Details dialog box shown to the right, where users may access information about a specified data point. The details shown vary depending on the type of experiment and the details selected.



5.2.2.5 Window Menu (Always Displays)



Cascade: Creates separate windows of equal size for each experiment and displays them one on top of the other. The window sizes remain unchanged regardless of the number of open experiments. Available only when an Hall Software file displays.

Tile: Creates separate windows of equal size for each experiment and displays them side by side. The window sizes decrease as the number of open experiments increases. Available only when an Hall Software file displays.

Arrange Icons: Locates the icons of minimized experiments to the lower left of the screen. Available only when an Hall Software file displays.

Close All: Closes all experiments. Available only when an Hall Software file displays.

Currently Open Windows: Displays all open Hall Software file windows. A check mark beside a file name indicates the active Hall Software file window. A number precedes the filename of each window, entering that number activates that window and deactivates the previously active window. Available only when an Hall Software file displays.

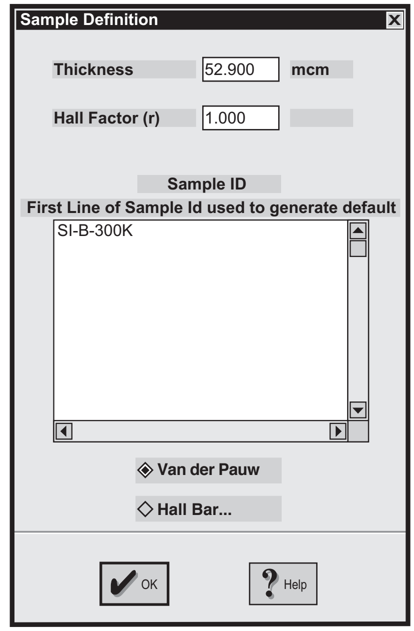
5.2.2.6 Help Menu (Always Displays)

Contents: Displays the main table of contents for the VSM Help Documentation

Using Help: Displays Help on using the VSM Help Documentation.

About: Displays the VSM software title, version, and copyright date.

5.2.2.7 Sample Definition Menu (Displays only with Data Window Active)



Select **Edit** to display the Sample Definition dialog box shown to the right, where users may modify the active sample definition, including the sample thickness, the Hall factor (r), sample ID, and sample contact configuration.

Thickness: Enter the sample thickness. Yellow indicates the box accepts scaled inputs.

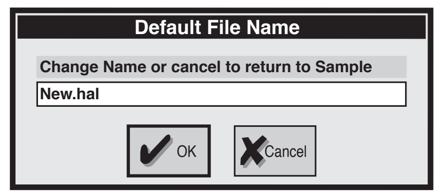
Hall Factor (r): Enter the Sample Hall Factor. The default is 1.000.

Sample ID: After entering attributes, click the Sample ID box and enter an experiment name. The Sample ID is required for new experiments. The software uses the first eight characters of this description as the filename when it saves the experiment, but the description holds up to 32,000 characters.

Van der Pauw: Refer to Paragraph 5.2.2.7.1 below.

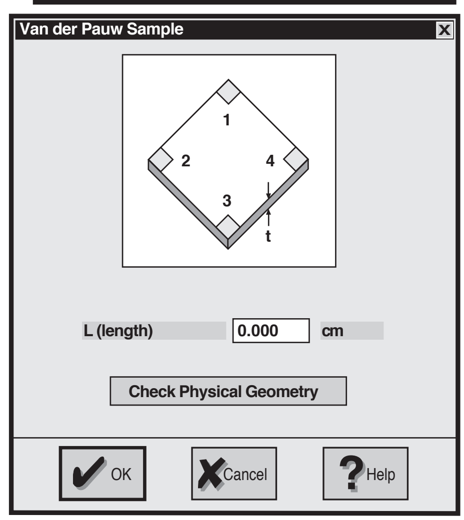
Hall Bar…: Refer to Paragraph 5.2.2.7.2 below.

Click **OK** to accept all information in the definition and display the Default File Name dialog box where users specify a name of a new Experiment Hall file rather than allowing the software to use the first eight characters of the Sample ID. Click **OK** after entering a name to close both the Default File Name and Sample Definition dialog boxes. This creates new data and graphics windows for the current sample. A New Experiment Hall screen displays with the graphics window active.



5.2.2.7.1 Van der Pauw

Click this button on the Sample Definition dialog box to display the Van der Pauw Sample dialog box shown to the right where users define the Van der Pauw sample configuration geometry and associated contact parameters when a Van der Pauw sample is used to measure Hall effect.



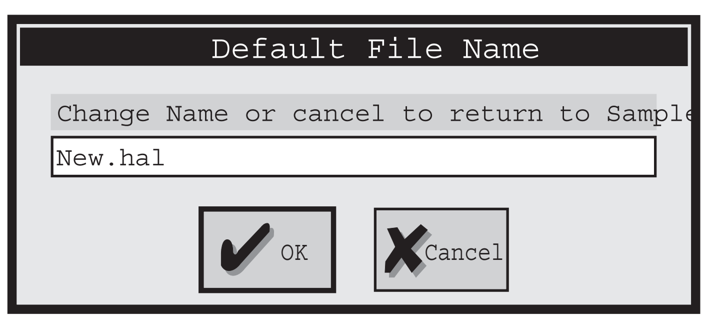
L (length): Enter the sample length as illustrated in the Van der Pauw diagram. Yellow indicates the box accepts scaled inputs.

Check Physical Geometry: Displays the Van der Pauw Geometry Check [ASTM F76-86] dialog box shown below and to the right. This box verifies the Van der Pauw configuration geometry and contact parameters in accordance with ASTM Standard F76-86.

The L-Value Status Box confirms whether the length of the Van der Pauw sample between contacts 1 and 4 (**L**) is greater than or equal to the product of fifteen times the thickness of the bar (**t**). This is false in the example shown to the right.

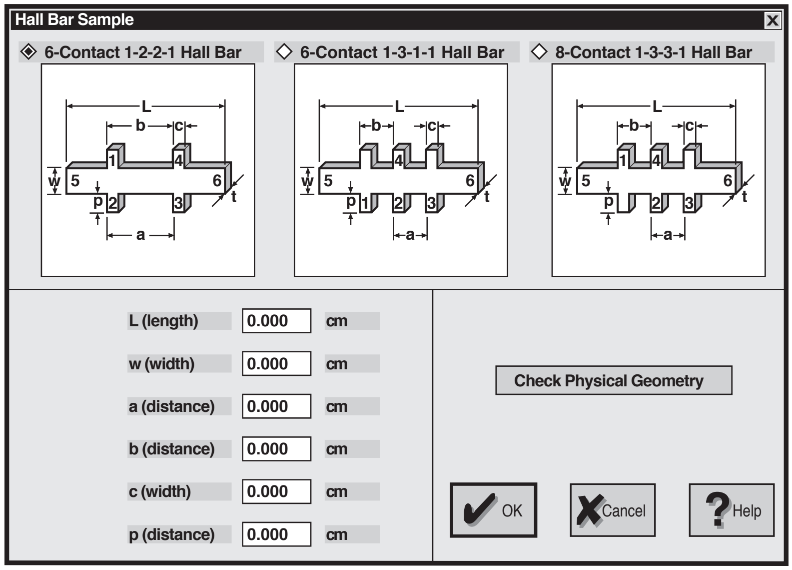
The t-Value Status Box confirms whether the thickness of the Van der Pauw sample (**t**) is less than or equal to 0.1 cm. This is true in the example shown to the right.

Click **OK** to close the check dialog box and return to the Van der Pauw Sample dialog box. Click **OK** in the Van der Pauw Sample dialog box to accept the Van der Pauw configuration and return to the Sample Definition dialog box



5.2.2.7.2 Hall Bar…

Displays the Hall Bar Sample dialog box where users define the Hall Bar geometry and associated contact parameters. The parameters and contacts listed in the dialog box depend on the configuration chosen. For example, the dialog box shown to the right shows parameters for a 1-2-2-1 Hall Bar configuration:



L-length: Enter the length (L) of the Hall Bar sample as shown in the 1-2-2-1 Hall Bar illustration.

w-width: Enter the width (w) across contact 5 as shown in the 1-2-2-1 Hall Bar illustration.

a-distance: Enter distance **a** from contact 2 to contact 3 as shown in the 1-2-2-1 Hall Bar illustration.

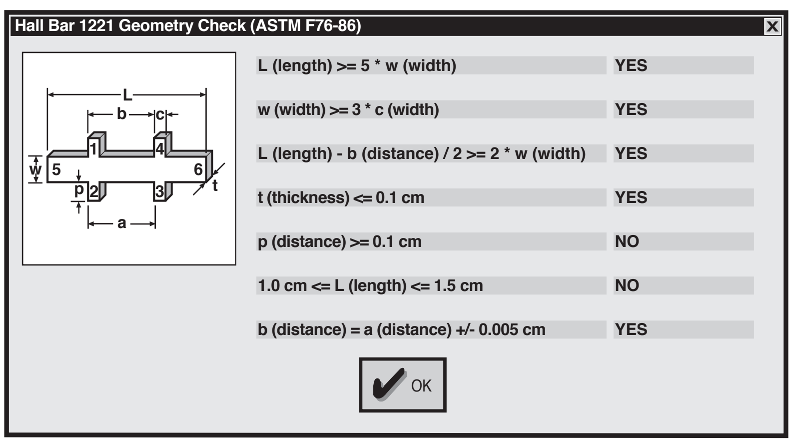
b-distance: Enter distance **b** from contact 1 to contact 4 as shown in the 1-2-2-1 Hall Bar illustration.

c-width: Enter width **c** across contact 4 as shown in the 1-2-2-1 Hall Bar illustration.

p-distance: Enter distance **p** from the base to the end of contact 2 as shown in the 1-2-2-1 Hall Bar illustration.

Check Physical Geometry: Displays the Hall Bar Geometry Check [ASTM F76-86] dialog box. There are different check dialogs for each of the three Hall Bar configurations. The check dialog verifies the specified Hall Bar configuration geometry and contact parameters in accordance with ASTM Standard F76-86.

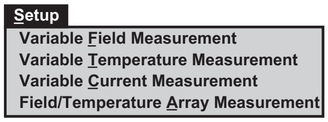
For a 1-2-2-1 Hall Bar, the Hall Bar Geometry Check dialog box (shown below) verifies these parameters:



- The length of Hall Bar sample (**L**) is greater than or equal to 5 times the width of contact 5 (**w**). This is true in the example shown.
- The width of contact 5 (**w**) is greater than or equal to 3 times the width of contact 4 (**c**). This is true in the example shown.
- The length of Hall Bar sample (**L**) minus half the distance between contacts 1 and 4 (**b**) is greater than or equal to twice the width of contact 5 (**w**). This is true in the example shown.
- The thickness of the Hall Bar sample (**t**) is less than or equal to 0.1 cm. This is true for the example shown.
- The distance **p** is greater than or equal to 0.1 cm. This is false in the example shown.
- The length of Hall Bar sample (**L**) is between 1.0 cm and 1.5 cm. This is false in the example shown.
- The distance **b** is equal to the distance **a** within a tolerance of ±0.005 cm. This is true in the example shown.

The parameters verified change depending on the configuration selected. Click **OK** to close the check dialog box and return to the Hall Bar Sample dialog box. Click **OK** in the Hall Bar Sample dialog box to accept the Hall Bar configuration and return to the Sample Definition dialog box.

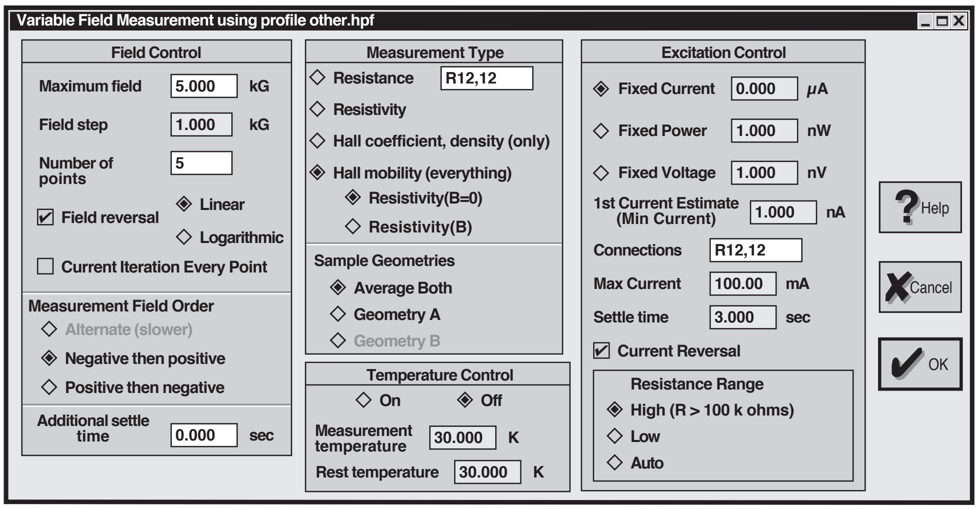
5.2.2.8 Setup Menu (Displays only with Data Window Active)



Select this menu to access dialog boxes to modify parameters associated with field, temperature, and current-voltage measurements.

5.2.2.8.1 Variable Field Measurement

Select this menu item to display the Variable Field Measurement dialog box shown to the right, where users modify field control, temperature control, measurement type, and excitation control associated with the measurement of a variable field.



5.2.2.8.1.1 Field Control Area

Maximum Field: Enter the maximum field value for the experiment in this text box. Yellow indicates the text box accepts scaled inputs. Maximum Field = Number of Points × Field Step. Enter any two values and the third automatically calculates.

Field Step: Enter the field value increment for each data point of the experiment in this text box. Yellow indicates the text box accepts scaled inputs. Field Step = Maximum Field / Number of Points. Enter any two values and the third automatically calculates.

Min. Field: Enter the minimum field value at which the experiment begins in this text box. Yellow indicates the text box accepts scaled inputs.

Number of Points: This text box appears when users click the Linear radio button. Enter the number of data points to run for the experiment in this text box. Number of Points = Maximum Field / Field Step.

Points/Decade: This text box appears when users click the Logarithmic radio button. Enter the number of measurement points in the active current-voltage profile.

Field Reversal: This check box enables (check in the box) or disables (empty box) field reversal.

Linear: Click this button to apply the field linearly.

Logarithmic: Click this button to apply the field logarithmically.

Current Iteration Every Point: A check mark in this box enables (or empty box disables) performing a current iteration after every change of field. This dramatically slows the experiment.

5.2.2.8.1.2 Measurement Field Order Area

Alternate (Slower): Click this button to apply the measurement field alternately: negative then positive then negative etc. Alternate order is the slowest of the three measurement orders.

Negative then Positive: Select to apply the measurement field from the most negative to the most positive.

Positive then Negative: Select to apply the measurement field from the most positive to the most negative.

Additional Settle Time: Enter a value in this Text Box to add to the default settle time of two seconds. Enter a whole number greater than or equal to zero (0). The actual measurement settle time is at least as long as the total of the default settle time plus the additional settle time, or as much as one second longer.

5.2.2.8.1.3 Measurement Type Area

Resistance: Click this button to measure sample resistance only across contact points designated in the Resistance Contact Points text box directly to the right.

Resistance Contact Points: In this text box, designate (using standard nomenclature) the contact points where sample resistance is measured.

Resistivity: Click this button to measure only sample resistivity

Hall Coefficient Density (Only): Click this button to measure only the sample Hall coefficient and density.

Hall Mobility (Everything): Click this button to measure all the sample characteristics, including Hall coefficient, mobility, density, and resistivity. Users may then determine whether to use the zero-field resistivity (B=0) or the actual field (B+ or B–) resistivities in the calculation of mobility.

Resistivity (B=0): Click this button to calculate sample mobility using the zero-field resistivity even if the positive and/or negative field resistivities are available as well.

NOTE: To select this radio button, first click the Hall Mobility (everything) radio button.

Resistivity (B): Click this button to calculate sample mobility using the appropriate positive and/or negative field resistivities. If both the positive and negative field resistivities are available, the average value of the two resistivities calculates and that value determines mobility.

NOTE: To select this radio button, first click the Hall Mobility (everything) radio button.

Average Both: Click this button to calculate sample measurements using the average of both Geometry A and Geometry B determined values.

Geometry A: Click this button to calculate sample measurements using only Geometry A determined values.

Geometry B: Click this button to calculate sample measurements using only Geometry B determined values.

5.2.2.8.1.4 Temperature Control Area

On: Click this button to ensure measurements are carried out under temperature control. If the temperature control is enabled, enter the temperature (in the Measurement temperature text box) at which to take measurements.

Off: Click this button to take all measurements without regard to a specified temperature.

Measurement Temperature: In this text box, enter the temperature at which to take sample measurements. Note: If the On radio button in this Temperature Control area is not selected, a value entered in this text box has no affect and the experimental measurements are made without temperature control.

5.2.2.8.1.5 Excitation Control Area

Fixed Current: To perform the experiment under a set current value, click the radio button and enter a value in the text box to the immediate right. Yellow indicates the text box accepts scaled inputs.

Fixed Power: To perform the experiment under a specific power value, click this button and enter a value in the text box to the immediate right. Yellow indicates the text box accepts scaled inputs. Click Fixed Power to conduct the excitation current determination at the beginning of a field ramp experiment. This determination is an iterative process that yields the excitation current not exceeding the user-entered power. If the temperature changes, the iterative process runs at the new temperature.

NOTE: If this radio button is selected, users may also specify the maximum current and the first current estimate (minimum current) using the corresponding text boxes in the Excitation Control area.

Fixed Voltage: To perform the experiment under a specific voltage value, click this button and enter the value in the text box to the immediate right. Yellow indicates the text box accepts scaled inputs. If Fixed Voltage is selected, the excitation current determination is done once at the beginning of a field ramp experiment. This determination is an iterative process that yields the excitation current not exceeding the user-entered voltage. If the temperature changes, the iterative process runs at the new temperature.

NOTE: If this radio button is selected, users may also specify the maximum current and the first current estimate (minimum current) using the corresponding text boxes in the Excitation Control area.

1st Current Estimate (Min Current): Enter the minimum current at which the experiment is conducted in this text box. Yellow indicates the text box accepts scaled inputs.

NOTE: The program recognizes this value only when the Fixed Current radio button IS NOT selected.

Connections: Enter the specific sample contact configuration used for the measurements in this text box. By default, the box contains **R12,12** when this dialog box opens. Entering another configuration overwrites this default measurement.

The sample contact configuration syntax consists of four digits: the first identifies the sample contact that connects to the positive current source; the second identifies the sample contact that connects to the current source return; the third identifies the sample contact that connects to the positive voltmeter input; the fourth identifies the sample contact that connects to the negative voltmeter input.

NOTE: The format is free-form and non-numerical digits are ignored. To measure VC for sample contacts **1** and **2**, enter either **R12,12**, **1212**, or **12:12** in the text box.

Max Current: Enter the maximum current at which experiment is conducted in this text box. Yellow indicates the text box accepts scaled inputs.

NOTE: The program recognizes this value only when the Fixed Current radio button IS NOT selected.

Settle Time: To enter a settle time different than the default of two seconds, select this text box. Yellow indicates the text box accepts scaled inputs.

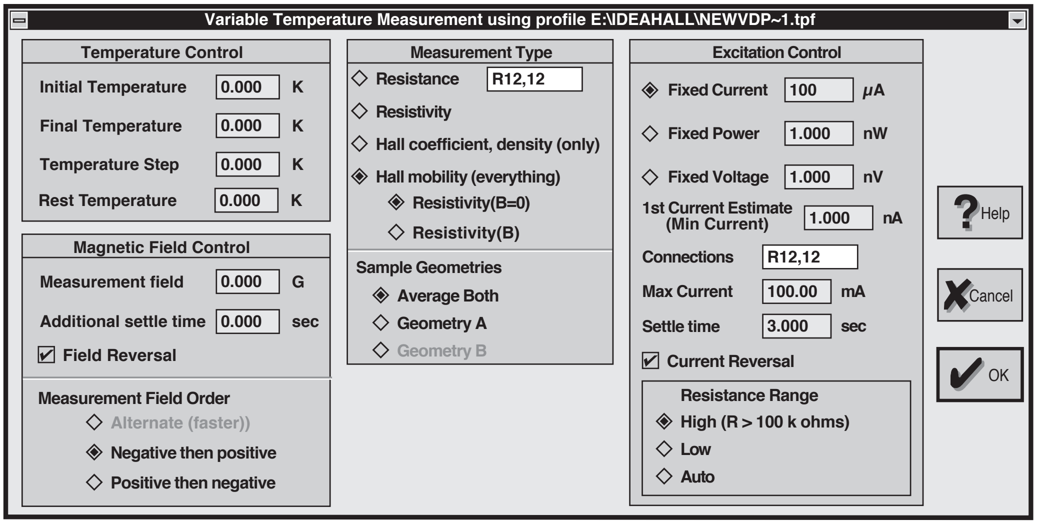
Current Reversal: Select this box to enable current reversal (check in the box); de-select it to disable current reversal (empty box).

Resistance Range Area:

High (R >100 kΩ): Indicates expected sample resistance range is high (>100 kΩ).
Low: Click this button to indicate expected sample resistance range is low (<100 kΩ).
Auto: Click this button to automatically determine the sample resistance range.

5.2.2.8.2 Variable Temperature Measurement

Select this menu item to display the Variable Temperature Measurement dialog box shown to the right, where users modify the temperature control, magnetic field control, measurement type, and excitation control associated with the measurement of a variable temperature.



5.2.2.8.2.1 Temperature Control Area

Initial Temperature: Enter the temperature at which the variable temperature experiment begins. Yellow indicates the text box accepts scaled inputs.

Final Temperature: Enter the temperature at which the variable temperature experiment ends. Yellow indicates the text box accepts scaled inputs.

Temperature Step: Enter the increment at which temperature changes from the initial temperature to the final temperature. Yellow indicates the text box accepts scaled inputs.

Rest Temperature: Go to this temperature when the experiment is concluded.

5.2.2.8.2.2 Magnetic Field Control Area

Measurement Field: In this text box, enter the magnetic field value under which to conduct the experiment. Yellow indicates the text box accepts scaled inputs.

Additional settle time: Enter a value in this Text Box to add to the default settle time of two seconds. Enter a whole number greater than or equal to zero (0). The actual measurement settle time is at least as long as the total of the default settle time plus the additional settle time, or as much as one second longer. Yellow indicates the text box accepts scaled inputs.

Field Reversal: Select whether to enable field reversal (check in the box) or disable field reversal (empty box).

5.2.2.8.2.3 Measurement Order Area

Alternate (faster): Click this button to apply the measurement field alternately: negative then positive then negative etc. Alternate order is the fastest of the three methods.

Negative then Positive: Click this button to apply the measurement field from the most negative to the most positive.

Positive then Negative: Click this button to apply the measurement field from the most positive to the most negative.

5.2.2.8.2.4 Measurement Type Area

Select measurements [resistivity, Hall coefficient and density only, or Hall mobility (everything)] and the sample geometry measurement method (Geometry A, Geometry B, or their average). If Hall mobility measurement is selected, select either zero-field resistivity (B=0) or the actual field (B+ or B–) resistivities for mobility calculation.

Resistance: Click this button to measure sample resistance only across contact points designated in the Resistance Contact Points text box directly to the right.

Resistance Contact Points: In this text box, designate (using standard nomenclature) the contact points where sample resistance is measured.

Resistivity: Click this button to measure only sample resistivity

Hall Coefficient Density (Only): Click this button to measure only the sample Hall coefficient and density.

Hall Mobility (Everything): Click this button to measure all the sample characteristics, including Hall coefficient, mobility, density, and resistivity. Users may then determine whether to use the zero-field resistivity (B=0) or the actual field (B+ or B–) resistivities in mobility calculation.

Resistivity (B=0): Click this button to calculate sample mobility using the zero-field resistivity even if the positive and/or negative field resistivities are available as well.

NOTE: To select this radio button, first click the Hall Mobility (everything) radio button.

Resistivity (B): Click this button to calculate sample mobility using the appropriate positive and/or negative field resistivities. If both the positive and negative field resistivities are available, the average value of the two resistivities calculates and that value determines mobility.

NOTE: To select this radio button, first click the Hall Mobility (everything) radio button.

Average Both: Click this button to calculate sample measurements using the average of both Geometry A and Geometry B determined values.

Geometry A: Click this button to calculate sample measurements using only Geometry A determined values.

Geometry B: Click this button to calculate sample measurements using only Geometry B determined values.

5.2.2.8.2.5 Excitation Control Area

Fixed Current: To perform the experiment under a set current value, click the radio button and enter a value in the text box to the immediate right. If Fixed Current is selected, no current iteration is done at the beginning of a field ramp experiment. Yellow indicates the text box accepts scaled inputs.

Fixed Power: To perform the experiment under a specific power value, click this button and enter a value in the text box to the immediate right. Yellow indicates the text box accepts scaled inputs. If Fixed Power is selected, excitation current determination occurs after the temperature settles at each point. This determination is an iterative process that yields the excitation current not exceeding the user-entered power.

NOTE: If this radio button is selected, users may also specify the maximum current and the first current estimate (minimum current) using the corresponding text boxes in the Excitation Control area.

Fixed Voltage: To perform the experiment under a specific voltage value, click this button and enter the value in the text box to the immediate right. Yellow indicates the text box accepts scaled inputs. If Fixed Voltage is selected, excitation current determination occurs after the temperature settles at each point. This determination is an iterative process that yields the excitation current not exceeding the user-entered voltage.

NOTE: If this radio button is selected, users may also specify the maximum current and the first current estimate (minimum current) using the corresponding text boxes in the Excitation Control area.

1st Current Estimate (Min Current): Enter the minimum current at which to conduct the experiment in this text box. Yellow indicates the text box accepts scaled inputs.

NOTE: The program recognizes this value only when the Fixed Current radio button IS NOT selected.

Excitation Control Area (Continued)

Connections: Enter the specific sample contact configuration used for the measurements in this text box. By default, the box contains **R12,12** when this dialog box opens. Entering another configuration overwrites this default measurement.

The sample contact configuration syntax consists of 4 digits: (1) the first identifies the sample contact that connects to the positive current source; (2) the second identifies the sample contact that connects to the current source return; (3) the third identifies the sample contact that connects to the positive voltmeter input; and (4) the fourth identifies the sample contact that connects to the negative voltmeter input.

NOTE: The format is free-form and non-numerical digits are ignored. To measure VC for sample contacts **1** and **2**, enter either **R12,12**, **1212**, or **12:12** in the text box.

Max Current: Enter the maximum current at which to conduct the experiment in this text box. Yellow indicates the text box accepts scaled inputs.

NOTE: The program recognizes this value only when the Fixed Current radio button IS NOT selected.

Settle Time: To enter a settle time different than the default of two seconds, select this text box. Yellow indicates the text box accepts scaled inputs.

Current Reversal: Select this box to enable current reversal (an check in the box); de-select it to disable current reversal (an empty box).

Resistance Range Area

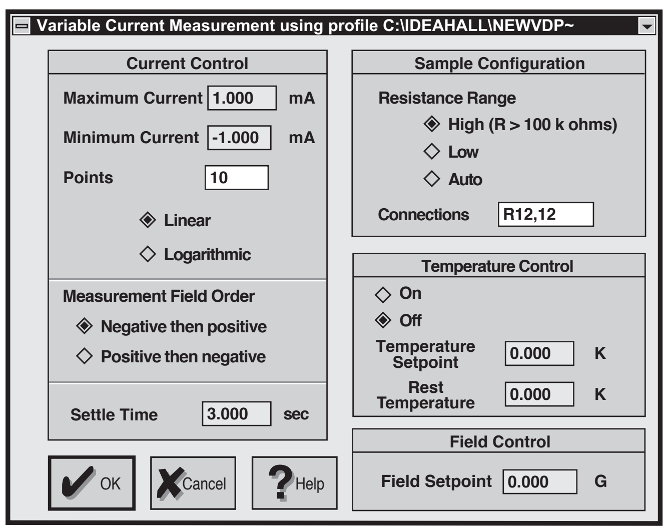
High (R > 100 kΩ): Indicates expected sample resistance range is high (>100 kΩ).

Low: Click this button to indicate expected sample resistance range is low (<100 kΩ).

Auto: Click this button to automatically determine the sample resistance range.

5.2.2.8.3 Variable Current Measurement (Available only with Data Window Active)

Select this menu item to display the Variable Current Measurement dialog box shown to the right, where users modify current control, sample configuration, temperature control, and field control associated with the measurement of a current-voltage interaction.



5.2.2.8.3.1 Current Control Area

Maximum Current: In this text box, enter the maximum current for the active current-voltage profile. Yellow indicates the text box accepts scaled inputs. Enter the appropriate units along with the value itself, and the corresponding value displays in the box with the resulting units displayed just to the right of the box.

Minimum Current: In this text box, enter a minimum current for the active current-voltage profile. Yellow indicates the text box accepts scaled inputs. Enter the appropriate units along with the value itself, and the corresponding value displays in the box with the resulting units displayed just to the right of the box.

NOTE: With the linear radio button clicked, the sign of the minimum current is optional. With the logarithmic radio button clicked, the sign of the minimum current must be the same sign as the maximum current. If not, an error message box displays. Click **OK** on the error message box to automatically convert the sign of the minimum current to the same sign as the maximum current.

Current Control Area (Continued)

If the minimum current is less than one-tenth the value of the maximum current, a second error message box displays. Click **OK** on this error message box to automatically convert the minimum current to one tenth the maximum current. Completion of the remainder of the profile is then possible.

Points: This text box appears when users click the Linear radio button. Enter the number of measurement points for the active linear current-voltage profile. To calculate the current step, the software divides the current range (defined by the maximum and minimum current) by the number of points in this text box.

Points/Decade: This text box appears when users click the Logarithmic radio button. Enter the number of measurement points per decade for the active logarithmic current-voltage profile. To calculate the current step, the software divides the current range (defined by the maximum and minimum current) by the number of points in this text box.

Linear: Click this button to define the current value for each data point incremented in a linear fashion.

The change in current per data point interval is (Maximum Current – Minimum Current) / (Points – 1), where 'Maximum Current', 'Minimum Current', and 'Points' are the values shown in the respective text boxes above. In this example, the resulting current values for each data point increment as displayed on the corresponding Profile Generator display window.

Logarithmic: Click this button to define the current value for each data point incremented in a logarithmic fashion.

The change in current per data point interval is (Maximum Current – Minimum Current) / (Points – 1), where 'Maximum Current', 'Minimum Current', and 'Points' are the values displayed in the respective text boxes above. In this specific example, the resulting current values for each data point increment as shown on the corresponding Profile Generator display window

5.2.2.8.3.2 Sample Configuration Area

Resistance Range Area:

High (R > 100 kΩ): Click this button to indicate expected sample resistance range is high (>100 kΩ).

Low: Click this button to indicate expected sample resistance range is low (<100 kΩ).

Auto: Click this button to automatically determine the sample resistance range.

Connections: Enter the specific sample contact configuration used for the measurements in this text box. By default, the box contains **R12,12** when this dialog box opens. Entering another configuration overwrites this default measurement.

The sample contact configuration syntax consists of four digits: the first identifies the sample contact that connects to the positive current source; the second identifies the sample contact that connects to the current source return; the third identifies the sample contact that connects to the positive voltmeter input; the fourth identifies the sample contact that connects to the negative voltmeter input.

NOTE: The format is free-form and non-numerical digits are ignored. To measure VC for sample contacts **1** and **2**, enter either **R12,12**, **1212**, or **12:12** in the text box.

5.2.2.8.3.3 Measurement Order Area

Negative Then Positive: Begin voltage measurements from the most negative current to the most positive current.

Positive Then Negative: Begin voltage measurements from the most positive current to the most negative current.

Settle Time: By default, the suggested minimum settle time is two seconds. Enter a different value only if it is a whole number greater than or equal to zero. The actual measurement settle time is at least as long as the requested time and may be one second longer.

5.2.2.8.3.4 Temperature Control Area

On: Click this button to turn on temperature control. Once on, users may specify the temperature setpoint in the text box immediately below.

Off: Click this button to turn off temperature control. By default, this button is activated.

Temperature Setpoint: By default, Temperature Setpoint = 0.000 K. This setpoint is functional only if the Temperature Control 'On' radio button is clicked. To specify a different setpoint once the radio button is clicked, enter a value in the text box. Yellow indicates the text box accepts scaled inputs. Enter the appropriate units along with the value itself, and the corresponding value displays in the box with the resulting units displayed just to the right of the box.

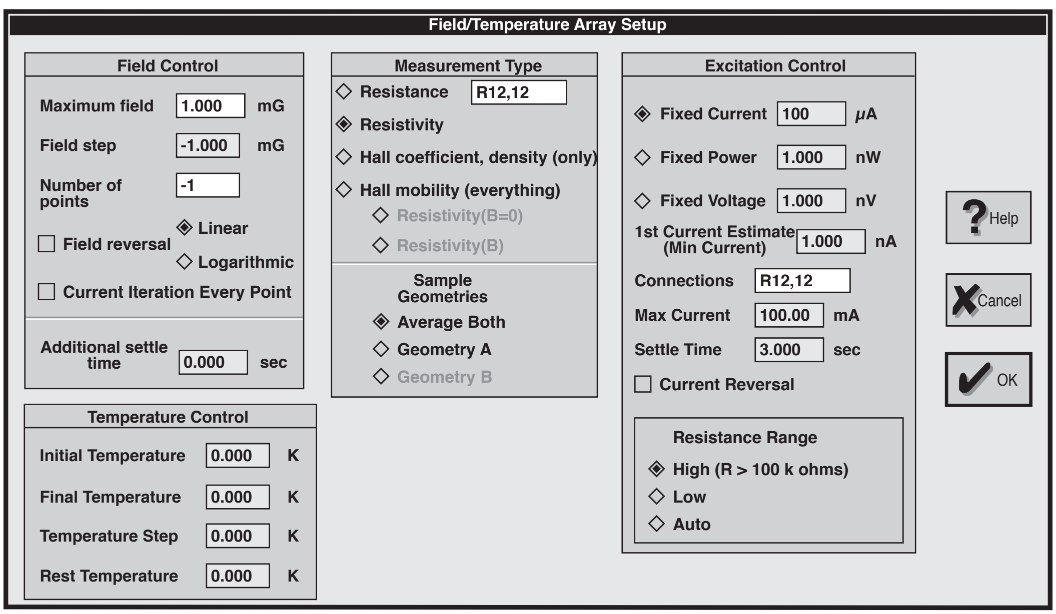
Rest Temperature: Go to this temperature when the experiment is concluded.

5.2.2.8.3.5 Field Control Area

Field Setpoint: By default, Field Setpoint = 0.000 G. To define a different magnetic field setpoint, enter a new value in this text box. Yellow indicates the text box accepts scaled inputs. Enter the appropriate units along with the value itself, and the corresponding value displays in the box with the resulting units displayed just to the right of the box.

5.2.2.8.4 Field/Temperature Array Measurement

Select this menu item to display the Field/Temperature Array Setup dialog box shown to the right, where users modify field control, sample configuration, excitation control, and temperature control associated with the measurement of field and temperature values.



5.2.2.8.4.1 Field Control Area

Maximum field: Enter the maximum field value for the experiment. Yellow indicates the text box accepts scaled inputs. Enter the appropriate units along with the value itself, and the corresponding value displays in the box with the resulting units displayed just to the right of the box.

NOTE: If the field step and the number of points are previously defined, the maximum field automatically calculates from the equation: Bmax = Number of Points × Field Step.

Field Control Area (Continued)

Field Step: Enter the field value to increment for each data point of the experiment. This is a 'smart' text box, denoted by the yellow background. Enter the appropriate units along with the value itself, and the corresponding value displays in the box with the resulting units just to the right of the box.

NOTE: If the maximum field and the number of points are previously defined, the field step automatically calculates from the equation: Field Step = Bmax / Number of Points.

Number of points: Enter the number of data points to run for the experiment.

NOTE: If the maximum field and the field step are previously defined, the number of points automatically calculates from the equation: Number of Points = Bmax / Field Step.

Field Reversal: Select this box to enable field reversal (an 'X' in the box); de-select it to disable field reversal (an empty box).

Linear: Click this button to apply the field linearly.

Logarithmic: Click this button to apply the field logarithmically.

Current Iteration Every Point: A check mark in this box enables (or empty box disables) performing a current iteration after every change of field. This dramatically slows the experiment.

Additional Settle Time: Enter a value in this Text Box to add to the default settle time of two seconds. Enter a whole number greater than or equal to zero (0). The actual measurement settle time is at least as long as the total of the default settle time plus the additional settle time, or as much as one second longer.

5.2.2.8.4.2 Measurement Type Area

The Measurement Type area contains options to select specific measurements to make and sample geometry measurement method to use. Select Hall mobility measurement to choose a zero-field resistivity (B=0) or the actual field (B+ or B–) resistivities to calculate mobility.

Resistance: Click this button to measure sample resistance only across the contact points designated in the Resistance Contact Points text box directly to the right.

Resistance Contact Points: Designate (using standard nomenclature) the contact points to measure sample resistance.

Resistivity: Click this button to measure sample resistivity only.

Hall coefficient density (only): Select the Hall coefficient density (only) radio button to instruct the Experiment Hall software to measure only the Hall coefficient and density of the sample.

Hall mobility (everything): Select the Hall mobility radio button to instruct the Experiment Hall software to measure all the characteristics of the sample, including Hall coefficient, mobility, density, and resistivity. Select this radio button to choose a zero-field resistivity (B=0) or the actual field (B+ or B–) resistivities to calculate mobility.

Resistivity (B=0): Select the Resistivity (B=0) radio button to calculate the mobility of the sample using the zero-field resistivity, even if the positive and/or negative field resistivities are available as well.

NOTE: In order to select this radio button, first select the Hall Mobility (everything) radio button.

Resistivity (B): Select the Resistivity (B) radio button to calculate the mobility of the sample using the appropriate positive and/or negative field resistivities. If both the positive and negative field resistivities are available, the average value of the two resistivities calculates and that value determines the mobility.

NOTE: To select this radio button, first select the Hall Mobility (everything) radio button.

Average Both: Click this radio button to calculate appropriate sample measurements using the average of both Geometry A and Geometry B determined values.

Geometry A: Click this radio button to calculate appropriate sample measurements using only Geometry A determined values.

Geometry B: Click this radio button to calculate appropriate sample measurements using only Geometry B determined values.

5.2.2.8.4.3 Temperature Control Area

Select the initial and final temperatures, and temperature step, at which to perform measurements.

Initial Temperature: Enter the temperature at which the variable field/temperature experiment is to begin in this text box. Yellow indicates the text box accepts scaled inputs. Enter the appropriate units along with the value itself, and the corresponding value displays in the box with the resulting units displayed just to the right of the box.

Final temperature: Enter the temperature at which the variable field/temperature experiment is to end in this text box. Yellow indicates the text box accepts scaled inputs. Enter the appropriate units along with the value itself, and the corresponding value displays in the box with the resulting units displayed just to the right of the box.

Temperature step: Enter the increment at which the temperature is to increase, from the initial temperature to the final temperature in this text box. Yellow indicates the text box accepts scaled inputs. Enter the appropriate units along with the value itself, and the corresponding value displays in the box with the resulting units displayed just to the right of the box.

Rest Temperature: Go to this temperature when the experiment is concluded.

5.2.2.8.4.4 Excitation Control Area

If a fixed current is not selected, define the maximum current and the first current estimate (minimum current). There is an option to define the specific experimental tab connections to make on the sample as well.

Fixed Current: To perform the experiment under a set current value, click the radio button and enter the value in the text box to the immediate right. Yellow indicates the text box accepts scaled inputs. Enter the appropriate units along with the value itself, and the corresponding value displays in the box with the resulting units displayed just to the right of the box.

Fixed Power: To perform the experiment under a specific power value, click this button and enter the value in the text box to the immediate right. Yellow indicates the text box accepts scaled inputs. Enter the appropriate units along with the value itself, and the corresponding value displays in the box with the resulting units displayed just to the right of the box.

NOTE: If this radio button is selected, define the maximum current and the first current estimate (minimum current) using the corresponding text boxes in the Excitation Control area.

Fixed Voltage: To perform the experiment under a specific voltage value, click this button and enter the value in the text box to the immediate right. Yellow indicates the text box accepts scaled inputs. Enter the appropriate units along with the value itself, and the corresponding value displays in the box with the resulting units displayed just to the right of the box.

NOTE: If this radio button is selected, define the maximum current and the first current estimate (minimum current) using the corresponding text boxes in the Excitation Control area.

1st Current Estimate (Min Current): Enter the minimum current at which the experiment is conducted in this text box. Yellow indicates the text box accepts scaled inputs. Enter the appropriate units along with the value itself, and the corresponding value displays in the box with the resulting units displayed just to the right of the box.

NOTE: The program recognizes this value only when the Fixed Current radio button IS NOT selected.

Connections: Enter the specific sample contact configuration used for the measurements in this text box. By default, the box contains **R12,12** when this dialog box opens. Entering another configuration overwrites this default measurement.

The sample contact configuration syntax consists of four digits: the first identifies the sample contact that connects to the positive current source; the second identifies the sample contact that connects to the current source return; the third identifies the sample contact that connects to the positive voltmeter input; the fourth identifies the sample contact that connects to the negative voltmeter input.

NOTE: The format is free-form and non-numerical digits are ignored. To measure VC for sample contacts **1** and **2**, enter either **R12,12**, **1212**, or **12:12** in the text box.

Excitation Control Area (Continued)

Max Current: Enter the maximum current at which experiment is conducted in this text box. Yellow indicates the text box accepts scaled inputs. Enter the appropriate units along with the value itself, and the corresponding value displays in the box with the resulting units displayed just to the right of the box.

NOTE: The program recognizes this value only when the Fixed Current radio button IS NOT selected.

Settle Time: To enter a settle time different than the default of two seconds, select this text box. Yellow indicates the text box accepts scaled inputs. Enter the appropriate units along with the value itself, and the corresponding value displays in the box with the resulting units displayed just to the right of the box.

Current Reversal: Select this box to enable current reversal (an check in the box); de-select it to disable current reversal (an empty box).

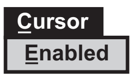
Resistance Range Area:

High (R > 100 kΩ): Click this button to indicate expected sample resistance range is high (>100 kΩ).

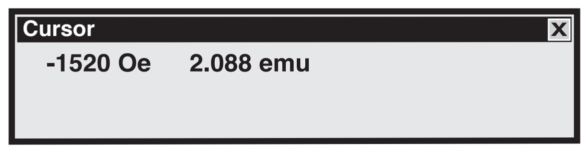
Low: Click this button to indicate expected sample resistance range is low (<100 kΩ).

Auto: Click this button to automatically determine the sample resistance range.

5.2.2.9 Cursor / Enabled



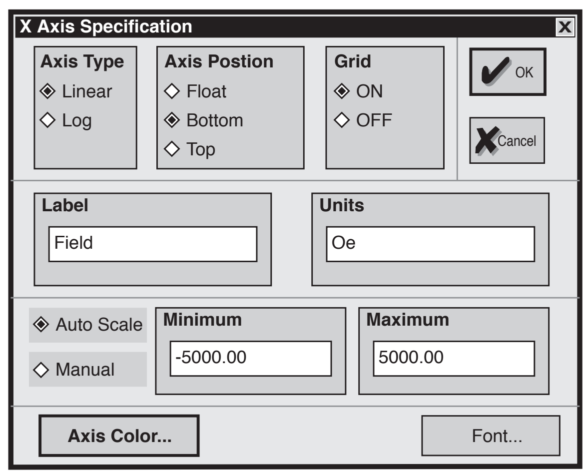
Displays coordinates in axis units of the cursor in the Graph Window. Axis units are specified in the Axis Specification dialog box. A check mark beside Enabled indicates the cursor coordinates box is active. Select Enabled again to disable.



Cursor Display Box

5.2.2.10 Axis

Displays the Axis Specification dialog box for either the X or Y axis. Here, users specify how the software creates the X and Y axes of the graph. The dialog boxes for each axis function identically.



Axis Specification Dialog Box

Axis Type: Click to specify an axis segmented linearly or logarithmically.

Axis Position: Sets the axis intersection.

Float: Intersects the specified axis with the zero of the other axis. If there is no zero, the specified axis intersects at the minimum absolute value of the other axis.

Bottom: Intersects the specified axis at the bottom (X) or left (Y) of the other axis.

Top: Intersects the specified axis at the top (X) or right (Y) of the other axis.

Grid: Click On to display grid lines for the axis. Click Off to display no grid lines.

Label: Enter the label of the axis to appear on the graph.

Units: Specifies the axis scale units. Enter a units string to display axis scaling in engineering units (0-1000) and the appropriate metric prefix (from atto to tera) in parenthesis after the axis Label. Enter no units to apply a scale between 1 and 15 times 10 to the proper exponent.

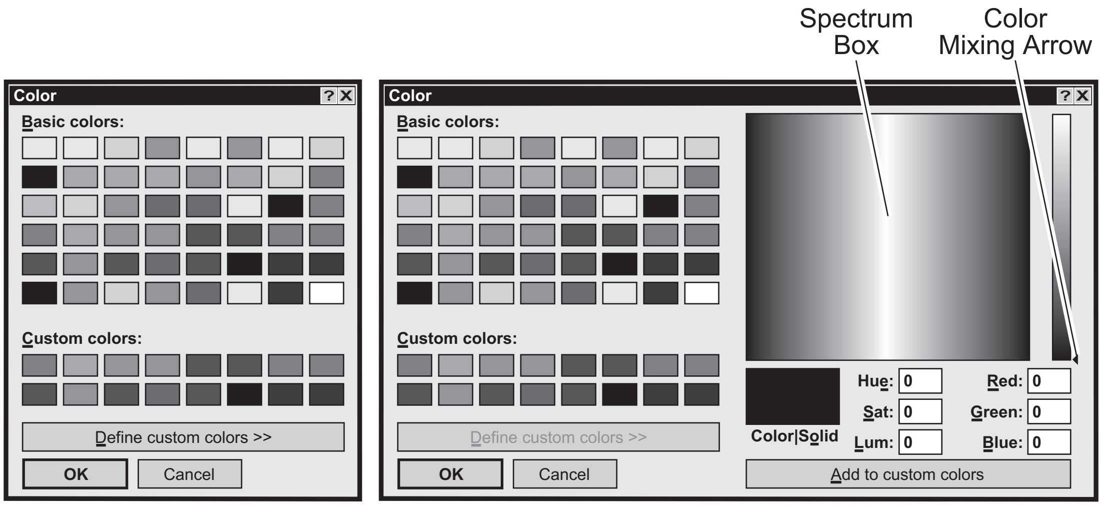
Auto Scale: Click to allow the software to automatically select proper minimum and maximum axis values.

Manual: Click to enter specific minimum and maximum axis values.

Minimum: Enter the minimum axis value. The software may lower the minimum to even out axis tick marks.

Maximum: Enter the maximum axis value. The software may raise the maximum to even out axis tick marks.

5.2.2.10.1 Axis Color



Color Dialog Box **Expanded Color Dialog Box**

Displays the Color dialog box. Click a Basic or Custom Color box, then click **OK** to apply that color to the axis. Click **Define custom colors** to expand the Color dialog box and display the Custom Color Definition section.

Basic Colors Area: Contains 48 predefined basic colors in an eight by six array of swatch boxes. Click on one of these basic color swatch boxes, then click the **Define Custom Colors...** button. The corresponding color values (hue, saturation, luminosity, red, green, and blue) for the selected color display in the Define Custom Colors dialog box. Also, the specific location of this color displays in the spectrum area located to the immediate right, and the intensity bar located at the far right indicates the relative color intensity.

Custom Colors Area: Contains 16 customized colors in an eight by two array of swatch boxes.

Define Custom Colors... Button: Click this button to expand the Color dialog box into the **Color {Define Custom Colors}** dialog box where users create custom colors and add them to the Custom Colors area.

In the **Color {Define Custom Colors}** dialog box users select a specific color from a spectrum of colors. Once selected, users may vary the color brightness. Alternatively, users may enter specific hue, saturation, luminosity, red, green, and blue color values to exactly match a color. Once customized, users may add the new color to one of the Custom Colors swatch boxes.

To create custom colors in the **Custom Colors Area**:

1. Click a swatch box of the **Custom Colors Area** in which to insert the custom color.
2. Click the **Define Custom Colors...** button to expand the Color dialog box.
3. Click anywhere in the Spectrum Box to select a color with the displayed Hue and Saturation. Slide the Color Mixing Arrow up or down to add desired Luminosity, Red, Green, and Blue to the base color.
4. After mixing the appropriate color, click **Add to custom colors**, to display the new color in the swatch box designated in Step 1 above.
5. Click the swatch box containing the new color, then click **OK** to apply the custom color to the axis.

Also, if users select a swatch box already containing a customized color and then click **[Define Custom Colors...]**, the **Color {Define Custom Colors}** dialog box indicates the corresponding color values (hue, saturation, luminosity, red, green, and blue) for the selected color. Also, the spectrum area located to the immediate right displays the color location, and the intensity bar located at the far right indicates the relative color intensity.

Color Spectrum Window: The color spectrum window area displays the color spectrum. Select any point within this area, to display five color values (hue, saturation, red, green, and blue) in the corresponding text boxes at the lower right of this dialog box. Note that luminosity remains unchanged.

Axis Color (Continued)

Color Intensity Window: Indicates color intensity – brightest is at the top, while darkest is at the bottom. By selecting any point within this area – by either clicking within this window or by sliding the handle along the right side, luminosity, red, green, and blue values change in the corresponding text boxes at the lower right of this dialog box. Note that neither hue or saturation change.

Color/Solid View Window: This window illustrates the appearance of the defined color.

Hue Text Box: The hue – also known as shade or tint – is a color characteristic that assigns it to a position in the spectrum. This text box displays the corresponding color hue value, ranging from 0 (the red end of the color spectrum) to 239 (the violet end of the color spectrum) for an existing or newly created color. Users may left click within this text box to enter a color hue value between the same range (0-239).

Sat Text Box: The saturation is the degree of color purity as measured by its freedom from mixture with white. This text box displays the corresponding color saturation value, ranging from 0 (no saturation and gray) to 240 (full saturation) for an existing or newly created color. Users may left click within this text box to enter a color saturation value between the same range(0-240).

Lum Text Box: The luminosity is the degree of brightness of a color. This text box displays the corresponding color luminosity value, ranging from 0 (fully dark or black) to 240 (fully bright or white), for an existing or newly created color. Users may left click within this text box to enter a color luminosity value between the same range (0-240).

Red Text Box: This text box displays the corresponding red color value, ranging from 0 to 255, for an existing or newly created color. Users may left click within this text box to enter a red color value between the same range (0-255).

Green Text Box: This text box displays the corresponding green color value, ranging from 0 to 255, an existing or newly created color. Users may left click within this text box to enter a green color value between the same range (0-255).

Blue Text Box: This text box displays the corresponding blue color value, ranging from 0 to 255, for an existing or newly created color. Users may left click within this text box to enter a blue color value between the same range (0-255).

RGB Color Value: The RGB Color Value analytically represents the appearance of a color. A given color is represented by the combination of various portions of three primary colors, **R**ed, **G**reen, and **B**lue (minimum 0 = none; maximum 255 = total) For example:

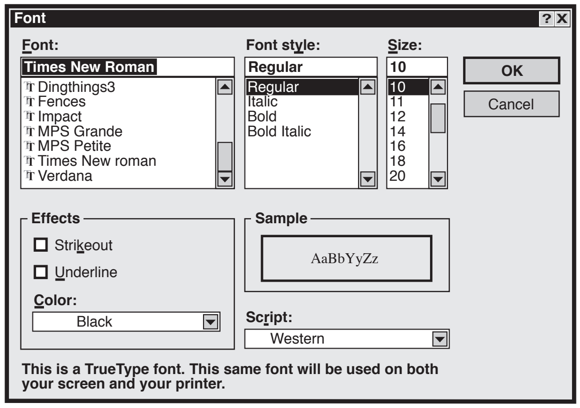
Black has an RGB color value of 0,0,0;	Cyan has an RGB color value of 0,255,255;
Red has an RGB color value of 255,0,0;	Blue has an RGB color value of 0,0,255;
Yellow has an RGB color value of 255,255,0;	Magenta has an RGB color value of 255,0,255;
Green has an RGB color value of 0,255,0;	White has an RGB color value of 255,255,255.

Add to Custom Colors Button: Click this button to add the color defined by the set of six color values to one of the sixteen swatch boxes in the Custom Colors area.

NOTE: First select the specific Custom Color swatch box in which to insert a custom color, then customize a color, before clicking **Add to Custom Colors**.

5.2.2.10.2 Font

Displays the Font dialog box which specifies the type and style of font to use for axis label and numbering. The software supports only TrueType fonts.



Font Dialog Box

Font: Select a font from the list of available fonts.

Font Style: Select a style to apply to a selected font.

Size: Select a desired size for a selected font.

Effect: Choose one of the following options:

Strikeout: Font prints with a bar through it.

Underline: Font prints with an underline.

Color: From the list, select a color to apply to the selected font.

Sample: Displays an example of the selected font with the selected attributes applied.

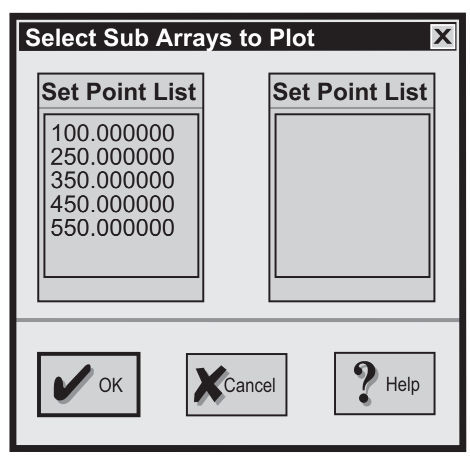
Script: Unapplied field.

5.2.2.11 Contract

Shrinks the currently magnified Graph window one level. Contract is grayed when the Graph window is unmagnified. Contract remembers up to ten levels. To magnify a portion of the graph, click anywhere within the graph box with the left mouse button and drag to draw a boundary box around the desired portion. The Graph window magnifies and displays only the desired portion.

5.2.2.12 Select Sub Array

Available only with array experiments. Displays the Select Sub Array to Plot dialog box shown on the right where users select sub-arrays of an active array experiment to plot in the experiment Graph Window. Double click on the desired sub-arrays listed in the Set Point List window to display them in the Selected List window. When finished, click **OK**. Only the sub-arrays in the Selected List now display in the experiment graph window. To remove sub-arrays from the Selected List simply double click on the desired sub-arrays.



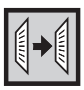
5.2.3 TOOL Bar


New – Initiates a new experiment. Displays the Sample Definition dialog box where the user enters sample attributes and the experiment name. Refer to Paragraph 5.2.1.1.

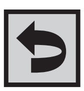

Open... – Opens an existing experiment saved to disk. Displays the Open dialog box. Refer to Paragraph 5.2.1.2.


Save – Saves currently active experiment to disk. Refer to Paragraph 5.2.1.4.


Cut – Removes highlighted text from the display and copies it to the clipboard.


Copy – Copies highlighted text to the clipboard without removing it from the display.


Paste – Copies the clipboard contents to the cursor location.


Undo – Undoes the last action performed.


Find – Finds a match to the specified text.


Find Next – Finds the next match to the specified text.


Print – Immediately outputs to the printer either the data or graph of an experiment. Refer to Paragraphs 5.2.1.12 and 5.2.1.13.


Print Preview – Displays a read-only view of the experiment data or graph before printing it. Refer to Paragraph 5.2.1.11.


Help – Accesses the VSM Software Help Documentation.

5.3 MEASUREMENT RESULTS DIALOG BOXES

On the two foldout pages that follow, you will find graphic representations of the single-point Hall measurements made by the Hall Software. The first foldout details the six levels of measurements and calculations that are required to produce one van per Pauw Hall measurement. Pin configurations shown in Level 6 represent actual measurements. All subsequent boxes are mathematically equated from those actual measurement. The second foldout details the six levels of measurement and calculations that are required to produce one Hall bar measurement. The three pin configurations detailed are 1-2-2-1, 1-3-3-1, and 1-3-1-1.

Subsequent paragraphs provide typical dialog boxes that are displayed at each level.

This Page Intentionally Left Blank

Foldout Goes Here

van der Pauw Structure Single-Point Hall Measurement

Use file: T:/My Documents/Software/Hall Software/Manual/Graphics/Hall_vdp.cvs

Blank page on reverse of foldout

Foldout Goes Here

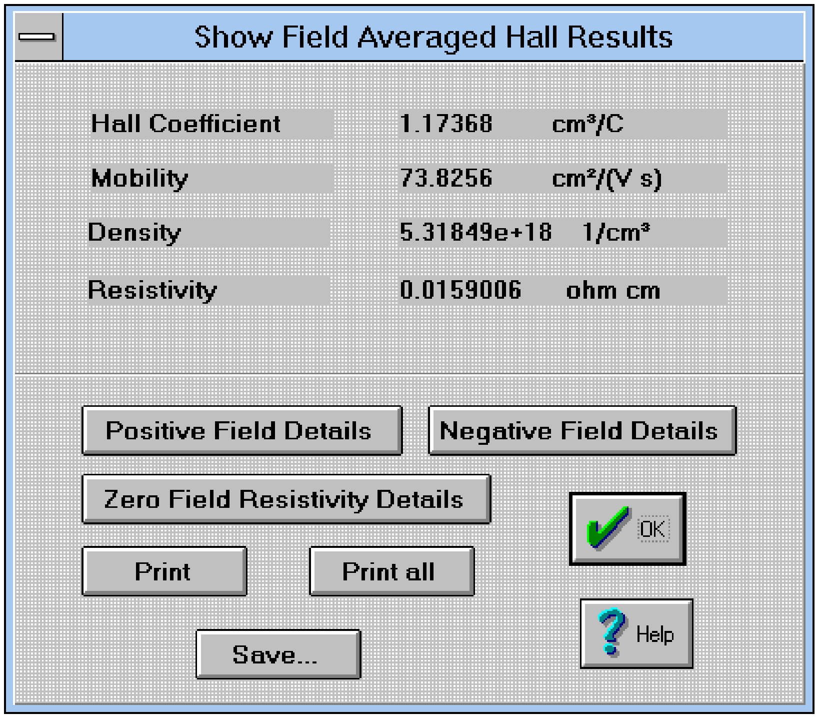
Hall Bar Structure Single-Point Hall Measurements

Use file: T:/My Documents/Software/Hall Software/Manual/Graphics/Hall_bar.cvs

Blank page on reverse of foldout

5.3.1 Level 1 - Show Field Averaged Hall Results Dialog Box

The Show Field Averaged Hall Results Dialog Box displays results of the Level 1 measurement. To display this dialog box click OK from the Show Details dialog box.



Hall0107.bmp

The Hall Coefficient, Mobility, Density, and Resistivity are actual numerical results of the measurement. Further details of the measurement can be displayed by selecting the various buttons.

Positive Field Details: Displays the “Show Hall Results” dialog box (Level 2). The values in this dialog box represent the positive field for the data point specified on the variable field measurement graph plot.

Negative Field Details: Displays the “Show Hall Results” dialog box. The values in this dialog box represent the negative field for the data point specified on the variable field measurement graph plot.

Zero Field Resistivity Details: Displays the “Resistivity Measurement Results” dialog box. The values in this dialog box represent the zero field for the data point specified on the variable field measurement graph plot.

Print: Click this button to print a four-page report summarizing the Field Averaged Hall Results for the data point identified on the variable field measurement graph plot. Refer to Paragraph 5.3.1.1 for an example printout.

Print All: Click this button to print an eleven-page report on the Field Averaged Hall Results for the data point identified on the variable field measurement graph plot. Refer to Paragraph 5.3.1.2 for an example printout.

Save…: Displays a Save As dialog box. Here, users may specify the location of a file containing the Hall Measurement data for the specific data point identified on the variable field measurement graph plot. The .txt extension automatically appends to the filename when it saves.

OK: Click this button to close the Show Field Averaged Hall Results dialog box and return to the main screen.

Help: Click this button to open the on-line help.

5.3.1.1 Sample Print

The following is an example when Print is selected from the Level 1 dialog box.

```
Printout - Zero Field Resistivity Details
      Friday May 23 2001  3:24:00 PM
Zero field resistivity
Resistivity          0.015898 ohm cm
Sheet Resistivity    0.300529 ohm/sqr
Thickness            0.0529 cm

Printout - Field Average Hall Results
       Friday May 23 2001  3:24:07 PM
Hall Measurement
Hall coefficient     1.17368 cm³/C
Mobility             73.8256 cm²/(V s)
Density              5.31849e+18 1/cm³
Field                4999.5 G
Temperature          1.58442e-197 K
Hall factor          1
Resistivity(B=0)      0.0159006 ohm cm

Printout - Positive Field Details
      Friday May 23 2001  3:24:12 PM
(B+)
Hall coefficient     1.19329 cm³/C
Mobility             75.0589 cm²/(V s)
Density              5.2311e+18 1/cm³
Field                5001 G
Temperature          1.58442e-197 K
Hall factor          1
Resistivity(B=0)      0.0159005 ohm cm

Printout - Negative Field Details
      Friday May 23 2001  3:24:17 PM
(B-)
Hall coefficient    1.15407 cm³/C
Mobility            72.5923 cm²/(V s)
Density             5.40884e+18 1/cm³
Field               -4998 G
Temperature         1.58442e-197 K
Hall factor         1
Resistivity(B=0)     0.0159008 ohm cm
```

5.3.1.2 Sample Print All

The following is an abbreviated example of when Print All is selected from the Level 1 dialog box.

```
Printout - Zero Field Resistivity and Geometry A Details
      Friday May 23 2001  3:11:50 PM
Zero field resistivity
Resistivity       0.015898 ohm cm
Sheet Resistivity    0.300529 ohm/sqr
Thickness         0.0529 cm

   Geometry A (B=0)
   Resistivity      0.0159052 ohm cm
   Sheet Resistivity    0.300666 ohm/sqr
   Thickness         0.0529 cm
   F value         0.999977
     R(12,43) (B=0)
     Set current      0.05 A
     Settle time       3 s
     Current        0.05 A
     Voltage     0.00334385 V
     Resistance    0.066877 ohm
```

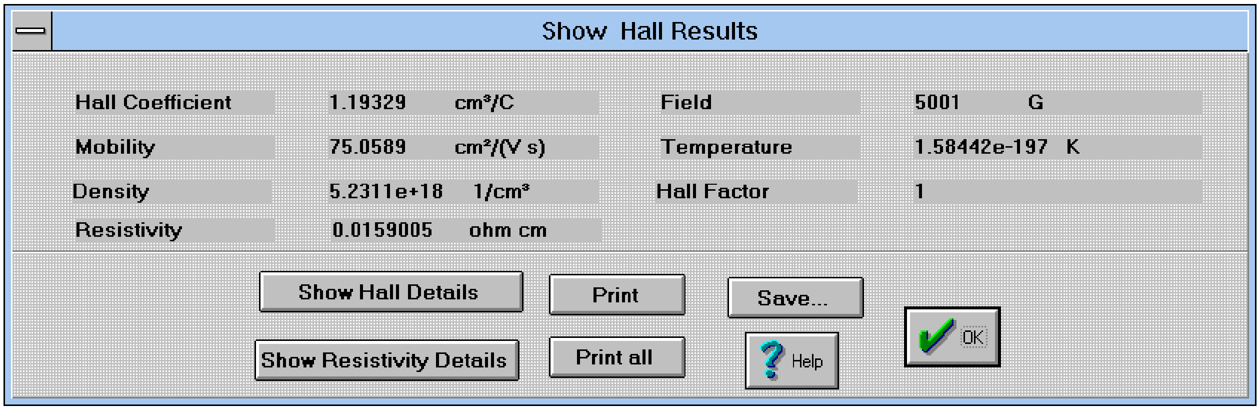
Sample Print All (Continued)

```
R(+12,43) (B=0)
        Set current      0.05 A
        Settle time       3 s
        Current        0.05 A
        Voltage     0.00334609 V
        Resistance    0.0669218 ohm

        R(-12,43) (B=0)
        Set current     -0.05 A
        Settle time       3 s
        Current       -0.05 A
        Voltage    -0.00334161 V
        Resistance    0.0668322 ohm

     R(23,14) (B=0)
     Set current      0.05 A
     Settle time       3 s
     Current        0.05 A
     Voltage     0.00329007 V
     Resistance    0.0658014 ohm

        R(+23,14) (B=0)
        Set current      0.05 A
        Settle time       3 s
        Current        0.05 A
        Voltage     0.0033007 V
        Resistance    0.066014 ohm

        R(-23,14) (B=0)
        Set current     -0.05 A
        Settle time       3 s
        Current       -0.05 A
        Voltage    -0.00327944 V
        Resistance    0.0655888 ohm

Printout - Zero Field Resistivity and Geometry B Details
      Friday May 23 2001  3:11:51 PM

Zero field resistivity
Resistivity       0.015898 ohm cm
Sheet Resistivity    0.300529 ohm/sqr
Thickness         0.0529 cm

   Geometry B (B=0)
   Resistivity      0.0158908 ohm cm
   Sheet Resistivity    0.300392 ohm/sqr
   Thickness         0.0529 cm
   F value         0.999982
     R(34,21) (B=0)
     Set current      0.05 A
     Settle time       3 s
     Current        0.05 A
     Voltage     0.00333747 V
     Resistance    0.0667495 ohm

        R(+34,21) (B=0)
        Set current      0.05 A
        Settle time       3 s
        Current        0.05 A
        Voltage     0.00333325 V
        Resistance    0.066665 ohm

        R(-34,21) (B=0)
        Set current     -0.05 A
        Settle time       3 s
        Current       -0.05 A
```

(The remainder of this printout has been omitted for brevity.)

5.3.2 Level 2 - Show Hall Results Dialog Box

To display this dialog box, click either the Positive or Negative Field Details button in the Show Field Averaged Hall Results dialog box for a variable field setup. Depending on the button selected, values for either the positive or negative field Hall Coefficient, mobility, density, resistivity, field, temperature, and Hall Factor display. To display more detailed Hall and resistivity values, use the appropriate buttons on the dialog box. Users may print details for the selected data point.



Hall0108.bmp

The Hall Coefficient, Mobility, Density, Resistivity, Field, Temperature, and Hall Factor are actual numerical results of the measurement. Further details of the measurement can be displayed by selecting the various buttons.

Show Hall Details: Displays a Show Hall Results {Geometry} dialog box. If the Positive Field Details button is originally selected from the Show Field Averaged Hall Results dialog box, the Hall result values represent the positive (B+) field. If the Negative Field Details button is originally selected, the Hall result values represent the negative (B–) field.

Show Resistivity Details: Displays the Resistivity Measurement Results {-} dialog box. The values in this dialog box represent the specific data point identified on the variable field measurement graph plot.

Print: Click this button to print a one-page report of the Hall Results displayed in the Show Hall Results dialog box, which represents the data point specified on the variable field measurement graph plot. Click the Positive Field Details button from the Show Field Averaged Hall Results dialog box to print Hall result values from the positive (B+) field. Click Negative Field Details to print values from the negative (B–) field.

Print All: Click this button to print a four-page report detailing the Hall Results for the specific data point identified on the variable field measurement graph plot. Click the Positive Field Details button from the Show Field Averaged Hall Results dialog box to print Hall result values from the positive (B+) field. Click Negative Field Details to print values from the negative (B–) field.

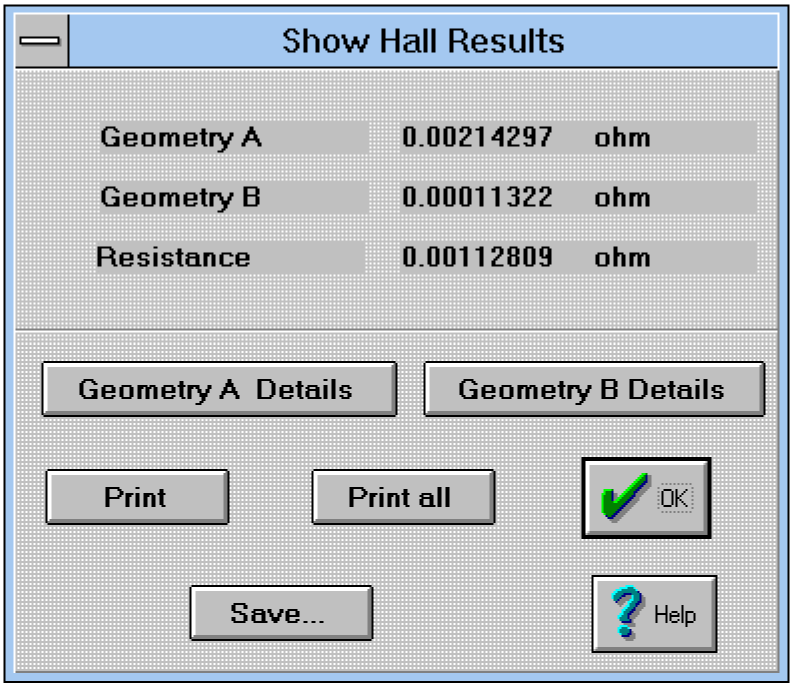
Save: Displays the Save As (*.txt text file type) where users may save a text file containing data which supports that shown in the current dialog box. See also: Hall System File

OK: Click this button to save changes, close the dialog box, and return to the previous dialog box or window.

Help: Click this button to open the on-line help.

5.3.3 Level 3 - Show Hall Results Dialog Box

To display the Level 3 dialog box, click the Show Hall Details button from any of the Show Hall Results dialog boxes for variable field setup. Also, depending on whether the Positive or Negative Field Details button was originally selected in the Show Field Averaged Hall Results dialog box, the average values for the respective positive or negative field Geometry A average current resistance, Geometry B average current resistance, and overall average resistance are shown. To display more detailed Geometry A and Geometry B values, click the appropriate buttons in this dialog box. All these details may be printed, in varying level of detail, for the specific data point selected.



Hall0109.bmp

Geometry A Details: Displays the corresponding Show Current Reversal Results dialog box.

Geometry B Details: Displays the corresponding Show Current Reversal Results dialog box.

Print: Click this button to print only data in the current dialog box. Typical printout contains:

```
     Wednesday January 1 2001  11:52:25 PM
Hall Measurement (B-)
R(42,13) (B-)          -7.577e-05 ohm
R(31,24) (B-)          -0.00210497 ohm
Hall Resistance        -0.00109037 ohm
```

Print All: Click this button to print all data contained in this and lower levels of the Variable Field Hall and which supports data in the current dialog box.

Save: Displays the Save As ('*.txt' text file type) dialog box, where users may identify and save a text file containing data which supports that shown in the current dialog box.

OK: Click this button to save changes, close the dialog box, and return to the previous dialog box or window.

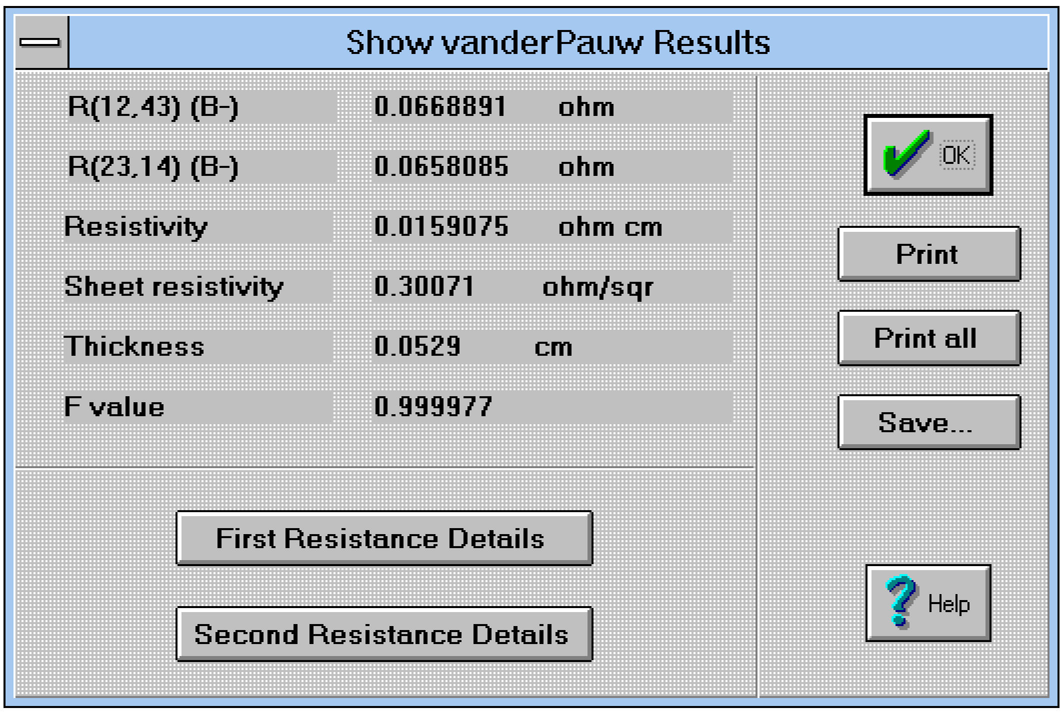
Help: Click this button to activate context-sensitive, on-line-help specific to the dialog box.

5.3.4 Level 4 - Show van der Pauw Results Dialog Box

Depending upon the field and the geometry selected, one of six variations of the Show van der Pauw Results dialog box are possible:

Positive Field and Geometry A
Positive Field and Geometry B
Negative Field and Geometry A
Negative Field and Geometry B
Zero Field and Geometry A
Zero Field and Geometry B

The following is a typical level 4 dialog box.



Hall0140.bmp

First Resistance Details: Displays the corresponding first resistance results dialog box.

Second Resistance Details: Displays the corresponding second resistance results dialog box.

Print: Click this button to print only data in the current dialog box.

Print All: Click this button to print all data contained in this and lower levels of the Variable Field Hall and which supports data in the current dialog box.

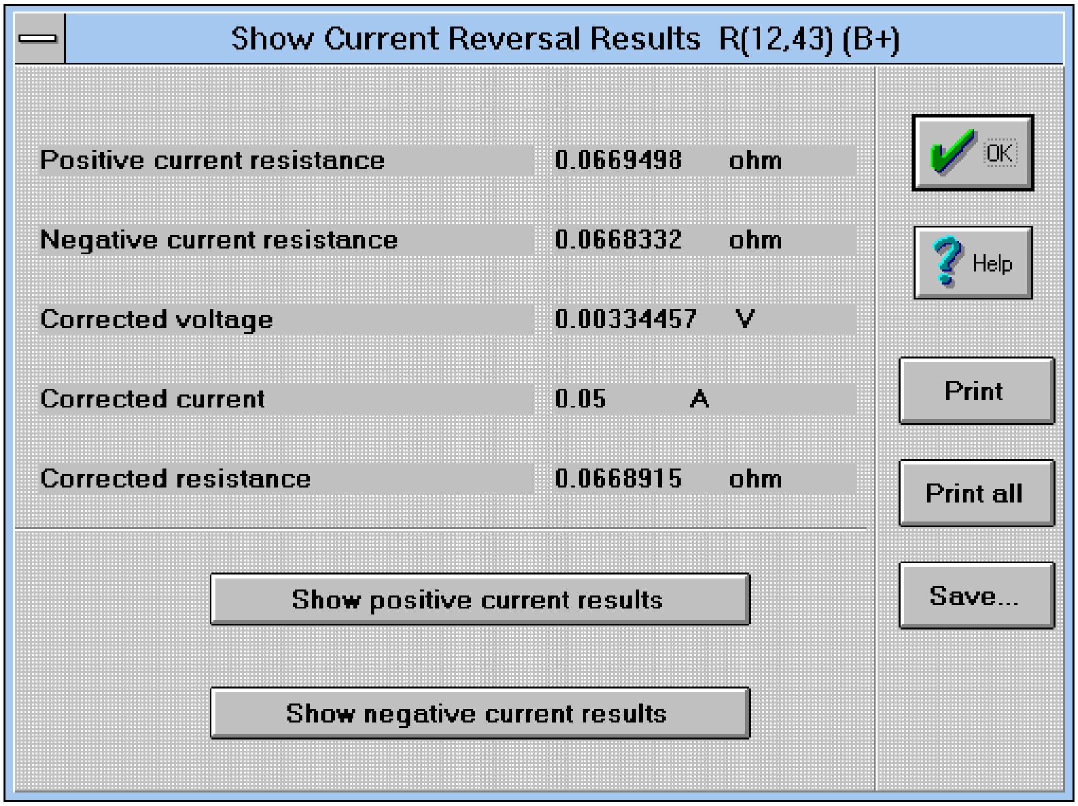
Save: Displays the Save As ('*.txt' text file type) dialog box, where users may identify and save a text file containing data which supports that shown in the current dialog box.

OK: Click this button to save changes, close the dialog box, and return to the previous dialog box or window.

Help: Click this button to activate context-sensitive, on-line-help specific to the dialog box.

5.3.5 Level 5 - Show Current Reversal Results Dialog Box

There are three variations of this dialog box, depending whether a positive field (B+), a negative field (B–), or a zero field (B=0) is applied. The typical dialog box shown below is representative of the other variations.



Hall0118.bmp

Positive Current Resistance: This value represents the resistance for data point Number 1 as calculated and displayed on the Show Resistance Results (R+ 12,43) dialog box.

Negative Current Resistance: This value represents the resistance for data point Number 1 as calculated and displayed on the Show Resistance Results (R– 12,43) dialog box. No value will be displayed if the experiment has only positive current applied.

Corrected Voltage: This result represents the average of the difference in measured voltages when both A and B geometries are included. This example uses only one geometry, performs no average, and uses zero as the value of the corrected voltage**.**

Corrected Current: This result represents the average of the difference in measured currents when both A and B geometries are included. This example uses only one geometry, performs no average, and uses zero as the value of the corrected voltage.

Corrected Resistance: The Corrected Resistance represents the result of the equation **Rc = Vc / Ic**, where **Rc** = corrected resistance in ohms, **Vc** = corrected voltage in volts, and **Ic** = corrected current in amperes. Since corrected voltage and corrected current equal zero, the result for corrected resistance is also zero.

Show Positive Current Results: Displays the Show Resistance Results dialog box, the source of the positive current resistance value shown above.

Show Negative Current Results: Displays the Show Resistance Results dialog box, the source of the negative current resistance value shown above. If only one geometry is used in the experiment, and a negative current is not applied, there are no negative current results and this button is inactive.

OK: Click this button to close the dialog box and return to the previous screen window.

Help: Click this button to activate context-sensitive, on-line-help specific to this dialog box.

Level 5 - Show Current Reversal Results Dialog Box (Continued)

Print: Click this button to print only the data which supports that shown in the current dialog box. The following illustrates a typical print format.

```
Tuesday September 4 2001  3:49:52 PM
Set current       0 A
Settle Time       2 s
Current           0 A
Voltage           0 V
Resistance        0 ohm
```

Print All: Click this button to print all the data contained in this and lower levels which supports that shown in the current dialog box. For this example, the printed document contains the data below:

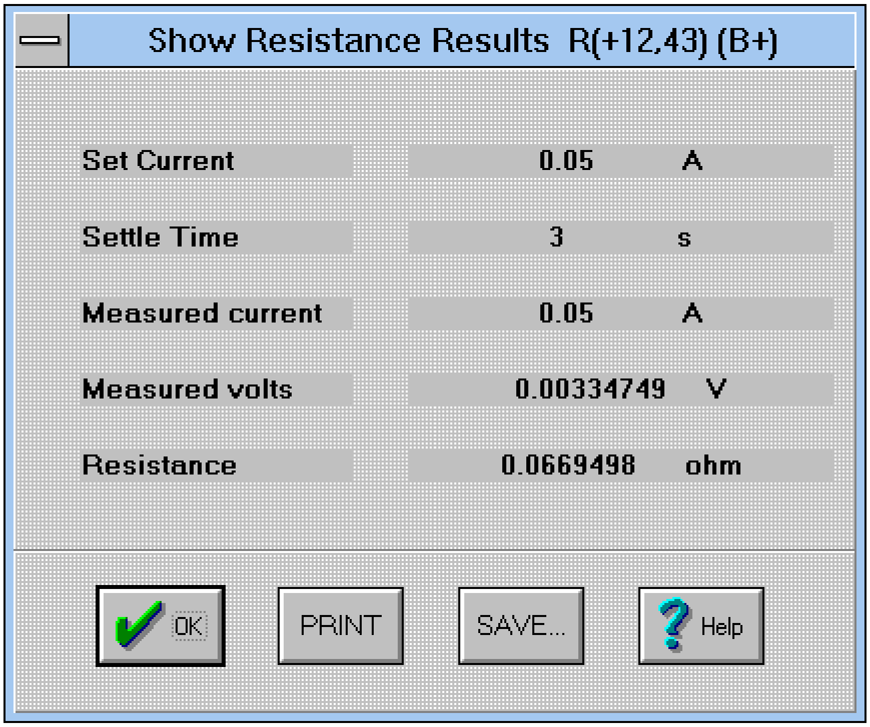
```
Tuesday September 4 2001  3:50:34 PM
Set current       0 A
Settle Time       2 s
Current           0 A
Voltage           0 V
Resistance        0 ohm

R(+12,12)
Set current       0 A
Settle Time       2 s
Current           -0.0009999 A
Voltage           -5.47017 V
Resistance        5470.72 ohm

Set current       0 A
Settle Time       2 s
Current           0 A
Voltage           0 V
Resistance        0 ohm
```

Save…: Displays the Save As ('*.txt' text file type) dialog box, where users may identify and save a text file containing the data which supports that shown in the current dialog box. For this example, the saved text file contains the data below:

```
Tuesday September 4 2001  3:53:16 PM
Set Current       0 A
Settle Time       0 s
Current           0 A
Voltage           0 V
Resistance        0 ohm

R(+12,12)
Set Current       0 A
Settle Time       2 s
Current           -0.0009999 A
Voltage           -5.47017 V
Resistance        5470.72 ohm

Set Current       0 A
Settle Time       0 s
Current           0 A
Voltage           0 V
Resistance        0 ohm
```

5.3.6 Level 6 - Show Resistance Results Dialog Box

There are several variations of Show Resistance Results dialog boxes, depending upon the specific contact pairs chosen. The display shown below is a typical representative of the data displayed.



Hall0119.bmp

Set Current: The value shown here represents the actual set point current under which the experiment is conducted.

Settle Time: The value shown here represents the predetermined settle time under which the experiment is conducted.

Measured Current: The value shown here represents the actual current as measured for a specific data point during an experiment.

Measured Volts: The value shown here represents the actual voltage as measured for a specific data point during an experiment.

Resistance: If the current is zero, the resistance is defined as the largest floating point number, i.e., ~10^302 ohms. If the current measured is not zero, the resistance (r) is calculated using the equation, r = V / I, where 'r' is the calculated resistance in ohms, 'V' is the measured voltage in volts, and 'I' is the measured current in amperes. If the measured current is greater than 2 mA, the set point current is used for this calculation.

Print: Click this button to print only the data which supports that shown in this current dialog box.
For this typical example, the resulting printed document would contain data similar to the following:

```
Tuesday September 4 2001  4:20:56 PM
R(+12,12)
Set current        0 A
Settle Time        2 s
Current            -0.0009999 A
Voltage            -5.47017 V
Resistance         5470.72 ohm
```

Level 6 - Show Resistance Results Dialog Box (Continued)

Save: Displays the Save As (‘*txt’ text file type) dialog box, where users may identify and save a text file containing data which supports that shown in the current dialog box. Typical output contains:

```
Tuesday September 4 2001  4:21:27 PM
R(+12,12)
Set Current       0 A
Settle Time       2 s
Current           -0.0009999 A
Voltage           -5.47017 V
Resistance        5470.72 ohm
```

OK: Click this button to save changes, close the dialog box, and return to the previous dialog box or window.

Help: Click this button to activate context-sensitive, on-line-help specific to the dialog box.

5.4 SYSTEM STARTUP SEQUENCE

5.4.1 Starting the Model 7504 From Complete Shutdown

- Power up the instrument rack and computer.
- Turn on the power supply.
- Wait one hour for instruments to warm up.
- Turn on water flow to magnet.
- Start the Hall System Software program with no other software running.

5.4.2 Starting the Model 7507 From Complete Shutdown

Do not turn on the power supply with a non-zero control voltage on its rear **Remote Reference** coaxial BNC. To check this, put a coaxial BNC Tee on the **Remote Reference** and monitor the voltage with a voltmeter. Verify the voltage is near zero whenever the power supply is turned on (by pushing the front panel **RESET** and **ON** buttons in the Instrument Power section).

1. Start with everything powered off
2. Turn on the water flow to the magnet
3. Power up the instrument rack and computer
4. Power supply:
   a. Set main breaker switch to **ON**.
   b. Set front panel Mode toggle switch to **I MODE**.
   c. Set front panel Local/Remote toggle switch to **REMOTE**.
   d. Set **LOCAL REFERENCE** potentiometer to 5.0 (0.0 gives negative and 10.0 gives positive full scale current when in **LOCAL** mode).
   e. Set both **VOLTAGE LIMIT** and **CURRENT LIMIT** potentiometers to 10.0.
5. Verify voltage supplied to the power supply rear **REMOTE REFERENCE** coaxial BNC is 0.0 volts. The **CORRECTED ANALOG OUTPUT** of the 450 Gaussmeter supplies this voltage (–10.0 gives negative and +10.0 gives positive full scale current when the power supply is in **REMOTE** mode).
6. If this voltage is not equal to 0.0 volts, do the following:
   a. Double click the 450 software icon.
   b. Click on the **Front Panel** menu item.
   c. Set control output to 0.0 and press Tab.
   d. The voltage to the power supply rear **REMOTE REFERENCE** coaxial BNC should now read 0.0 volts. Do not continue unless it does.
   e. Exit the 450 software for proper Hall System Software startup sequence.

Starting the Model 7507 From Complete Shutdown (Continued)

7. Turn on the power supply:
   a. Press front panel **REST** button in the Instrument Power section.
   b. Verify green front panel **READY** and **+15V SUPPLY** status lights are On, and all red lights are off.
   c. Press front panel **ON** button in the Instrument Power section.
   d. The green front panel **ON** status light should light.
8. Start the Hall effect computer program:
   a. The power supply green front panel **ON** status light should be lit.
   b. The computer should have Windows running with the Program Manager window displayed. No other software should be running.
   c. Double click the Hall System Software program icon.

5.5 HALL PROGRAM ENVIRONMENT

There are two main windows in the Hall System Software display: numerical data and graphical data. The two windows have separate functions associated with them, and the upper menu bar displays different options depending on which window is highlighted.

5.5.1 Getting Started

Accessing the Software Applications. To access the Hall Software applications, click on the desired icons on the Program Manager window. To open the Hall System Software application, click on the icon, then minimize the Windows Program Manager window to allow icons for other applications to display at the bottom of the screen. To access individual applications, click on icons located at the bottom of the screen. These icons represent minimized running applications.

Minimizing Windows. The Hall System Software creates a flexible Windows environment that allows users to maximize and minimize windows. When an application is minimized, it may still be running. If a window is **closed** instead of **minimized**, the computer is unable to access that instrument, and the system may crash. A minimized window is represented by an icon at the bottom of the screen. To minimize a window, click on the leftmost button (the dash "–") in the upper right corner or select minimize under the **File** menu. To close a window, click on the rightmost button (the "X") in the upper right corner, or select close under the **File** menu.

5.5.2 Creating and Saving Files

From within the Hall application, it is possible to create a completely new file or to modify a previous run. The advantage of modifying a previous run is that the file name can simply be changed to create another run with the same sample or configuration.

The first line of the dialog box under Sample Definition becomes the file name unless overridden by the operator. **The file name is limited to eight (8) characters**, followed by the '.hal' extension which will be appended automatically.

There are three ways to create a file:

1. **New:** Creates a new, blank file using Hall System Software default settings. Under File, select New, or click the New icon in the upper left corner. It is best to close open files before doing this.
2. **Save As:** Creates a new file using the current file as a template. The **Sample Definition** menu will open. Changing the first line of the sample definition (the file name) creates a new file after clicking OK. This option facilitates large numbers of similar runs.
3. **Sample Definition:** Creates a new file using the current file as a template. Under **Sample Definition**, select Edit. Changing the first line of the sample definition (the file name) creates a new file after clicking OK. This option facilitates large numbers of similar runs.

5.5.3 Data Display

To affect the display of the data, highlight the data window. The upper menu bar displays options associated with the display and manipulation of numerical data. Some tips:

1. The data window must be highlighted to set up a run.
2. Highlighted text within the data window, activates the icon bar below the upper menu for editing.
3. Use Sample Definition to edit comments/experiment information, create a new file, and specify sample parameters such as thickness. The first line of the dialogue box is the file name.
4. Use Display to select results and statistics for display.
5. Use Window to change the display format.
6. Use Setup to set up an experiment.

5.5.4 Detailed Measurements

To display the details of any one reading, select **Show Details** from the menu. An input dialog box requests the point number. Enter the point number for which you want details. For temperature sweeps, point n is the nth temperature; for field sweeps, point n is the nth field. In either case, both positive and negative field details display regardless of the order in which data was acquired.

After selecting **OK** on the input dialog box, a new dialog box displays the field averaged results (the same information in the text window) and several buttons. One button views the details of the zero field resistivity measurement. In field sweep mode, the resistivity is measured at zero field at the beginning of the experiment. Two other buttons view both the positive and negative field hall results.

The **Print** and **Print All** buttons print results. The **Print** button prints only the top level; **Print All** prints all lower levels (outputs 8 pages). The **Save** button saves information (with labels and names) as an ASCII file.

To save all the details for each point in an ASCII file, one point per line, select **Save As Ext. Text** from the **File** menu of the text window. A header line shows the order of the data. Read this file into a spreadsheet program for further analysis.

Moving down to the next level, for the positive and negative Hall results, the results for the measurements at field appear. Here, a button shows resistivity results. If **resistivity vs. B** was selected, then this is the measurement at field; if not, then it is a copy of the zero field resistivity results. Each Hall measurement is an average of two different geometric configurations. Click **Geometry A** or **Geometry B** to view these results.

At this level, the current reversal correct voltages, currents and resistance display. Two buttons allow selection of positive and negative measurements, which show the actual measured voltages and currents.

Click **Resistivity** to display a similar tree. Two different geometric configurations of the van der Pauw measurement, each two current corrected resistance measurements, each with two sets of current and voltage readings.

5.5.5 Graphics Display

Several features are built into the Hall application to make the graphics easier to understand. When the graphics window is highlighted, the menu bar focuses on graphical display options. Some tips:

1. Draw a border on the graph with the mouse (click and drag) to zoom in on the bordered region. Select **Contract** on the upper menu to move the graphic display back one magnification.
2. Format options:
   Display: specifies axes of the graph.
   Axis: formats the axes.
   Curve Information: formats the graph.
3. **Window** changes the display window format.
4. **Contract** returns the graphics display to previous view, not original view.

5.5.6 Helpful Hints

1. When entering a value, default units may not be set as desired. Enter the numerical value, then type the metric prefix for the unit desired with no space between the number and the unit prefix. (For example, input 4m for 4 mA or 3.5ų for 3.5 µA). To enter this value and move on to the next line, press the Tab key. This displays the newly entered units. If Tab is not pressed, the new value displays, but the units do not change. The new units are, in fact, entered into the system, but they do not display.
2. The system measures either zero field resistivity or the resistivity at field, and uses resistivity to calculate mobility. Under **Setup**, there is a category titled Measurement Type. There are two options that deal specifically with resistivity measurement: **Resistivity(B=0)** and **Resistivity(B)**. To calculate zero field mobility, select **Resistivity(B=0)**. The ASTM standard uses Resistivity(B=0) to calculate Hall mobility.
3. The settle time for the system must be a whole number (0,1,2, …). The measurement settle time is at least as long as the requested time and as much as one second longer. The suggested minimum settle time is two seconds.
4. Specify the ramp rate, the length of time it takes the magnet to reach full field. The suggested ramp rate is 60 seconds. Values below this may also work well, but one minute is known to be stable.
5. When minimizing a window, be sure it is *minimized* and not *closed*. If an application that the system needs is closed, the program crashes.

5.5.7 Hall Software Application Components

1. **Chart Recorder:** Specifies the axes and the format (Chart Input).
2. **Front Panel:** Displays a virtual instrument front panel. Options allow users to:
   - Display the front panel readings/values
   - Control the field or temperature
   - Enter the current, voltage settings, etc.
   - Format displays
   - Pause, Reset and Over Ride the program
   - Display results and simple statistics
   - Set the alarm
3. **Help:** Always available. Search for a specific topic, a general category, or system information.
4. **Profile Generator:** Configures and runs temperature or magnetic field ramps. Open or edit files or search for a specific name or characteristic.
5. **Run:** Configures the field.
6. **Sample Definition:** Input up to 64,000 characters of experiment information and comments that can be saved to a file. Use an output data file as a template to quickly initiate a similar set of measurements.
7. **Setup:** Establishes a temperature or magnetic field ramp. Users may select several options to characterize and control the ramp.
8. **Timing:** Controls the Measurement Time or the Average Window. Measurement Time is how often the field control driver updates and reports data (i.e., how far apart the data points are). Average Window specifies the number of data points to average when doing calculations. These applications do not affect field control.
9. **Utilities:** Headings under this category vary with the specific application. Typical options:
   - Domains: Specifies beginning and ending current, ramp rate, and wait time.
   - Ramp to Current.
   - Ramp Edit (Segment definition): Specifies first and last value of the ramp, the increment, and the number of points.
   - Chart Recorder.
   - Alarms.
10. **Window:** Formats the display window. Tile restores the window to the original format of graphic and data displays. The highlighted window appears on the left.

5.6 FIELD AND TEMPERATURE CONTROL

This section describes the individual applications for controlling the magnetic field and temperature. To provide more direct control over the temperature and magnetic field, access the Field Control and Magnetic Field applications without entering the Hall application.

5.6.1 Field Control

The Field Control program is run by the Hall application to control the magnetic field (induction). Access the Field Control software in one of two ways: click either the Field Control button on the left of the Hall panel or the Field Control icon below it. To set the field:

1. Enter the desired field in the upper right hand area.
2. Turn the Control and the Auto Tune buttons ON to activate system control.
   NOTE: To turn the magnet OFF, set the field to 0 Gauss. Do not turn off the control.
3. To return to the Hall System Software front panel, minimize (do not close) Field Control.

5.6.1.1 Electromagnet Characterization

Control of the magnetic field requires knowledge of the relationship between the current supplied to the magnet and the resulting field. The relationship stores as a set of paired points in a configuration file. The relationship need not be exact, but an approximately correct relationship is required.

When the gap between the magnet poles or the pole diameter changes, the relationship between current and field also changes. Re-characterize the magnet whenever the relationship between the current and magnetic field changes significantly. An alternative is to create characterization files for frequently used configurations (e.g., two files for an EM4-HV (4 inch) electromagnet with 3 inch pole faces and pole gaps of either 1.75 or 1.0 inches) and then select the appropriate file when the configuration changes.

CAUTION: Using the wrong configuration file may result in an unstable field that oscillates.

To characterize an electromagnet and create a characterization file:

WARNING: The software assumes that an increasing current produces an increasing magnetic field. Field control fails if an increasing (more positive) current produces a decreasing (more negative) magnetic field. Verify proper operation manually before characterizing the electromagnet.

WARNING: If electromagnet has been moved and not yet powered to full current, the magnet coils may shift the first time the electromagnet is energized, allowing the Gaussmeter probe holder to fall out and possibly damaging the Gaussmeter probe. After moving the electromagnet , manually run the electromagnet to full current before installing the Gaussmeter probe holder.

1. Configure the magnet, experimental apparatus, and Hall probe as desired. Note that the magnetic field reading can be sensitive to the Hall probe position, especially when the Hall probe is near a pole face.
2. Start the Field Control software on the computer. The Hall System Software program must not be running.
3. For 647 MPS (7504 HMS) only: Bring up the MPS software window (click on icon at bottom of screen) and select the menu Utilities/Domains. Set the following:

	Domain 1	Domain 2
Begin current	–100	100
End current	100	–100
Ramp rate (A/min)	102	102
First: wait time (min)	0.01	0.01
Second: Function	“none”	“none”
Third: wait time	0.0	0.0

   Click Save, OK, then minimize the MPS window (do not exit).

Electromagnet Characterization (Continued)

4. For 665/668 MPS (7507 or 7512 HMS) only: In the Field Control software window, select the menu item: Edit/Properties. Set the following:

	665MPS	668 MPS
Max. current (A)	100	130
Ramp rate (A/s)	1	1

5. Bring up the 450 Gaussmeter software window (click on the 450 application button in the Task Bar at bottom of screen) and do the following:
   Open the front panel.
   Select the 30 kG (3 T) range to turn Autorange OFF.
   In the Analog Output section, select Control. (The value should be zero.)
   Minimize the 450 window.
6. With Field Control in focus, select the menu item: Setup/Characterize Magnet. Input the following parameters in the dialog box which appears:

	647 MPS (7504 HMS)	**665 MPS** (7507 HMS)	**668 MPS** (7512 HMS)
Max. current (A)	75	100	130
No. points	76	101	131
Description (example)	EM4_pole4_gapZZmm	EM7_ pole3_gapZZmm	EM12_ pole12_gapZZmm

   Note on Number of Points: Twice the maximum current plus one is generally a good number.

   Note on Descriptions: Enter up to a 19-character description. No spaces are permitted in the description. Enter the actual gap in place of "ZZ."
7. Click on OK to begin the characterization. Watch the magnet power supply (MPS) front panel to make sure the current slowly ramps up to the full positive current requested. The characterization should take 2 – 5 minutes.
8. When the characterization is complete, maximize the B vs. I plot and examine it closely. The characterization must be redone if the B vs. I curve has dips or other strange behavior. If not acceptable, close the window, Cancel saving the file, and return to step 5 to redo the characterization. For characterization with a 647 MPS, the first wait time can be doubled to increase the settling time.
9. If acceptable, enable the cursor to show the B and I values on the curve. Place the cursor over the highest current point on the plot. Back off about 100 G and round down to the nearest 100 G to get the Max Field for input in the Properties dialog box.
10. If possible, Print the B vs. I curve at this time by selecting menu item: File/Print within the plot window.
11. Close the B vs. I plot window. Save the file. The suggested file name format is EMxPyGzz.cfg where:

    x = magnet pole size in inches
    y = pole face diameter in inches
    zz = pole gap in millimeters
        Note: for EM12 systems with y > 9, the 8-character name limit
        allows space for only the pole face diameter: EMPyyGzz.cfg.

    NOTE: The name is limited to eight (8) characters. The suggested format is not mandatory.
12. With the Field Control software in focus, select the menu item: Edit/Properties. Input the following parameters in the dialog box which appears:

	647 MPS (7504 HMS)	665 MPS (7507 HMS)	668 MPS (7512 HMS)
Description (example)	EM4_pole4_gapZZmm	EM7_ pole3_gapZZmm	EM12_ pole12_gapZZmm
Pole face size (in.)	4 (or actual)	3 (or actual)	12 (or actual)
Gap size (in.)	1	1	1
Max field (G)	_______(6500+)	_______(12000+)	_______(?)
Max. current (A)	75	100	130
Ramp rate (A/s)	1.7	1	1

Electromagnet Characterization (Continued)

Click OK.
Select the menu item: File/Save. This saves the changes entered above.

13. Bring up the 450 Gaussmeter software window (click on icon at bottom of screen). Open the front panel and click on Autorange. Minimize the 450 window.
14. Exit the Field Control program.

5.6.1.2 Loading Magnet Configuration Files

If the electromagnet configuration changes significantly (e.g., different air gap or pole faces), use a different magnet characterization file. If an applicable configuration file exists, do the following:

1. Open the Field Control software program.
2. Under the File menu item, select Open...
3. Find or enter the name of the appropriate configuration file. The new file opens and replaces the previously opened configuration file.

5.6.2 Temperature Control

5.6.2.1 Accessing Temperature Control

The temperature control software is set up in much the same way. To access it, click either the Cryogenic Control button on the left side of the Hall panel or the 330/340 icon at the bottom of the screen.

To return to the Hall panel, minimize (do not close) Temperature Control.

5.6.2.2 Verify Temperature Controller Setup

The temperature controller must be set up for the sample probe or sample module in use. If no temperature controller settings file exists, create one (Refer to Chapter 4).

1. Otherwise, start the 340 software driver on the computer and load the appropriate settings file.
2. Open the Front Panel and check that the input channels are reading properly and assigned.

5.6.2.3 Temperature Control Domains

The Temperature Control Software application uses domains. When ramping to a specified temperature, the application searches the domains in numerical order until it finds one with a temperature range containing the specified temperature. Then it sets control parameters (P,I,D, slew rate, and heater power) and initiates temperature ramping and control.

Different sample modules may require different control parameters. Verify proper domain and control value set up after installing a different temperature controlled sample module.

Domains do not have to be in order of temperature. Set up a domain with a temperature range higher than desired and zero heater power to prevent thermal runaway.

A good approach is to set PID parameters so temperature does not significantly overshoot the setpoint (critically damped). Use as the second wait condition: sample drift <0.05 K/min. Specify a looser or tighter condition, depending on the tolerable temperature drift.

Find further information in the help files for the temperature controller in use.

To specify the temperature control domains, click on the **Utilities** menu item and select **Domains**. The domain number is selected at the bottom of the dialog box.

5.7 MAKING MEASUREMENTS USING THE HALL PROGRAM

This section details the basic procedure to set up a run. It outlines procedures which are essential to the successful use of the Hall software applications, such as creating a file, defining a sample, determining the excitation current, and setting up a run.

When taking measurements, select from several standard sample geometries and contact arrangements. Specify the excitation current, settle time, magnetic flux densities, and temperatures at which data is taken along with the measurement characteristics and sequence.

5.7.1 Sample Checking

New samples or sample types often require some testing to determine suitable excitation and typical behavior. This section details some typical sample checking procedures.

5.7.1.1 Using Resistance Software to Take a Measurement

To access the Resistance application, click either the **Virtual Resistance** button at the left of the Hall panel or the Resistivity icon at the bottom of the screen. This application calculates Resistivity or Hall Resistance using van der Pauw measurements. The application displays a schematic of the current source, voltmeter, and sample. As measurements are taken, the active connections display. To take measurements:

1. Open the Resistance Software. Click Sample Definition.
2. Set the desired excitation current.
   NOTE: Details on selecting a suitable excitation current are given in Section 0.
3. Specify the sample thickness. If unknown, use 1 as the default. Unit thickness (1 cm in cgs units or 1 m in mks/SI units) will cause sheet values to be calculated although the results will still be given with bulk units.
4. At the right of the panel are a series of options. Use the High Resistance option if sample resistance is greater than 100 kΩ (only applicable for wide resistance range systems such as -HVWR or -LVWR).
5. Specify Resistivity or Hall Resistance measurement (at far right).
6. To begin, click TAM (Take A Measurement) button on the lower menu bar or Measure Now.
7. To return to the Hall window, minimize the Resistance window.

5.7.1.2 Current-Voltage Characterization

Current-voltage (I-V) characterizations are useful in selecting the excitation current. Linear current-voltage characteristics indicate ohmic contacts, which are best for Hall effect measurements. Current-voltage plots are also useful for determining the maximum current possible, thus maximizing the output signal (desirable within power and voltage limitations).

CAUTION: The system **must not** be set to more than 7 V. Exceeding this limit <u>might</u> cause irreparable damage to the Hall Effects Card.

The Hall software program Setup menu contains the option: Variable Current Measurement. Select this item to bring up the setup dialog box.

The voltage measuring procedure is described as follows:

1. Select the contact set for the variable current measurement. A common set for checking van der Pauw samples is R13,13 and then R24,24. The voltages read as follows:

   $\mathbf{V}_{\mathbf{ij,kl}}$ where: **i** is the positive current sample contact,
   j is the negative current sample contact,
   k is the positive voltage sample contact,
   l is the negative voltage sample contact.

   Example: $V_{12,34}$ has current flowing from 1 to 2 and voltage measured between 3 and 4.
2. Select the range of excitation current and other parameters. Click OK, then Start Measurement.
3. The voltages can then be plotted as a function of current. The highest voltage in the linear region is the maximum excitation current that should be used for that sample (within voltage and power limitations).
4. Faulty contacts result in non-linear plots and high resistances. Faulty contacts should be fixed before proceeding to produce the most accurate measurement results. Check other contact sets as required.

5.7.1.3 Determining Excitation Current

The greater the sample excitation, the greater the output signal. The larger the output signal relative to the noise and other error sources, the more accurate the measurement. Large excitations can also dissipate excessive power in the sample, raising its temperature and creating temperature gradients which can affect a Hall effect measurement. Large electric fields can also change the conduction mechanisms within the material. Power and electric field limits favor lower excitations. The goal is to find an excitation which balances the conflicting demand for large output signal, low power dissipation, and realistic electric fields.

The 7500 series instrumentation provides a dc excitation current to the sample, but the software is able to control the current source to provide either constant current, constant power, or constant voltage excitation. For constant power or voltage excitation, the current is varied to achieve the desired power or voltage, but then remains constant for a set of measurements at a given field or temperature. A resistivity or Hall effect measurement at a single point is always made with the same current magnitude. Note that the power or voltage will vary if different sets of contacts have different resistances.

The system limits are as follows:

1. Current maximum: I max = 101 mA (Keithley 220 Current Source)
2. Voltage maximum: V max can be limited by any of the following:
   - Current source compliance = ±100 V (Keithley 220 Current Source).
   - Switch cards:
     - -HVWR: ±100 V.
     - -LVWR: Keithley 7065 Hall effect card rating is ±8 V, but ±7 V is recommended limit.
     - -HVLR: ±100 V.
     - -LVLR: ±3 V.
   - Lead resistance, typically ~ 25 Ω, check sample module specifications.
   - Contact resistance to the sample.
   - Voltage or electric field limits of the sample.
3. Power limits determined by the sample and its environment.

CAUTION: The Voltage limit **must not** be set to more than 8 V for -LVWR measurement configurations. Exceeding this limit <u>might</u> cause irreparable damage to the Keithley 7065 Hall Effect Card.

Bulk samples near room temperature can typically tolerate power dissipations on the order of 1 mW. The allowable power dissipation might be significantly larger or smaller depending on the thermal conductivity of the sample, the amount of heating at the contacts relative to the bulk, or for thin film samples. A non-linear current-voltage characteristic can be caused by heating of the sample or by non-ohmic contacts. Choosing an excitation in the ohmic region is suggested to avoid the possibility that the sample is heating.

Use the following procedure below to determine the sample excitation:

1. Get a rough idea of the sample resistance. Use an ohm meter to measure the sample across different contact pairs.
2. Mount the sample and check that:
   - Sample is mounted correctly (see Chapter 3)
   - Sample is at the desired temperature
   - All the cables are connected to the sample module
3. Measure the sample resistance.
   - Enter the Resistance program either from the Windows Program Manager or from the Hall program by clicking the Virtual Resistance button.
   - Choose the Sample Definition menu and select the appropriate sample type. Use the ohm meter measurement of sample resistance or guess a constant current. Select Resistance measurement across leads R13,13 (for Hall bars: R56,56). If the sample has a high resistance, you will need to click the High Resistance mode (or Auto selection) check box. Click OK to return.

Determining Excitation Current (Continued)

- Choose Measure Now or click TAM (Take A Measurement) to begin measurements. If the V-LIMIT light on the Model 220 current source front panel blinks, the Model 220 is in compliance and the chosen current is too high. If the light does not blink, the current is low enough for the current source to operate, but may be too low for accurate voltage measurements. Note the measured resistance. Try a different excitation current and check if the resistance changes with excitation current, indicating non-ohmic contacts or possible sample heating.
- Find for the highest current possible within the voltage limits. Check the details of the resistance measurement to find the actual voltages measured

4. Calculate the maximum current to stay below the voltage and power limits:
   - I max = V-limit / R, where V-limit = 7 V is typical.
   - I max = sqrt (P-limit / R), where P-limit = 1 mW is a reasonable first guess.
5. Run a variable-current experiment using the Hall program. For van der Pauw samples, make measurements on more than one contact pair.
6. Select a current in the linear range, but reasonably high. Run a Hall effect measurement at a single field. Repeat with a higher or lower excitation current to check for constant resistivity (rho) and Hall coefficient (Rh) values. Also check the measurement details for consistency and van der Pauw F values > 0.95.
7. Check measurement repeatability. Repeat the last measurement once or twice.
   - If the measurement is noisy, increase the excitation current settle time or the magnitude of the excitation.
   - Hall effect measurements can also suffer from large misalignment voltages (Vm) due to Hall voltage contacts which are not electrically opposite each other. Change the contact pattern or move the contacts to reduce the misalignment voltage.
8. If constant power or constant voltage excitation is desired, calculate the required quantity from the measured resistance and current.

5.7.2 Set Up Measurements

Under the Setup menu, select the desired experiment type. Following are some general points:

Settle Time – The settle time has a resolution of 1 second. An entered settle time of 2 seconds causes the software to wait at least 2 seconds, possibly 3 seconds, before taking a reading.

System Sensitivity – Many samples are sensitive to both light and temperature. Therefore, the system must settle before running experiments to minimize photo-induced excitations and stabilize temperature.

High vs. Low Resistance Range – The Hall Program offers two resistance settings: high (R>100 kΩ) or low. These can be chosen manually or the software can be allowed to select the appropriate range using the single resistance specified by ‘connections’ (typically R12,12). In high resistance mode, buffer amplifiers are used to isolate the voltmeter from the sample. This prevents the voltmeter input resistance from shunting the sample at the expense of a small amount of added noise.

Determine the appropriate sample resistance range by following one of the procedures below:

1. Place the two test leads of an ohm meter across two opposite leads of the sample. The displayed resistance should determine if a high or low setting is needed.
2. Raise current until it reaches system compliance. This voltage limit is 7 volts. Apply a current of 10 µA. If the V-LIMIT light blinks on the 220 Current Source front panel, use the high resistance setting.

CAUTION: The Voltage Limit ***must not*** exceed 7 V. Exceeding this limit may cause irreparable damage to the Hall Effect Card.

5.7.2.1 Set Up Variable Magnetic Field Measurement

This application is designed for a variable field run at constant temperature. To set up the measurement:

1. Under the **Setup** menu, select **Variable Field Measurement**.
2. Enter the values for at least two of the following: **Maximum Field**, **Field Increment**, and **Number of Points**. These three values are related by the equation: **B_{max}= Number of points × Field Increment**. Specify any two of the values, and the program supplies the third. There is also an option for field reversal (normally selected).
3. **Measurement Field Order** offers additional field control options: **Alternate** (fastest), **Negative then Positive** (field reversals), **Positive then Negative**, or **Additional Settle Time**. Alternate field order can be useful when making measurements at multiple temperatures.
4. If the run requires a constant temperature, click the Temperature Control On. Specify the desired temperature. For no temperature control, input a temperature below ambient (0 Kelvin is a good choice).
5. In the **Measurement Type** section, there are four options: **Resistance**, **Resistivity**, **Hall coefficient density (only)**, and **Hall mobility (everything)**. Under the final entry there are two further selections: **Resistivity (B=0)** and **Resistivity (B)**. These specify whether to use zero field resistivity or the resistivity at field measurement to calculate mobility. The ASTM standard uses Resistivity (B=0) to calculate Hall mobility.
6. **Van der Pauw Geometry** specifies the desired geometry: **Average Both**, **Geometry A**, or **Geometry B** (see Appendix A).
7. Under **Excitation Current**, enter desired excitation current and settle time. There is also an option for current reversal.

NOTE: The settle time must be a whole number. The actual settle time will be at least the specified settle time and possibly as much as one second longer.

8. Select low or high resistance. Click **OK**.
9. To begin the run, click **Start Measurement**. To stop the run at any point, click **Stop Measurement**.

5.7.2.2 Set Up Variable Current Measurements

To run a variable current measurement, start a new experiment (rather than modifying an old Hall experiment) and under **Setup** select **Variable Current Measurement**. Specify maximum and minimum current, number of points, linear or log spacing, current settle time, sample temperature, and fixed field.

NOTE: If **Linear** is selected, then the min. and max. current can be either positive or negative. If **Log** is selected, then the min. and max. must be of the same sign.

The **Configuration Box** specifies the sample terminals used for the measurement. The syntax is four digits selected for 1,2,3 or 4. The first digit is the sample terminal connected to the positive current source. The second digit is the sample terminal connected to the current source return. The third digit is the sample terminal connected to the positive voltmeter input. The fourth digit is the sample terminal connected to the negative voltmeter input.

NOTE: The format is free form; only digits matter. Non-digits are ignored.

For instance, to measure IV for sample terminals 1 and 2, any of the following are valid:

R12,12 1212 12:12

Note that the current source and voltmeter need not be attached to the same pair of sample terminals: thus, R12,34 is also valid.

NOTE: For I-V curves, the current and field reversal options are always Off. The **Show Details** and **Save Extended Functions** options also work for IV measurements.

Click **Start Measurement**. The display shows I, V field reading, temperature reading, and plots I vs. V.

5.7.2.3 Set Up Variable Temperature Measurement

This application is designed for a variable temperature run at constant field. To set up the run:

1. Under **Setup**, select **Variable Temperature Run**. Enter the values for **Initial Temperature**, **Final Temperature**, and **Temperature Increment**.

   NOTE: To run a sample at a constant field and temperature, set the initial and final temperatures equal to each other, and set the temperature increment to zero.

2. **Magnetic Field Control** specifies the desired field and controls the additional settle time and field reversal (normally selected).
3. **Measurement Field Order** offers other field control options: **Alternative** (slower), **Negative then Positive** (field reversals), **Positive then Negative**, and **Additional Settle Time**.
4. In the **Measurement Type** section, there are three options: **Resistivity**, **Hall coefficient density (only)**, and **Hall mobility (everything)**. Under the final entry there are two further selections: **Resistivity (B=0)** and **Resistivity (B)**. These determine whether to use zero field resistivity or the resistivity at field measurement to calculate mobility. The ASTM standard uses Resistivity (B=0) to calculate Hall mobility.
5. **Van der Pauw Geometry** specifies the desired geometry setting: **Average Both**, **Geometry A**, or **Geometry B** (Refer to Appendix A).
6. Under **Excitation Current**, enter the desired excitation current and settle time. There is also an option for current reversal.

NOTE: The settle time must be a whole number. The actual settle time is at least the specified settle time and possibly as much as one second longer.

7. Select low or high resistance. Click **OK**.

5.7.3 Start Measurement

1. Click on the **Start Measurement** button.
2. If for any reason the run must be stopped, click **Stop Measurement**.
3. The dialog box above the data and graphics display windows indicates the run status.

Upon completion, the dialog box displays a message reading: **Done. Returning field to zero**. Once the field is at zero, the message reads: **Done**.

5.8 CUSTOM SOFTWARE

It is possible to write custom software through use of the DDE Interface and programs such as Visual BASIC. Contact Lake Shore for further information.

5.9 SYSTEM DIFFICULTIES

Many problems are not serious and can be fixed by the user. See troubleshooting information in Chapter 8 and in individual instrument User's Manual.

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6. TRAINING EXAMPLES

Contents:

6.1 RESISTOR MEASUREMENTS

6.1.1 1 GΩ Resistor Measurement in the 75013 SCSM

1. Set up the Model 75013 Sample Card Sample Module (**75013 SCSM**) for operation.
2. If the measurement configuration is either **-LVWR** or **-LVWR-HS** (KI 7065 Hall card, but no second 7152 matrix switch card), verify that the coaxial cable is attached to the BNC bulkhead marked "**Current Meter**".
3. Start the **Resistance** software program.
4. Insert a 5x5 cm card mounted **1 GΩ resistor** (PN 671-290) in the 75013 SCSM and cover with the enclosure. The enclosure can be left out of the magnet poles as no magnetic field will be used for this measurement.
5. Select the menu Sample Definition > **van der Pauw** and specify:
   Fixed current = **1 nA** (enter "1n" in the box)
   Settle time = **30 s**
   Measurement: **Resistance**
   R14,23
   (√) **High** resistance range
6. Click "**OK**".
7. Click "**Measure Now**" on the menu bar. The measurement takes about 1 minute.
8. Examine the results. The resistance measured should be within the accuracy printed on the resistor (0.5%). Some measurement configurations are not capable of accurately measuring a 1 GΩ resistance. Check **Table 6-1** for the limits of your system. Note that complete information is available in sections **1.2.4** Hall System Measurement Configurations and Specifications and **1.5** System Measurement Performance.
9. Click "**Save as text**" and give the file the name "**R1G.txt**". This text file can now be opened and edited with Notepad or any other text editing program.
10. "**Print all**" now or wait until later and print the text files.
11. In systems capable of measuring high resistances, the accuracy of this measurement is typically limited by the accuracy of the current source or the current meter. The measurement accuracy can be improved in some cases by using larger excitation currents. The current is limited by the measurement system, as specified in Chapter **1** and as discussed in the section in Chapter **5** on selecting an excitation current. Repeat the measurement with a larger excitation current, within the limitations of the measurement system. Suggested excitation currents are given in **Table 6-1**.
12. Close the Resistance software program.

Table 6-1. Suggested maximum excitation currents for a 1 GΩ resistor measurement

Measurement Configuration	Maximum voltage	Maximum accurately measurable resistance	Suggested maximum excitation current
-HVWR -HVWR-HS	100 V	70 GΩ	80 nA
-LVWR -LVWR-HS -LVWR-SWT -LVWR-HS-SWT	8 V	200 GΩ 200 GΩ 100 GΩ 100 GΩ	5 nA
-HVLR -HVLR-HS	100 V	10 MΩ	80 nA
-LVLR	3 V	1 MΩ	2 nA

6.1.2 0.1 Ω Resistor Measurement in the 75013 SCSM

1. Set up the Model 75013 Sample Card Sample Module (**75013 SCSM**) for operation.
2. If the measurement configuration is either **-LVWR** or **-LVWR-HS** (KI 7065 Hall card, but no second 7152 matrix switch card), find the coaxial cable attached to the BNC bulkhead marked "**Current Meter**". Move this end to the bulkhead marked "**Shorted**" as this measurement will require a current greater than 2 mA.
3. Start the **Resistance** software program.
4. Insert a 1x1 cm card mounted **0.1 Ω resistor** in the 75013 SCSM and cover with the enclosure. Leave the enclosure positioned where it can be reached out of the magnet poles.
5. Select the menu Sample Definition > **van der Pauw** and specify:
   Fixed current = **100 mA** (enter "100m" in the box), or maximum possible
   if the maximum for your measurement configuration is less than 100 mA
   Settle time = **3 s**
   Measurement: **Resistance**
   R14,23
   (√) **Low** resistance range
6. Select "**Measure Now**" from the menu.
7. Examine the results. The resistance measured should be within the accuracy printed on the resistor (1%). Note that measurements on resistors less than 1 Ω are sensitive to the location of the voltage connections on the leads. The voltage taps on the 0.1 Ω resistor supplied with the 75013 SCSM are not at the location specified by the manufacture for testing, so some difference is expected. The difference becomes more significant as the specified resistance decreases. Lake Shore Hall effect measurement systems are tested before shipment by making measurements on calibrated high current shunts (e.g. 100 A, 400 μΩ). If you have access to a calibrated shunt, you could wire one to a sample card (or sample insert for sample modules other than the 75013 SCSM) for testing the low resistance measurement accuracy of your system.
8. Click "**Save as text**" and give the file the name "**Rp1.txt**".
9. "Print all" now or wait until later and print the text files.
10. Close the Resistance software program.

6.2 SEMICONDUCTOR SAMPLE MEASUREMENTS

Test samples (1x1 cm^2 pieces) of GaAs pHEMT are available from Lake Shore. Annealed indium dots at the four corners provide ohmic contacts. Direct contact with sharp needle probes to the indium dots can make adequate contacts at room temperature.

6.2.1 R13,13 Current-Voltage Measurement

For van der Pauw samples, contacts 1 and 3 are opposite each other (as are contacts 2 and 4). Measuring R13,13 sends the excitation current from the switch card down cable 1 and back on cable 3. The voltage is measured between the same cables, so the resistance measured includes the cable resistance, contact resistances at both contacts, and the sample resistance between the two contacts. The cabling resistance can be significant (100 W) in sample modules designed for operation far from ambient temperature - check the specifications given in Chapter **4** for the sample module in use.

The voltage measured across the same contacts used to supply current (e.g. R13,13 or R24,24) will tell you the voltage levels at the current source and other instruments connected to the switch card. Use the voltages measured in this test to keep within the limits of your measurement configuration.

Ohmic contacts are required for accurate Hall effect measurements. We recommend that you test the current-voltage characteristics between contacts to verify ohmic behavior before making Hall effect measurements on an unknown sample. With experience, you may find that some samples almost always have ohmic contacts and do not require contact testing.

Measuring both R13,13 and R24,24 tests all four contacts on a van der Pauw sample and is the minimum number of tests required to determine if all four contacts are ohmic. If one or more of the contacts is non-ohmic, additional tests may be required to identify the bad contact(s).

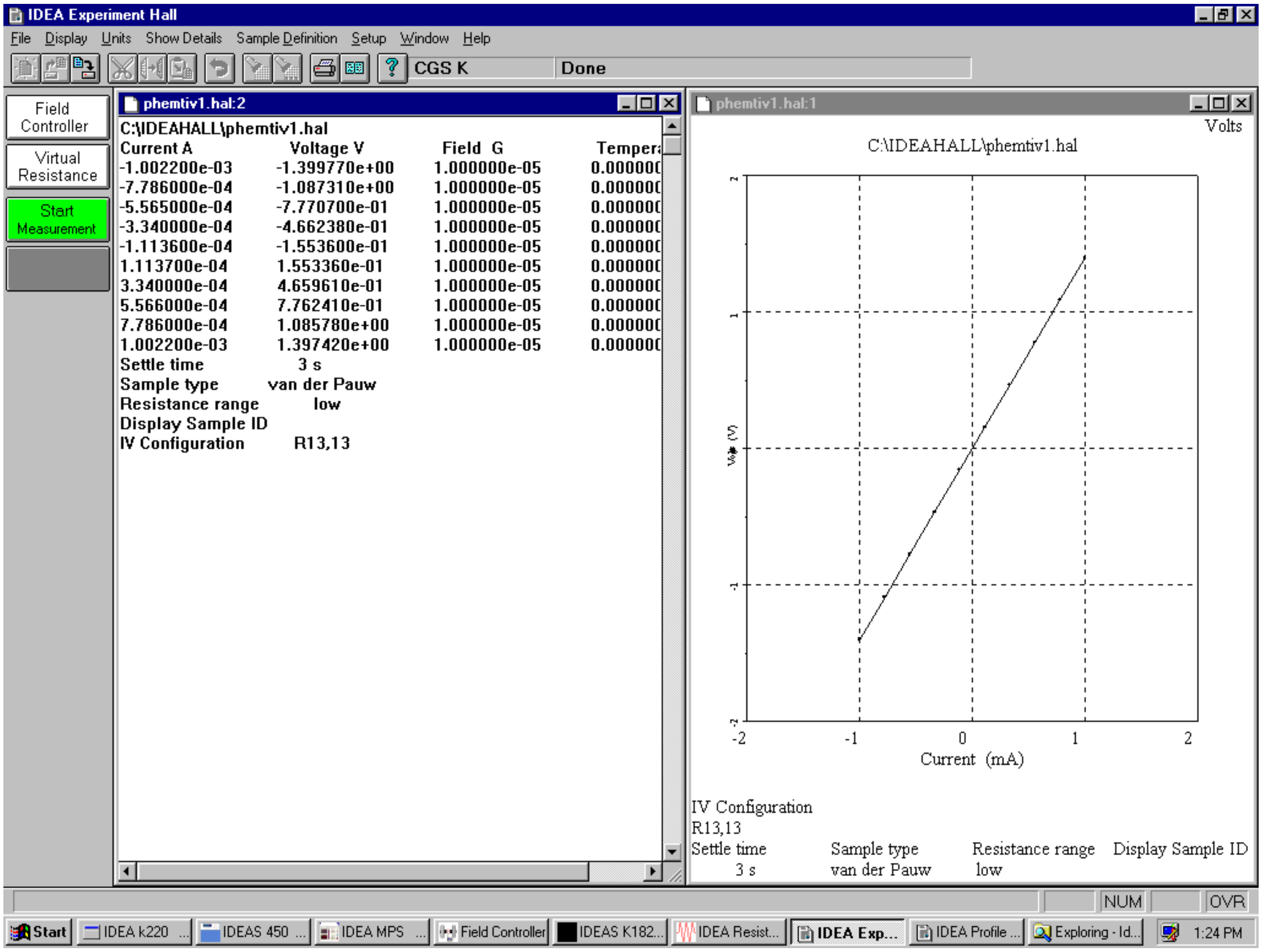
1. If the measurement configuration is either **-LVWR** or **-LVWR-HS** (KI 7065 Hall card, but no second 7152 matrix switch card), verify that the coaxial cable inside the back of the instrument console is attached to the BNC bulkhead marked “**Shorted**” as the following measurement will require a current greater than 2 mA.
2. For Electromagnet Systems only: Make sure cooling water to the magnet is ON and install the dewar and cradle in the electromagnet.
3. Start the **Hall** System Software program.
4. Insert the 1x1 cm card mounted **GaAs pHEMT** sample in the 75013SCSM and cover with the enclosure. Locate the enclosure between the magnet poles in Hall measurement position. Note that other sample modules may require mounting of the sample or other procedures for insertion in the magnet.
5. If an existing file comes up, Close it and select **New** under the File menu. In the “Sample Definition” dialog box that pops up, specify:
   - Thickness = **1 cm**
   - Hall factor = **1**
   - Sample ID:
     - **pHEMTIV1**
     - **R13,13**
     - **pHEMT test sample, card mounted**
     - **HMS 75xx-yyyy** (insert actual Model, for example, HMS 7504-LVWR)
     - **Current meter connected** (-LVWR or -LVWR-HS configurations only)
     - **Room temperature**
     - **Date, user name (optional)**
6. Click “OK” and accept “**pHEMTIV1.hal**” as the file name.

7. Under the menu: Setup -> **Variable Current Measurement**, input the following:
   max current = **1mA**
   min current = **-1 mA**
   Number of points = **10**
   (√) Linear
   (√) Negative then positive
   Settle time = **3 s**
   Temperature control: (√) **OFF**
   (√) **Low** resistance range
   Measurement connections: **R13,13**
   Field setpoint = **0 G**
8. Click "**OK**" to accept.
9. Click on the "**Start Measurement**" button.
10. With the Data window in focus, select the menu item: **Display -> Results** and choose ONLY the following:
    Display sample ID
    IV configuration
    Resistance range
    Sample type
    Settle time
11. When the run is Done, check the data and the plot. The results should look similar to those shown in **Figure 6-1**.

    Straight line plots that pass through zero are a good indication of ohmic contacts. Remember that lead and sample resistance are also included in the measurement and they could hide a smaller non-ohmic contribution from poor contacts in some cases.

    Note that the current is not measured if any portion of the current-voltage measurement exceeds the measurement capability of the current meter, or if no current meter is present. In these cases, the current recorded is the current requested, which might be different from the current which actually passes through the sample. If the actual current is different from the requested current, the curve will appear distorted when it might actually be straight, for instance, if the current souce reaches its voltage compliance limit and is unable to supply the requested current.

    Determining which contact is bad from a set of non-ohmic current-voltage curves requires knowledge of the dominant carrier in the material type (n or p) and some basic energy band models of semiconductor-metal junctions. The easiest way to find one bad contact is to do four sets of current-voltage measurements (e.g. R13,13; R24,24; R12,12; and R34,34) and look for the one contact common to the two non-ohmic current-voltage curves. If more than one contact appears to be bad, the best approach is usually to rework all of the contacts.
12. Under the File menu, select "Save as short text" and name the file **pHEMTIV1.txt**".
13. Select the menu item: File -> **Print** now (**I-V plot** and **data**) or wait until later and print from another computer.



pHEMTIV1.bmp

Figure 6-1. R13,13 measurement 'pHEMTIV1.hal' results in the Hall program

6.2.2 R24,24 Current-Voltage Measurement

1. Under the File menu, select "**Save As...**", change the first line in the Sample ID box to "**pHEMTIV2**", the second line to "R24,24", click "**OK**", and accept as the file name "pHEMTIV2.hal".
2. Under the menu: Setup -> **Variable Current Measurement**, input the following:
   Measurement connections: **R24,24**
3. Click on the "**Start Measurement**" button.
4. When the run is Done, check the data and the plot. The results should be similar to the measurement of R13,13.
5. Under the File menu, select "**Save as short text**" and name the file "**pHEMTIV2.txt**".
6. Select the menu item: File -> **Print** now (**I-V plot** and **data**) or wait until later and print from another computer.

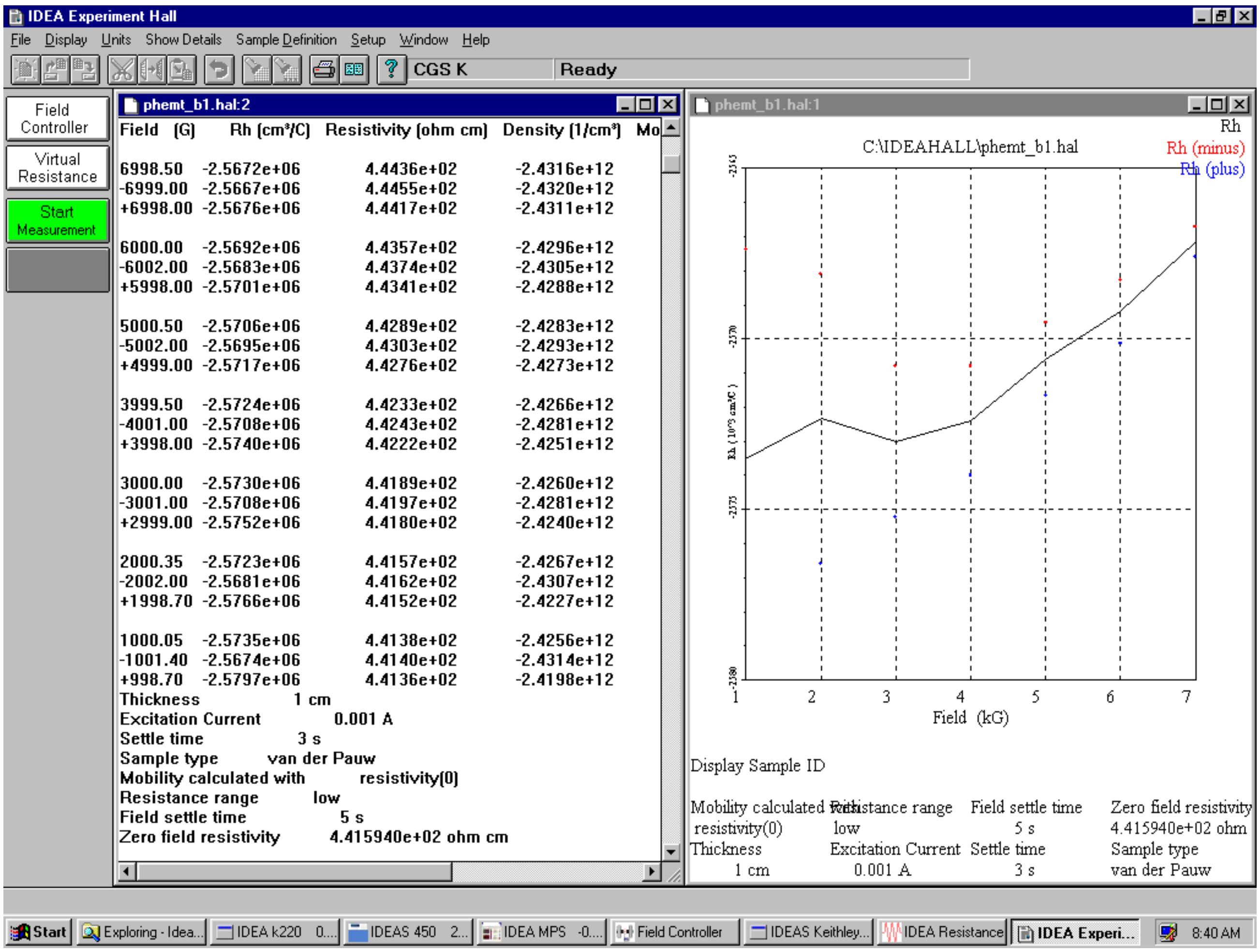
6.2.3 Hall Effect Measurement at Room Temperature

1. Under the File menu, select "**Save As...**". The "Sample Definition" menu will appear.
2. Change the first line of the Sample ID box to read: "**pHEMT_B1**", and the second line to "Hall measurement".
3. Click "**OK**" and accept the file name "pHEMT_B1.hal".
4. Under the menu: Setup -> **Variable Field Measurement**, input the following:
   max field = **7000 G** (or max attainable rounded down to nearest 1000 G)
   field step = **-1000 G**
   Number of Points = **7** (or whatever appears)
   (√) Linear
   (√) Field reversal
   (√) Positive then Negative
   Additional settle time = **5 s**
   Temperature control: (√) **OFF**
   (√) Hall mobility (everything)
   (√) resistivity (B=0)
   (√) Average both geometries
   Fixed current = **1 mA** (type "1m" or ".001" into the box)
   Settle time = **3 s**
   (√) Current reversal
   (√) **Low** resistance range
5. Click "**OK**". Also OK if a dialog box appears about document having changed.
6. Click on the "**Start Measurement**" button.
7. With the Data window in focus, select the menu item: **Display -> Results** and choose the following by double clicking on the items in the top box (they will then appear in the lower box):
   Display sample ID
   Excitation current
   Field settle time
   Mobility calculated with resistivity (0)
   Resistance range
   Sample type
   Settle time
   Thickness
   Zero field resistivity
8. With the Plot window in focus, select the menu item: **Display -> Display Results** and choose **Field vs. Mobility**.
9. When the measurement is Done, check the data and the plot. The results should look similar to those shown in Figure 6-2. At 5000 G, the Hall coefficient R_H should be in the range of - 2.5 to - 2.7 x10^6 cm^2/C, and the sheet resistivity ρ should be in the range of 400 – 500 Ω/square.

   Note that the Hall coefficient R_H or mobility μ measured at +B can be significantly different from that measured at -B. Most Hall effect samples have a slight electrical offset between the Hall voltage contacts which produces what is known as the misalignment voltage, V_m. A measurement of the Hall voltage at one magnetic field (+B or -B) contains both V_H and V_m, even when measurements are made with both current polarities. Hall measurements taken at both +B and -B must be combined to eliminate the misalignment voltage. For additional information see the section on Sources of Measurement Error in Appendix **A**: Hall Effect Measurements.

   The relative size of the difference between $R_H(+B)$ and $R_H(-B)$ gives an indication of the relative uncertainty of the measurement and the relative contributions of the Hall and misalignment voltages. The ratio $[R_H(+B) - R_H(-B)] / R_H(B)$ should be less than about 0.2 for good measurements.

10. The Hall voltage is proportional to magnetic field, whereas the misalignment voltage is constant, so the ratio will generally decrease with increasing magnetic field. A variable magnetic field measurement can be used to determine an adequate magnetic field for measurement of similar samples.
    The misalignment voltage can also be reduced by positioning the Hall voltage contacts such that there is zero voltage between them when the sample is excited in zero magnetic field. Common approaches to doing this are to 1) make a symmetrical sample in a geometry which minimizes contact size and location effects, 2) pattern a thin film using photolithography, or 3) cut a square sample and locate small contacts in the corners, which is easier to do accurately than placing contacts along the centers of the sides - actually a better location for minimizing the contact size effect on the measurement.
11. Under the File menu, select "**Save as short text**" and name the file "**pHEMT_B1.txt**".
12. Select the menu item: File -> **Print** now (**mobility plot** and **data**) or wait until later and print from another computer.



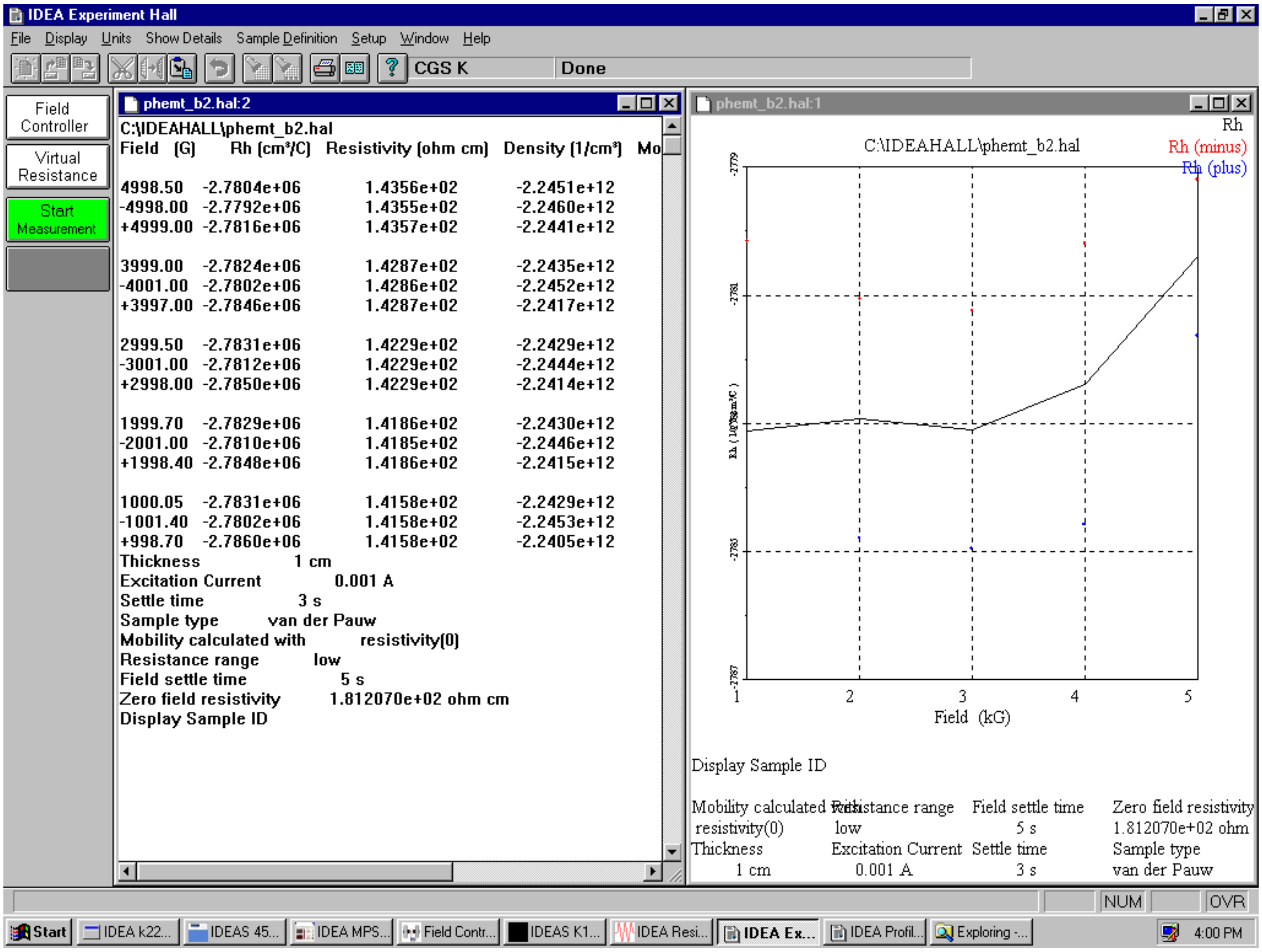
pHEMT_B1.bmp

Figure 6-2. Variable field Hall effect measurement 'pHEMT_B1.hal' results in the Hall program

6.2.4 Hall Effect Measurement at Liquid Nitrogen Temperature

These instructions assume: 1) the 75013 SCSM is installed on an electromagnet platform with the liquid nitrogen dewar in place, and 2) the measurement described in the previous section has just been completed.

1. **IF 750TC Option** (otherwise skip this): **Start the Chart Recorder**:
   Maximize the 340 Software program.
   Select the menu item: Timing-> Log Time. Set the log time to 5 seconds.
   Select the menu item: Utilities -> Chart Recorder. Select the following item to plot:
   Sample temperature
   In the plot window, select the menu item: File -> Log…, name the file "**75013_T1.log**" and click OK.
2. Fill the dewar with **liquid nitrogen**.
3. **IF 750TC Option** (otherwise skip this): Note the time of start, time to reach low temperature, and the name of the cooldown log file.
4. The cooldown to 77 K should take about 10 minutes. The surface of the liquid nitrogen should be fairly still (no violent boiling) and slightly above the sample enclosure header before beginning the measurement.
5. Under the File menu, select "**Save As...**". The "Sample Definition" menu will appear.
   Change the first line of the Sample ID box to read: "**pHEMT_B2**".
   Change the line in the Sample ID box:
   Room temperature –> 77 K
6. Click "**OK**" and accept the file name "pHEMT_B2.hal".
7. Under the menu: Setup -> **Variable Field Measurement**, input the following:
   max field = **5000 G**
   field step = **1000 G**
8. Click "**OK**".
9. Click on the "**Start Measurement**" button.
10. When the run is Done, check the average readings at 5000 G. The results should look similar to those shown in 6-3. At 5000 G, the Hall coefficient R_H should be in the range of - 2.7 to - 2.9 $x10^6$ cm^2/C, and the sheet resistivity should be in the range of 130 – 170 Ω/square.
11. Under the File menu, select "**Save as short text**" and name the file "**pHEMT_B2.txt**".
12. Select the menu item: File -> **Print** now (**data** only) or wait until later and print from another computer.
13. Check that the dewar has not frosted excessively. Remove the sample enclosure from the dewar, empty the remaining liquid nitrogen from the dewar, and warm the sample enclosure and dewar back to room temperature with a heat gun.
14. **IF 750TC Option** (otherwise skip this): Close the Chart Recorder log file.



pHEMT_B2.bmp

Figure 6-3. Variable field Hall effect measurement at liquid nitrogen temperature 'pHEMT_B2.hal' results in the Hall program

7. OPTIONS, ACCESSORIES, AND CABLES

Contents:

7.1 7500 SERIES HALL MEASUREMENT SYSTEM EQUIPMENT

Table 7-1 7500 Series Hall Measurement System Available Equipment List

7504	7507	Model #	Description
Options:			
1		7504	Hall Effect System with EM4-HV Electromagnet
	1	7507	Hall Effect System with EM7-HV Electromagnet
		750HS	High Sensitivity Option
		750SWT	Fully Automated Switching Option
		750TC	Temperature Controller Option
1	1	75013	Sample Card Sample Module
		75014	Closed Cycle Refrigerator Sample Module
Vacuum Accessories:			
		PA-25-16	NW-25 to NW-16 reducer
		PA-40-16	NW-40 to NW-16 reducer
		PA-40-25	NW-40 to NW-25 reducer
		PA-RHOSE	Rubber hose
		PA-SHOSE	Stainless flex hose, 25 mm with NW-25 fitting
		PA-ST255	For line sorption trap
		PS-EXT70	Turbomolecular vacuum pump station
		PS-R2010	Rotary oil sealed vacuum pump

7504	7507	750SWT	Model #	Description
Sample Accessories:				
			750SC10-10	Hall sample card, 1x1 cm samples (pkg. 10)
1	1		750SC10-50	Hall sample card, 1x1 cm samples (box 50)
1	1		750SC50-10	Hall sample card, 5x5 cm samples (box 10)
			671-250	Box for 25x75 mm sample cards (1x1 cm samples)
1	1		671-260	Wire for sample contacts, box
Cables:				
4	3		8072	Cable, IEEE-488, 1 m
5	5		673-005	Cable, triax, 3 m, 2-slot to 3-slot
1	1		673-100	Adapter, 3-lug triax to BNC
		1	673-102	Triax tee, 2-lug
			673-200	Card edge connector, 20 contact
		1	673-300	M-series plug to 5 triax, 3-slot, 3 m
		1	673-302	M-series plug to 5 triax, 0.6 m

List is subject to change without notice.

7.2 7500 SERIES MEASUREMENT CONFIGURATION OPTIONS

7.2.1 Model 750HS: High Sensitivity Option

A sensitive digital nanovoltmeter (Keithley Model 182 Digital Voltmeter) is incorporated into the system to provide much greater voltage sensitivity and accuracy. This option is useful for measuring heavily doped, low mobility, and low resistance samples.

7.2.2 Model 750SWT: Fully Automated Switching Option

A Keithley 7152 Low Current Switch Card, along with the necessary cabling and software, allows automated switching between sample types. The current meter (2 mA maximum) also switches in and out automatically to allow operation from 500 fA to 100mA without recabling.

Sample geometry: Hall bar or van der Pauw.

Number of contacts: 4 or 6.

Shunt resistance: >1 TΩ (10^{12} Ω)

7.2.3 Model 750TC: Temperature Controller Option

The 750TC option adds a Lake Shore Model 340 Autotuning Temperature Controller to the basic system. This allows the user to measure and record the temperature of the sample holder. Further, when used in conjunction with a heater or oven, the system can control the temperature. This option is particularly useful when dealing with temperature sensitive samples.

7.3 MODEL 75013 SCSM - SAMPLE CARD SAMPLE MODULE

This is the standard system option. The two temperature environment uses liquid nitrogen to reach 77 K. The sample probe and the attachment base are provided. Plug in samples facilitate sample exchange and storage. The Sample Holder Module is accessible and easy to use.

Sample geometry: 12 mm square maximum; van der Pauw or Hall bar.

Number of contacts: 4 or 6.

Shunt resistance: >10 TΩ (10^{13} Ω)

Table 7-2 Lake Shore Model 75013 SCSM Available Equipment List

	75013	Model #	Description
Options:			
	1	75013	Sample Card Sample Module
Accessories:			
	1	750SC10-10	Hall sample card, 1x1 cm samples (pkg. 10)
	1	750SC10-50	Hall sample card, 1x1 cm samples (box 50)
	1	750SC50-10	Hall sample card, 5x5 cm samples (box 10)
	1	655-401	Heater, 1/8" OD x 1" long, 50 Ω
	1	671-205	Prober sample card, 5x5 cm
		671-250	Box for 25x75 mm sample cards (1x1 cm samples)
	1	671-260	Wire for sample contacts, box
	2	671-261	Pen, permanent marker, fine point
	2	671-265	Sample, Si:B, medium R (~10.5 W cm), 1x1 cm
	2	671-266	Sample, Si:B, low R (~0.016 W cm), 1x1 cm
		671-267	Sample, Si:B, medium R, 1x1 cm, with Al contacts
	1	IF-5	Indium foil sheets, (5) 2 x 2 x 0.005 inch
	1	PT-103	Platinum temperature sensor
Cryogenic Accessories:			
	1	672-125	Dewar, LN2, rectangular
		672-315	Valve operator for Cryolab ½" seal-off valve on dewar

7.4 MODEL 75014 CCRSM - CLOSED CYCLE REFRIGERATOR SAMPLE MODULE OPTIONS

Table 7-3 Lake Shore Model 75014 CCRSM Available Equipment List

	75014	Model #	Description
Options:			
	1	75014	Closed Cycle Refrigerator Sample Module
Accessories:			
	1	655-451	Cable to Sample Insert 10-pin connector
	1	671-210	Rotation stage for 75014 CCRSM
	1	671-211	Sample Insert for 75014 CCRSM
		671-175	Maintenance kit for APD 204SL CCR
		671-176	Tool kit, F255968A
		671-177	Adsorber, HC-4 compressor, F256390A
		671-179	Valve stem, DE-204SL, 50Hz
	1	671-260	Wire for sample contacts, box
	1	671-265	Sample, Si:B, medium R (~10.5 Ω cm), 1x1 cm
	2	671-266	Sample, Si:B, low R (~0.016 Ω cm), 1x1 cm
	2	671-267	Sample, Si:B, medium R, 1x1 cm, with Al contacts
	1	673-245	Heater, Button, 78 Ω
	1	IF-5	Indium foil sheets, (5) 2 x 2 x 0.005 inch
Vacuum Accessories:			
		PA-25-16	NW-25 to NW-16 reducer
		PA-40-16	NW-40 to NW-16 reducer
		PA-40-25	NW-40 to NW-25 reducer
		PA-RHOSE	Rubber hose
		PA-SHOSE	Stainless flex hose, 25 mm with NW-25 fitting
		PA-ST255	For line sorption trap
		PS-EXT70	Turbomolecular vacuum pump station
		PS-R2010	Rotary oil sealed vacuum pump

7.5 9500 SERIES HALL MEASUREMENT SYSTEM EQUIPMENT

Table 5-1. 9500 Series Hall Measurement System Available Equipment List

Model #	Description
Options	
9501	Hall Effect System with 1 T Superconducting Magnet
9505	Hall Effect System with 5 T Superconducting Magnet
9509	Hall Effect System with 9 T Superconducting Magnet
9512	Hall Effect System with 12 T Superconducting Magnet
750HB	Hall Bar Configuration Option
750HS	High Sensitivity Option
750SWT	Fully Automated Switching Option
PA-25-16	NW-25 to NW-16 reducer
PA-40-16	NW-40 to NW-16 reducer
PA-40-25	NW-40 to NW-25 reducer
PA-RHOSE	Rubber hose
PA-SHOSE	Stainless flex hose, 25 mm with NW-25 fitting
PA-ST255	For line sorption trap
PS-EXT70	Turbomolecular vacuum pump station
PS-R2010	Rotary oil sealed vacuum pump
Sample	
671-260	Wire for sample contacts, box
Cables	
8072	Cable, IEEE-488, 1 m
673-005	Cable, triax, 3 m, 2-slot to 3-slot
673-100	Adapter, 3-lug triax to BNC
673-102	Triax tee, 2-lug
673-200	Card edge connector, 20 contact
673-300	M-series plug to 5 triax, 3-slot, 3 m
673-302	M-series plug to 5 triax, 0.6 m

7.6 MODEL 330 TEMPERATURE CONTROLLER

Table 7-4 Lake Shore Model 300 Temperature Controller Available Equipment List

7504	7507	Model #	Description
Options:			
		330-11	Silicon Diode/Silicon Diode inputs
		330-12	Silicon Diode/Platinum Resistor inputs
		330-13	Silicon Diode/GaAlAs Diode inputs
		330-22	Platinum Resistor/Platinum Resistor inputs
		330-23	Platinum Resistor/GaAlAs Diode inputs
		330-33	GaAlAs Diode/GaAlAs Diode inputs
		330-41	Thermocouple/Silicon Diode inputs
		330-42	Thermocouple/Platinum Resistor inputs
		330-43	Thermocouple/GaAlAs Diode inputs
		330-44	Thermocouple/Thermocouple inputs
Accessories:			
		115-006	Detachable 120 VAC line cord
		106-233	Sensor mating connector
		106-009	Heater output connector
		3003	Heater output conditioner: filter reduce noise
		HTR-25	25 Ω cartridge heater, 25 W, ¼″ diameter x 1″ long
		HTR-50	50 Ω cartridge heater, 50 W, ¼″ diameter x 1″ long
Cables:			
		2001	RJ11 4.66 m modular four-wire cable assembly
		2002	RJ-11 to DB25 adapter
		2003	RJ-11 to DB9 adapter
		8072	IEEE-488 computer cable assembly (1 m)
		655-451	Sensor/heater cable assembly

7.7 MODEL 340 TEMPERATURE CONTROLLER

Table 7-5 Lake Shore Model 300 Temperature Controller Available Equipment List

7504	7507	Model #	Description
Accessories:			
		115-006	Detachable 120 VAC line cord
		106-233	Sensor mating connector
		106-009	Heater output connector
		117-3464	Thermocouple input card, 2 inputs
		3003	Heater output conditioner: filter reduce noise
		HTR-25	25 Ω cartridge heater, 25 W, ¼″ diameter x 1″ long
		HTR-50	50 Ω cartridge heater, 50 W, ¼″ diameter x 1″ long
Cables:			
		2001	RJ11 4.66 m modular four-wire cable assembly
		2002	RJ-11 to DB25 adapter
		2003	RJ-11 to DB9 adapter
1	1	8072	IEEE-488 computer cable assembly (1 m)
1	1	655-451	Sensor/heater cable assembly

7.8 MODEL 450 GAUSSMETER

Table 7-6 Lake Shore Model 450 Gaussmeter Available Equipment List

7504	7507	Model #	Description
Options:			
1	1	450-10	Gauss meter with ±10 V analog output
Accessories:			
1	1	XMMT-1100	Transverse Hall probe, metal, 2.75" L, 16 ft cable
		MMA-2508-VG	Axial Hall probe, metal, .025" dia. X 8" length
		MMT-6J04-VG	Transverse Hall probe, metal, 0.25" dia. X 4" L
		MMT-6J08-VG	Transverse Hall probe, metal, 0.25" dia. X 8" L
1	1	4031	Hall probe holder
		4030-12 (24)	Hall probe stand, 12 (24) inch post
1	1	4060	Zero gauss chamber, standard
		4065	Zero gauss chamber, gamma
		4040	Handle carrying kit with feet
		4041	Soft probe case (strap-on type)
Cables:			
1	1	115-006	Detachable 120 VAC line cord
		4001	RJ11 cable assembly
		4002	RJ11 to DB25 adapter
		4003	RJ11 to DB9 adapter
		MPEC-10 (-20,-50,-100)	Probe extension cable, for model 450, 3 m (10 ft.) (25, 50, 100 ft.)

7.9 MODELS EM4-HV AND EM7-HV ELECTROMAGNETS

Table 7-7 Lake Shore Electromagnets Available Equipment List

7504	7507	Model #	Description
Accessories:			
		MRT-062	Transverse reference magnet
		RC- (150)	Recirculating chiller (4" magnet)
Cables:			
		EM4-CABLE	Power supply cable, #4 AWG, 10' long

Disclaimer: Lists is subject to change without notice.

7.10 MODEL 620/622 POWER SUPPLY

Table 7-8 Lake Shore Model 622 Power Supply Available Equipment List

7504	7507	Model #	Description
Options:			
1		6224	IEEE-488/RS-232C serial interface option
Cables:			
1		2001	Modular cable, 14 feet long

7.11 MODEL 647 POWER SUPPLY

Table 7-9 Lake Shore Model 647 Power Supply Available Equipment List

7504	7507	Model #	Description
Options:			
1		6224 6476 6477 6476T 6476A	IEEE-488/RS-232C serial interface option Gaussmeter input card option High resolution display and programming option Gaussmeter card, transverse hall probe Gaussmeter card, axial hall probe
Accessories:			
		MST-410 MSA-410 HGCT-3020 HGCA-3020 MCT-3160-WN MCA-2560-WN	Probe, electromagnetic fields, transverse Probe, electromagnetic fields, axial Hall sensor, magnetic field, cryogenic, transverse Hall sensor, magnetic field, cryogenic, axial Probe, magnetic field, cryogenic, transverse Probe, magnetic field, cryogenic, axial
Cables:			
1		2001	Modular cable, 14 feet long

7.12 MODEL 665 POWER SUPPLY

Table 7-10 Lake Shore Model 665 Power Supply Available Equipment List

7504	7507	Model #	Description
Options:			
	1	665-208 665-230 665-380 665-480	±100 A, ±50 V, input voltage 208 V, 3 phase ±100 A, ±50 V input voltage 230 V, 3 phase ±100 A, ±50 V, input voltage 380 V, 3 phase ±100 A, ±50 V, input voltage 480, 3 phase
Accessories:			
		102-091 103-674	Power supply FET Power supply ballast resistor Mating input power connector DB25 male connector
Cables:			
	1	653-151	Coaxial BNC reference cable, 10 ft length

8. TROUBLESHOOTING

Contents:

8.1 GENERAL

This chapter helps isolate and correct common problems encountered in the field. Generally, difficulties are easily corrected and require no factory consultation. **Table 8-1** lists possible problems, probable causes, and the section related to the problem. Read individual instrument User's Manuals before operating and/or troubleshooting the system.

Table 8-1 7500 Series Hall System Symptoms.

SYMPTOM/PROBLEM	PROBABLE CAUSE	SEE SECTION
Instrument or system not responding	No power to instrument Computer power cycling Instrument in Local mode	8.6.1 8.6.2, Ch.5 8.6 (#12)
Nonsensical values	Gaussmeter probe oriented incorrectly Excitation current too high Faulty sample contact Settle time too short Magnet characterization curve wrong Computer Data processing No power to instrumentation Cables	8.6 (#2), 4.4.3 8.6 (#3), 5.4.3 8.6.4, 4.3 8.6 (#4), 5.3.3 8.6 (#8), 5.4.1 8.4.3, Ch. 5 Ch. 5 8.6.1 8.6.5
V-LIMIT light blinks on current source	Voltage limit exceeded Excitation current too high Faulty sample contact	 8.6 (#3), 5.4.3 8.6.4, 4.3
Field does not ramp correctly	Gaussmeter probe oriented incorrectly Magnet characterization curve wrong Field control turned off No/insufficient power Water flow insufficient Cables	8.6 (#2), 4.4.3 8.6 (#8), 5.4.1 8.6 (#13) 8.6.1 8.6 (#5) 8.6.5
Power source shuts off	Water flow insufficient No/insufficient power Cables	8.6 (#5) 8.6.1 8.6.5
Field and current signs (±) disagree	Gaussmeter probe oriented incorrectly	8.6 (#2), 4.4.3
V-LIMIT light blinking Non-linear V-I curves Nonsensical values	Faulty sample contact	8.6.4, 4.3
System crashes	Needed application(s) are closed, etc.	8.6.2
System hangs	Configuration difficulties	8.6.3
Power supply FAULTs	Power Up difficulties	8.6.2
Hall software application will not display desired menu	Highlighted either data or graphics	8.6 (#11), 5.6.1, 5.6.3
System Autotuning	Did not turn off Autotune	8.6 (#14)
Switch error message	Did not Open All switches	8.6 (#15)
System will not warm	No power to instrumentation Thermometry No heater output Cables	8.6.1 8.4.5 8.4.4 8.6.5
System will not cool	Blockage of liquid nitrogen lines RMC Cryostat: needle valve difficulties Insufficient liquid nitrogen in system	8.6.1
Control temperature sensors disagree	Thermometry Cables Computer	8.6.2 8.6.5 8.4.3, Ch. 5
Unable to maintain temperature	Not enough/too much cooling power Heater Thermometry No power to instrumentation Cables	8.6 8.4.4 8.4.5 8.6.1 8.6.5
Liquid nitrogen leaks	Loose connections	8.5
System will not cool	Blockage of liquid helium lines Insufficient liquid helium in system	8.5

8.2 GENERAL SYSTEM CHECK

If erroneous readings occur, the tests below verify proper 7500 Series Hall System operation:

1. Check power to instruments. Reset breaker on power strip if necessary,

2. Exit and restart Windows. Restart application.

3. Check settings on instruments.

4. Verify sample is positioned properly.

5. Check data processing or acquisition parameters. Correct incorrect parameters and try again.

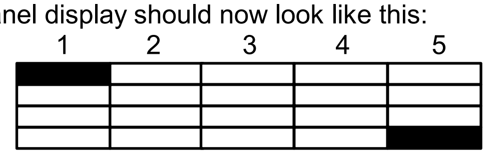
8.3 OFFSET CURRENT TEST (-LVWR Measurement Configurations <u>Only</u>)

For measurement configurations other than the -LVWR (Low Voltage, Wide Resistance range), skip to Section 8.4.

1. Turn on cooling water to the magnet.
2. Turn on power to the instrument console, then power up all instruments. All the front panel lights should come on.
3. Turn on power to the MPS. Check that the power supply fault light is not lit, indicating sufficient water flow to the magnet.
4. Allow the instruments to warm up for 1 hour before performing this test.
5. Zero the KI 485 current meter: push in ZERO CHECK button on front panel, adjust potentiometer through the front panel hole marked "zero" using a small screwdriver until the display shows all zeroes. Push ZERO CHECK button again to release.
6. Triaxial input cables "1","2", "3" and "4" should be connected to the back of the 7065 Hall Effect card. The other ends of the cables should be disconnected. Also locate Input cables "5" and "6" which should be in the Instrumentation Accessories bag.
7. The wiring for this test can be any of the standard -LVWR configurations except for those specifically for Hall bars (HB). If necessary, rewire to the nearest configuration for van der Pauw samples (vdP) to run this test.
8. Check that the current meter coaxial cable is connected between the 7065 Hall Effect card (Card #1) left-hand plug and the bulkhead coax marked "Current Meter". For systems wired with the -SWT Fully Automated Switching configuration: disconnect the cable marked "0" and the adapter first, then disconnect the coax from the front side (not visible from rear of instrument console) of the bulkhead marked "Current Meter" and connect the 485 directly to the 7065 switch card left-hand plug without passing through the bulkhead.
9. Any sample module with 6 triaxial bulkhead connectors may be used, but the sample holder must be empty. Start with all triaxial sample cables <u>disconnected</u> from the sample module.
10. On the front panel of the Keithley 7001, press "Open All" to open all switches and then "Clear List" (7001 must be in Local mode).
11. Press "1!4!5" then "Close". Note: only press the numbers - the ! separators are added automatically. A comma separator between point sets is created by pressing the ">" key below the number pad or the "ENTER" key.

<u>Cable "1" to sample</u>

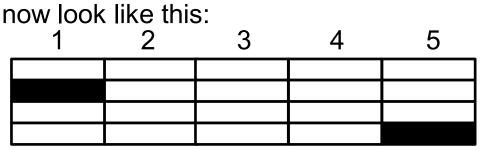
12. Press "Clear List" then "1!1!1" then "Close".
13. The left front panel display should now look like this:



14. Check the current reading from the Keithley 485 Picoammeter.
    - Wait 10 seconds for the reading to stabilize. Hold still during settling as cable or bodily movement can induce currents through the meter. If the current does not change initially or flicker, check that the Zero Check button on the current meter is out.
    - The current must be less than 0.0010 nA. If not, the cable has too much leakage and must be replaced (first check the current reading with no cable connected to make sure the cable is the problem - contact an engineer if the current remains too high).
15. Record the current reading on a copy of Table 8-2 under "sample end disconnected."
16. Plug the other end of the cable into the sample module junction box and record the current reading under "sample end connected".

<u>Cable "2" to sample</u>

17. Press "Open" then "Clear List" then "1!2!1" then "Close".
18. The left front panel display should now look like this:



19. Check the current reading for cable "2". Follow the procedure in steps 14 thru 16 and record the current readings on Table 8-2.

<u>Cable "3" to sample</u>

20. Press "Open" then "Clear List" then "1!3!1" then "Close".
21. Check the current reading for cable "3". Follow the procedure in steps 14 thru 16 and record the current readings on Table 8-2.

<u>Cable "4" to sample</u>

22. Press "Open" then "Clear List" then "1!4!1" then "Close".
23. Check the current reading for cable "4". Follow the procedure in steps 14 thru 16 and record the current readings on Table 8-2.
24. Unplug cable "4" from 7065 Hall Effect card input #4.
25. Find the triax cable attached to the far right input on the 7065 Hall Effect card (673-007). Unplug the other end, which should have been connected to the back of the 6167 Guarded Adapter on the back of the 220 Current Source.
26. Press "Clear List" then "1!4!2" then "Close" to also connect the current source input to the current monitor.
27. The front panel display should now look like this:

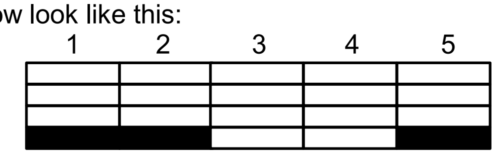
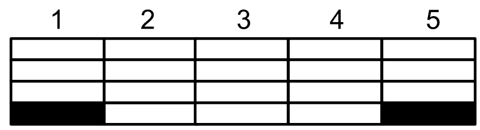


Table 8-2. Offset Current Test Form

Line	Cable #	Input #	Offset Current, I [nA] (pass if: $-.0010 < I < .0010$ nA)	
			Sample end disconnected	Sample end connected
1	**1**	1		
2	**2**	2		
3	**3**	3		
4	**4**	4		
5	673-007	4+5		NA
6	**5**	4		
7	**6** (& 5)	4		
The following are only for systems with the 750SWT option				
8	**5** (to 7152 Row) (& 5)	4		
9	**6** (to 7152 Row) (& 5)	4		
10	**0** (to 7152 Row) (& 5)	4		NA
11	**3** (to 7152 Col) (& 5)	4		NA
12	**5** (to 7152 Col) (& 5)	4		NA
13	**4** (to 7152 Col)	4		NA

28. Check the current reading for cable 673-007. Follow the procedure in step 14 and record the current reading on Table 8-2 under "sample end disconnected".
29. Press "Open" then "Clear List".
30. The front panel display should now look like this again:



31. Plug the triax current source cable 673-007 back into the 6167 Guarded Adapter on the back of the 220 Current Source.

<u>Cable "5" to sample</u>

32. Find the triaxial cable marked "5" used for Hall bar measurements in the -LVWR (HB) configuration (not presently connected, look in Instrumentation Accessories bag for PN 673-005). Plug the 2-slot triax connector end onto input #4 on the 7065 Hall Effect card. The other end of cable "5" should not be connected.
33. Check the current reading for cable "5". Follow the procedure in steps 14 thru 16 and record the current readings on Table 8-2.

<u>Cable "6" to sample</u>

34. Find the triaxial cable marked "6" used for Hall bar measurements in the -LVWR (HB) configuration (not presently connected, look in Instrumentation Accessories bag for PN 673-005). Also find a 3-lug triaxial tee (LS part #673-103, usually found on the 100 GΩ resistor box). Connect cable "6" to the free end of cable "5" (unplug from the junction box) using the triax tee. The other end of cable "6" should not be connected.
35. Check the current reading for cable "6" (reading also includes cable "5"). Follow the procedure in steps 14 thru 16 and record the current readings on Table 8-2. To take a reading connected to the junction box, connect the triaxial tee to position 6 on the J-box.
36. Unplug cable "6" and return to the Instrumentation Accessories bag.
37. If the system does not include the -SWT Fully Automated Switching configuration, then jump to step 55.

<u>Cable "5" (7152 Row, PN 673-300) to sample</u>

38. Find the long 3-slot triax cable marked "5" coming from the 7152 matrix switch card Row connector. Connect to the 3-slot end of sample input cable "5" using the triax tee.
39. Check the current reading for cable "5". Follow the procedure in steps 14 thru 16 and record the current readings on Table 8-2.

<u>Cable "6" (7152 Row, PN 673-300) to sample</u>

40. Find the long 3-slot triax cable marked "6" coming from the 7152 matrix switch card Row connector. Connect to the 3-slot end of sample input cable "5" using the triax tee.
41. Check the current reading for cable "6". Follow the procedure in steps 14 thru 16 and record the current readings on Table 8-2.

<u>Cable "0" (7152 Row, PN 673-300) to current monitor output on 7065 card</u>

42. Find the short 3-slot triax cable marked "0" coming from the 7152 matrix switch card Column connector. Unplug from the adapter on the far left 7065 card bulkhead and connect to the 3-slot end of sample input cable "5" using the triax tee.
43. Check the current reading for cable "0". Follow the procedure in step 14 and record the current reading on Table 8-2 under "sample end disconnected".
44. Reconnect cable "0" to its original position.

Cable "3" (7152 Col, PN 673-302) to current monitor

45. Find the short 3-slot triax cable marked "3" coming from the 7152 matrix switch card Column connector. Unplug from the adapter on the "Current Meter" bulkhead and connect to the 3-slot end of sample input cable "5" using the triax tee.
46. Check the current reading for cable "3". Follow the procedure in step 14 and record the current reading on Table 8-2 under "sample end disconnected".
47. Reconnect cable "3" to its original position.

Cable "5" (7152 Col, PN 673-302) to short

48. Find the short 3-slot triax cable marked "5" coming from the 7152 matrix switch card Column connector. Unplug from the adapter on the "Shorted" bulkhead and connect to the 3-slot end of sample input cable "5" using the triax tee.
49. Check the current reading for cable "5". Follow the procedure in step 14 and record the current reading on Table 8-2 under "sample end disconnected".
50. Reconnect cable "5" to its original position.
51. Unplug cable "5" from input #4 and return to the Instrumentation Accessories bag.

Cable "4"(7152 Col, PN 673-302) to current source

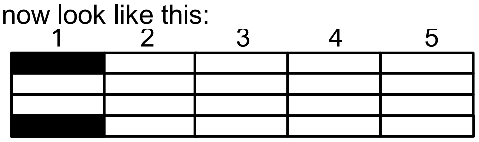
52. Find the short 2-slot triax cable marked "4" coming from the 7152 matrix switch card Column connector. Unplug from the back of the 6167 and connect to input #4 on the 7065 Hall Effect card.
53. Check the current reading for the cable. Follow the procedure in step 14 and record the current reading on Table 8-2 under "sample end disconnected".
54. Reconnect this cable from the 7152 back to the 6167 Adapter where it was previously.
55. Return the 3-lug triaxial tee.
56. Connect sample cable "4" back to 7065 Hall Effect card input #4. Make sure all sample cables are properly connected to the sample module junction box.
57. Press "Clear List" then "Open All" on the 7001 Switch System.

8.4 OFFSET CURRENT TEST (-HVWR Measurement Configurations Only)

1. Turn on cooling water to the magnet.
2. Turn on power to the instrument console, then power up all instruments. All the front panel lights should come on.
3. Turn on power to the MPS. Check that the power supply fault light is not lit, indicating sufficient water flow to the magnet.
4. Allow the instruments to warm up for 1 hour before performing this test.
5. Zero the KI 487 current meter: push in ZERO CHECK button on front panel and allow the reading to settle. Press SHIFT then CORRECT (both in orange lettering). You should see "correcting" on the display.
6. Any sample module with 6 triaxial bulkhead connectors may be used, but the sample holder must be empty. Start with all triaxial sample cables disconnected from the sample module.
7. Check the front panels of the two 6512 Electrometers to make sure they are NOT in ZERO CHECK mode.
8. On the front panel of the Keithley 7001, press "Open All" to open all switches and then "Clear List" (7001 must be in Local mode).

Cable "1" to sample (-HVWR)

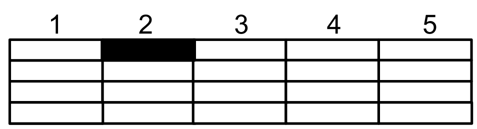
9. Press "1!1!1, 1!4!1" then "Close".
   Note: only press the numbers - the ! separators are added automatically. A comma separator between point sets is created by pressing the ">" key below the number pad or the "ENTER" key.
   Note: the first switch connects cable 1 to the picoammeter to check the offset current and the second switch connects to the right electrometer used to drive the guard. This test also checks the cable to the electrometer.
10. The left front panel display should now look like this:



11. Check the current reading from the Keithley 487 Picoammeter.
    - Wait 10 seconds for the reading to stabilize. Hold still during settling as cable or bodily movement can induce currents through the meter. If the current does not change initially or flicker, check that the picoammeter is not in Zero Check mode.
    - The current must be less than 0.0010 nA. If not, the cable has too much leakage and must be replaced (first check the current reading with no cable connected to make sure the cable is the problem - contact an engineer if the current remains too high).
12. Record the current reading on Table 8-2 under "sample end disconnected".
13. Plug the other end of the cable into the sample module junction box and record the current reading under "sample end connected".

Cable "2" to sample (-HVWR)

14. Press "Open" then "Clear List" then "1!1!2, 1!4!2" then "Close".
15. The left front panel display should now look like this:



16. Check the current reading for cable "2". Follow the procedure in steps 11 thru 13 and record the current readings on Table 8-2.

Cable "3" to sample (-HVWR)

17. Press "Open" then "Clear List" then "1!1!3, 1!4!3" then "Close".
18. Check the current reading for cable "3". Follow the procedure in steps 11 thru 13 and record the current readings on Table 8-2.

Cable "4" to sample (-HVWR)

19. Press "Open" then "Clear List" then "1!1!4, 1!4!4" then "Close".
20. Check the current reading for cable "4". Follow the procedure in steps 11 thru 13 and record the current readings on Table 8-2.

Cable "5" to sample (-HVWR)

21. Press "Open" then "Clear List" then "1!1!5, 1!3!5" then "Close".
    Note: the second switch connects to the left electrometer used to drive the guard. This test also checks the cable to the electrometer.
22. Check the current reading for cable "5". Follow the procedure in steps 11 thru 13 and record the current readings on Table 8-2.

<u>Cable "6" to sample (-HVWR)</u>

23. Press "Open" then "Clear List" then "2!2!5, 2!2!2" then "Close".
24. Check the current reading for cable "6". Follow the procedure in steps 11 thru 13 and record the current readings on Table 8-2.

<u>Cable to current source (-HVWR)</u>

25. Unplug the end of the triax connected to the back of the 6167 Guarded Adapter on the back of the 220 Current Source. The end should dangle free.
26. Unplug sample cable "1" from the junction box.
27. Press "Open" then "Clear List" then "1!1!1;1!2!1" then "Close" to connect the current source input cable to the current monitor. Sample input cable "1" will also be connected to the current monitor input.
28. The front panel display should now look like this:

29. Check the current reading for the current input cable. Follow the procedure in step 11 and record the current reading on Table 8-2.
30. Connect the triax current source cable back onto the 6167 Guarded Adapter on the back of the 220 Current Source.
31. Press "Open" then "Clear List".
32. Make sure all sample cables are properly connected to the sample module junction box.
33. Press "Clear List" then "Open All" on the 7001 Switch System.

8.5 CRYOGENICS CHECK

The various checks described below cover common difficulties encountered when working with cryogenics.

8.5.1 System Cooling Too Slowly

1. Verify no lines are blocked.

2. Verify that there is sufficient liquid helium in the system.

8.5.2 Difficult to Maintain or Control Temperature

1. Verify sufficient liquid helium in dewar.

2. Verify valves are in position desired.

3. Verify sample space is evacuated.

8.5.3 Rapid Boil Off

Rapid boil off of liquid helium may be due to a cryostat that is "soft" (i.e. has lost its vacuum). The cryostat is very cold to the touch and, in the worst case, water condenses on the outside surface. This also occurs when first adding liquid helium because of the temperature differential. In this case, it is normal.

1. Warm system to room temperature.

2. Pump out the dewar vacuum space.

CAUTION: Never pump the dewar when it is cold or contaminants may be cryopumped into the dewar from the attached vacuum pump. The system must be at room temperature.

3. Restart run.

8.5.4 Cracking or Popping Noises

Occasional cracking or popping noises when filling the dewar with liquid helium are normal and no cause for alarm. This occurs mostly when first adding liquid nitrogen because of the temperature differential. When the metal of the dewar begins to cool, there is often rapid and noisy boiling.

8.5.5 System Warming Too Quickly

If during a run the system is warming faster than the setpoint and is difficult to control, there is probably insufficient cooling power to maintain a given temperature setpoint. Solution: add more liquid helium.

8.6 COMMON DIFFICULTIES AND MISCELLANEOUS CHECKS

Detailed below are some of the most common difficulties encountered when dealing with the 7500 Series Hall Effects System. These are not problems associated with dysfunctional hardware, but rather associated with the setup and operation of the instruments.

1. **Faulty sample contacts:** If contacts are bad or one has become disconnected, it needs to be reset before the run can be restarted. A faulty contact can cause the voltage limit to be exceeded, and may distort the linearity of current-voltage curves. Solution: test and repair sample contacts. (See Paragraph 8.6.4)
2. **Gaussmeter probe orientation:** A Gaussmeter probe reversed in the magnetic field reads a negative field for a positive current. Solution: reorient probe. (See paragraph 4.4.3)
3. **Excitation current too high:** May cause system to exceed the voltage limit. (See Paragraph 5.4.3)
4. **Settle time too short:** If the settle time is less than two seconds, the system does not have time to complete all applications necessary to take the next measurement. Solution: increase settle time.
5. **Water flow insufficient:** The power supply turns itself off if water flow to the magnet is insufficient. Solution: increase water flow.
6. **Insufficient liquid nitrogen in system:** If the system will not stay cold or the temperature will not stabilize, verify sufficient LN_2 in the system.
7. **Configuration Problems;** If the system hangs when attempting to start up or open/create a file, there may be a problem with the configuration. (See Paragraph 8.6.3)
8. **Magnet characterization:** If the field appears to oscillate or otherwise misbehave, the magnet characterization curve may be wrong. Solution: recharacterize the magnet. See Paragraph 5.4.1.
9. **System crashes:** The system may crash for any number of reasons. See Paragraph 8.6.2.
10. **Power supply FAULTs:** The power supply may fault when the system is brought up. This is due to the fact that the Corrected Analog Output is erratic. See Paragraph 8.6.2.
11. **Hall software window will not display desired menu:** If the window will not display the desired menu option (e.g. Sample Definition) it is possible that the wrong display window is highlighted, Solution: highlight the other window (data or graphics) and try again. See Paragraphs 5.6.1 and 5.6.3.
12. **Local mode:** Hall software programs cannot access instruments in Local mode. If an instrument does not respond or the computer gives an error message, verify the instrument is not in Local mode.
13. **Control turned off:** When the Control is turned off, the Hall programs *do not* control the field. To turn off the magnet, simply set the field to zero without turning off the control.
14. **Autotune turned on:** The system Autotunes until it is directed to stop (i.e. Autotune is no longer on).
15. **Open All (switches:** If an error message about switches displays, verify that the Hall Effects card is not attempting to close more than one switch at the same position. All switches must be open at the beginning of a run. If they are not, select Open All.

8.6.1 Checking Power

1. If there is no power to instruments, check that they are plugged in.
2. Ensure fuse(s) have not blown. There is a breaker in the power strip located in the Instrument Console.
3. Ensure cables are properly attached to instruments.

8.6.2 System Crashes and Power Supply FAULTs

Upon a system crash or Magnet Power Supply FAULT, do the following

1. Exit the Hall software program, if possible.
2. Exit Windows by exiting the Program Manager
3. If the C> prompt appears, restart Windows by typing “win” followed by a return. If the prompt does not appear within 10 seconds, turn off the power to the computer, wait 15 seconds, and turn on the power again.
4. Perform the Power Up Sequence in Section 5.2.

NOTE: Do not cycle the power to the 450 Gaussmeter when the 665 power supply is ON. The CORRECTED ANALOG OUTPUT is erratic on power up and can cause the power supply to fault. Always turn the power supply Instrument Power OFF before turning on power to the 450 Gaussmeter

8.6.3 File Configuration

If the system simply hangs when attempting to start up or open/create a file, there may be a problem with the configuration. Follow the procedure below:

1. Exit Hall software applications.
2. Open Notepad from the Windows Program Manager.
3. Open the file “ideacfg.ini” in the C: Windows directory. In this file are a number of different groupings with bracketed headings. Scroll down to the [Hall] heading.
4. One of the lines reads “Last Experiment=” and a file name. Change the file name to “none”. This causes the Hall software program to open with default settings and a new file instead of the last experiment file. If this is unsuccessful, restart Windows.

8.6.4 Checking Sample Contacts

See Chapter 4 and Appendix A and B for sample mounting details.

1. Verify contacts by taking current-voltage curve data. If data is non-linear, contacts may be faulty.
2. Once faulty contacts are suspected, examine the sample for dislodged or loosened leads.
3. Re-solder faulty contacts.

8.6.5 Checking Cables

1. If there appears to be a problem with an instrument, but it cannot be isolated, check cables.
2. Check BNC cables for continuity and shorts.
3. Visually inspect power and IEEE cables to ensure that they are securely fastened.

If can communicate with just direct connect to computer but not with other cables.

1. Check addresses. Ensure that 2 instruments are not using the same address.
2. Check cables.

8.7 DISASSEMBLY AND RETURN OF HARDWARE

If the 7500 Series System or any system component appears to operate incorrectly, contact Lake Shore Cryotronics at 614-891-2243 from 9 A.M. – 5 P.M. EST or a factory representative for a Returned Goods Authorization (RGA) number. Before accepting any equipment for service, Lake Shore requires the following information:

1. Instrument model and serial number
2. User's name, company, address, and phone number
3. Malfunction symptoms
4. Description of system
5. Returned Goods Authorization (RGA) number
6. Completed Hazardous Declaration Form (see Paragraph 8.7.3).
7. Independent proof of decontamination if the system was used with dangerous substances (see Paragraph 8.7.3).

8.7.1 Removal of Instruments

1. Contact factory before removing any instrument.
2. To remove any instrument for repair/service, turn instrument off, and disconnect power to unit.
3. Unplug electrical connections from rear of instrument.
4. Remove screws holding instrument to rack/console and carefully lift instrument out.

8.7.2 System Shutdown and Repackaging for Storage or Shipment

If repackaging for return to the factory, call Lake Shore for a Return Goods Authorization (RGA) Number.

1. Warm up system to room temperature. Turn off power to all instruments. Unplug power cords to instrument rack and power supply at source.
2. Remove or disconnect the following:
   a. IEEE-488 and power cables to computer and monitor. Gather inside Instrument Console.
   b. Instrument cable at back of the Temperature Controller (A, B, and heater).
   c. Magnet current output cables from power supply.
   d. Input cable to voltmeter and tie to rack mount handle. (750HS with Keithley 182 Sensitive Voltmeter only.)
3. Gather magnet current cables on side of Instrument rack. Put all other cables inside the console.
4. Box computer and monitor. Pack magnet power supply cables and other hardware into another box (20 x 20 x 15 inches).
5. Lift and place Instrument Console on a pallet. The console is supported by dense foam at four corners. Additional foam is used in front of Instrument Console for weight of MPS. The sample interface is stored above the console. Ensure all cables are tied and instruments in rack are supported. Put packing box for hardware on top of Instrument Console.
6. Wrap plastic sheets around console to protect and keep together. Pack wooden sides outside consoles and re-install lid. Packing box should rest on pallet and fit tight against consoles.
7. Strap whole box to pallet. Screw wood stops against box to pallet.
8. Label both pallets for storage or shipment.
9. Mount the electromagnet and stand in a box on a second pallet.

8.8 COMPLETING THE HAZARDOUS DECLARATION FORM

To comply with Health and Safety Laws, inform the factory of dangerous substances used in or around the system before returning any equipment. The Hazardous Declaration form is included on the following page. Fax or mail the form to the factory in advance of returning any equipment. If this is not done, Lake Shore must assume the equipment contains dangerous materials and may refuse delivery.

Use the following guidelines to determine if the equipment is hazardous:

- Equipment is "uncontaminated" if used only with substances that are not dangerous. Equipment is "contaminated" if it has been used with *any* dangerous substances.
- If equipment has been used with radioactive or biologically active substances, decontaminate it before returning it to the factory. Send independent proof of decontamination (e.g. a certificate of analysis) to the factory with the Hazardous Declaration form.

Fax or post a copy of the Declaration to Lake Shore. The Declaration must arrive *before* the equipment. Contact Lake Shore for advice if you have questions.

HAZARDOUS MATERIALS DECLARATION FORM

Section 1: Equipment

Model Number________________________________ Serial Number________________________________

Has equipment been used, tested, or operated? ☐ Yes **(Go to Section 2)** ☐ No **(Go to Section 4)**

Section 2: Substances in Contact with Equipment

Are any of the substances used or tested on the equipment:

1. Radioactive? ☐ Yes ☐ No

2. Biologically active? ☐ Yes ☐ No

3. Dangerous to human health or safety? ☐ Yes ☐ No

If you answered "Yes" to any of the above questions, complete Section 3. If you answered "No" to all the above questions, proceed to Section 4.

Lake Shore accepts no delivery of equipment contaminated with radioactive or biologically active substances unless you:

- Decontaminate the equipment.
- Provide proof of decontamination.

Contact Lake Shore for advice before returning the equipment

Section 3: List of Substances in Contact with Equipment

Substance Name	**Chemical Symbol**	**Precautions Required (e.g., use protective gloves, etc.)**	**Action Required after Spillage of Human Contact**

Section 4: Return Information

Reason for return and symptoms of malfunction: ____

____

____

____

Lake Shore RGA Number:______________________________ Equipment under Warranty? ☐ Yes ☐ No

Section 5: Declaration

Print the following information clearly and legibly:

Name:____________________________________ Job Title:____________________________________

Organization:____

Address:____

Telephone Number:__________________________ Fax Number:______________________________

I made reasonable inquiry and supplied accurate information in this Declaration. I withheld no information. I filled out this form in accordance with the instructions in Paragraph 8.8 of the Model 7500 User's Manual.

Signed____ Date:__________________________

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APPENDIX A

HALL EFFECT MEASUREMENTS

Contents:

A.1 GENERAL

The model Hall effect system consists of a uniform slab of electrically conducting material through which a uniform current density flows in the presence of a perpendicular applied magnetic field. The Lorentz force deflects moving charge carriers to one side of the sample and generates an electric field perpendicular to both the current density and the applied magnetic field. The Hall coefficient is the ratio of the perpendicular electric field to the product of current density and magnetic field, while the resistivity is the ratio of the parallel electric field to the current density

Experimental determination of a real material's transport properties requires some significant departures from the ideal model. To begin with, one cannot directly measure the electric field or current density inside a sample. Current density is determined from the total excitation current and the sample's geometry. Electric fields are determined by measuring voltage differences between electrical contacts on the sample surface.

Electrical contacts are made of conductive material, and usually have a higher conductivity than the sample material itself. Electric current therefore tends to flow through the contacts rather than the sample, distorting the current density and electric field in the sample from the ideal. Excitation current flowing through the contacts used to measure voltage differences reduces both current density in the vicinity and the Hall field. If a contact extends across the sample in the same direction as the Hall field, it can conduct current from one side of the sample to the other, shorting out the Hall voltage and leading to an underestimate of the Hall coefficient. Finally, if pairs of contacts used in a voltage measurement are not aligned properly either perpendicular or parallel to the excitation current density, then the voltages measured will not correctly determine the perpendicular or parallel component of the electric field. To minimize these geometrical problems, one must take care with the size and placement of electrical contacts to the sample.

There are also many intrinsic physical mechanisms that alter current density and electric field behavior in a real material. Most of these relate to the thermoelectric behavior of the material in or out of a magnetic field. Some of these effects can be minimized by controlling temperature in the sample's vicinity to minimize thermal gradients across it. In addition, most errors introduced by intrinsic physical mechanisms can be canceled by reversing either the excitation current or the magnetic field and averaging measurements.

A.2 HALL EFFECT MEASUREMENT THEORY

Hall effect measurements commonly use two sample geometries: (1) long, narrow Hall bar geometries and (2) nearly square or circular van der Pauw geometries. Each has advantages and disadvantages. In both types of samples, a Hall voltage is developed perpendicular to a current and an applied magnetic flux. The following is an introduction to the Hall effect and its use in materials characterization. A number of other sources are available for further information[1,2,3,4].

Hall bar geometry: Some common Hall bar geometries are shown in Figure A-1. The Hall voltage developed across an 8-contact Hall bar sample with contacts numbered as in Figure A-1 is:

$$V_H = V_{24} = \frac{R_H B I}{t}$$

where V_{24} is the voltage measured between the opposing contacts numbered 2 and 4, R_H is the Hall coefficient of the material, *B* is the applied magnetic flux density, *I* is the current, and *t* is the thickness of the sample (in the direction parallel to *B*). This section assumes SI units. For a given material, increase the Hall voltage by increasing *B* and *I* and by decreasing sample thickness.

The relationship between the Hall coefficient and the type and density of charge carriers can be complex, but useful insight can be developed by examining the limit $B \to \infty$, when:

$$R_H = \frac{r}{q(p-n)}$$

where *r* is the Hall scattering factor, *q* is the fundamental electric charge, *p* is the density of positive and *n* the density of negative charge carriers in the material. For the case of a material with one dominant carrier, the Hall coefficient is inversely proportional to the carrier density. The measurement implication is that the greater the density of dominant charge carriers, the smaller the Hall coefficient and the smaller the Hall voltage which must be measured. The scattering factor *r* depends on the scattering mechanisms in the material and typically lies between 1 and 2.[1,5]

Another quantity frequently of interest is the carrier mobility, defined as: $\mu_H = \frac{|R_H|}{\rho}$

where μ_H is the Hall mobility and ρ is the electrical resistivity at zero magnetic flux density. The electrical resistivity can be measured by applying a current between contacts 5 and 6 of the sample shown in Figure A-1 and measuring the voltage between contacts 1 and 3, then using the formula:

$$\rho(B) = \frac{V_{13}}{I_{56}} \frac{wt}{b}$$

where *w* is the width and *t* is the thickness of the Hall bar, *b* is the distance between contacts 1-3, and *B* is the magnetic flux density at which the measurement is taken. The Hall bar is a good geometry for making resistance measurements since about half of the voltage applied across the sample appears between the voltage measurement contacts. For this reason, Hall bars of similar geometries are commonly used when measuring magnetoresistance or Hall mobility on samples with low resistances.

Disadvantages of Hall bar geometries include the following: A minimum of six contacts to make mobility measurements; accuracy of resistivity measurements is sensitive to the geometry of the sample; Hall bar width and the distance between the side contacts can be especially difficult to measure accurately. The accuracy can be increased by making contact to the sides of the bar at the end of extended arms as shown in Figure A-2. Creating such patterns can be difficult and can result in fragile samples.

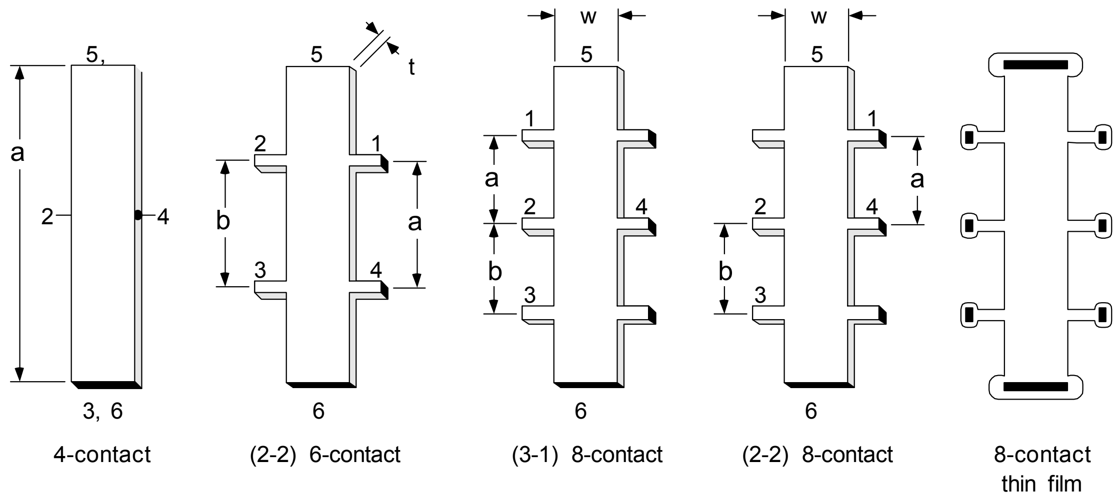

Figure A-1 Common Hall Bar Geometries. Sample thickness, t, of a thin film sample = diffusion depth or layer thickness. Contacts are black, numbered according to the standard to mount in Lake Shore sample holders.

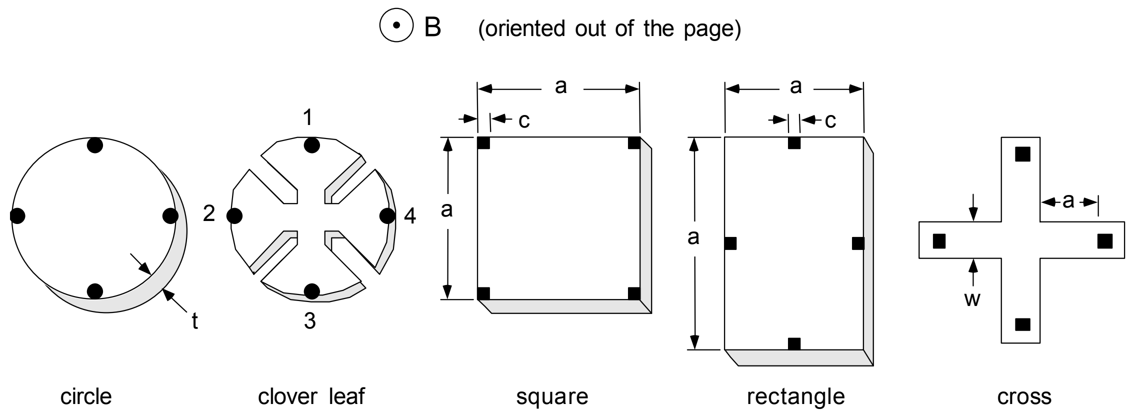

Figure A-2 Common van der Pauw Sample Geometries. The cross appears as a thin film pattern and the others are bulk samples. Contacts are black.

van der Pauw geometry: Some disadvantages of Hall bar geometries can be avoided with van der Pauw sample geometries (see Figure A-2). Van der Pauw [5,6] showed how to calculate the resistivity, carrier concentration, and mobility of an arbitrary, flat sample if the following conditions are met:

1. The contacts are on the circumference of the sample.
2. The contacts are sufficiently small.
3. The sample is of uniform thickness, and:
4. The sample is singly connected (contains no isolated holes).

The resistivity of a van der Pauw sample is given by the expression:

$$\rho = \frac{\pi t}{\ln(2)} \frac{V_{43}}{I_{12}} + \frac{V_{14}}{I_{23}}$$

where V_{23} is defined as $V_2 - V_3$ and I_{12} indicates the current enters the sample through contact 1 and leaves through contact 2. Two voltage readings are required with the van der Pauw sample, whereas the resistivity measurement on a Hall bar requires only one. This same requirement applies to Hall coefficient measurement as well, so equivalent measurements take twice as long with van der Pauw samples.

The quantity F is a transcendental function of the ratio R_r, defined as:

$$R_r \equiv \frac{V_{43}}{I_{12}} \frac{I_{23}}{V_{14}} \equiv \frac{R_{12,43}}{R_{23,14}} \quad \text{or} \quad R_r \equiv \frac{I_{12}}{V_{43}} \frac{V_{14}}{I_{23}} \equiv \frac{R_{23,14}}{R_{12,43}}$$

whichever is **greater**, and F is found by solving the equation:

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

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.

Squares and circles are the most common van der Pauw geometries, but contact size and placement can significantly effect measurement accuracy. A few simple cases were treated by van der Pauw. Others have shown that for square samples with sides of length *a* and square or triangular contacts of size δ in the four corners, if $\delta/a < 0.1$, then the measurement error is less than 10%[6]. The error is reduced by placing the contacts on square samples at the midpoint of the sides rather than in the corners[7]. The Greek cross shown in Figure A-2 has arms which serve to isolate the contacts from the active region. When using the Greek cross sample geometry with a/w > 1.02, less than 1% error is introduced[8]. A cloverleaf shaped structure like the one shown in Figure A-2 is often used for a patternable thin film on a substrate. The active area in the center is connected by four pathways to four connection pads around its perimeter. This shape makes the measurement much less sensitive to contact size, allowing for larger contact areas.

The contact size affects voltage required to pass a current between two contacts. Ideal point contacts would produce no error due to contact size, but require an enormous voltage to force the current through the infinitesimal contact area. Even with square contacts in the corners of a square sample with $\delta/a < 0.1$, the ratio of the output to input voltage V_{43}, V_{12} is on the order of 1/10. Van der Pauw sample geometries are thus much less efficient at using the available excitation voltage than Hall bars.

Advantages of van der Pauw samples: Only four contacts required. No need to measure sample widths or distances between contacts. Simple geometries can be used.

Disadvantages: Measurements take about twice as long. Errors due to contact size and placement can be significant when using simple geometries.

Mobility spectra: Hall effect measurements are usually performed at just one magnetic flux density, although polarity is reversed and the voltage readings averaged to remove some sources or error. The resulting single mobility calculated from the measurements is a weighted average of the mobilities of all carriers present in the sample. Beck and Anderson[9] developed a technique for interpreting magnetic flux-dependent Hall data which generates a mobility spectrum. The result is a plot of the carrier concentration of conductivity as a function of the mobility. The number of peaks appearing in a mobility spectrum indicates the number of distinct charge carriers active in the material. This powerful technique has virtually eliminated the need for destructive testing techniques such as differential profiling. An example mobility spectrum analysis performed on a GaAs/AlGaAs five-quantum-well heterostructure is shown in Figure 2-9 of their paper.

A technique combining mobility spectrum analysis and multi-carrier fitting was developed by Brugger and Kosser[10], yielding some improvement. The development of quantitative mobility spectrum analysis by Antoszewski et al.[2,11,12,13] has produced even greater improvements in capability.

A.3 SAMPLE GEOMETRIES AND MEASUREMENTS SUPPORTED BY IDEAS HALL SOFTWARE

This section describes common sample geometries useful in Lake Shore's 9500 Series Hall Measurement System and formulas used to calculate resistivities, Hall coefficients, carrier concentrations, and mobilities.

A.3.1 System of Units

Hall effect and magnetoresistance measurements commonly use two systems of units: the SI system and the so-called "laboratory" system. The laboratory system is a hybrid, combining elements of the SI, emu, and esu unit systems. Table A-1 lists the most common quantities, their symbols, their units in both systems, and the conversion factor between them.

Table A- 1 Unit Systems and Conversions

Quantity	Symbol	SI	= Factor x	Laboratory
Capacitance	*C*	farad	1	farad
Carrier concentration	*c,n,p*	m^{-3}	10^{-6}	cm^{-3}
Charge	*q,e*	coulomb	1	coulomb
Conductivity (volume)	σ	(ohm m)-1	10-2	$(ohm\ cm)^{-1}$
Current	*I*	ampere	1	ampere
Current density	*j*	$ampere/m^2$	10^{-4}	$ampere/cm^2$
Electric field intensity	*E*	volt/m	10^{-2}	volt/cm
Hall coefficient	R_H	$m^3/coulomb$	10^6	$cm^3/coulomb$
Magnetic induction	*B*	tesla (= V s/m2)	10^4	gauss
Mobility	μ_H	$m^2/V\ s$	10^4	$cm^2/V\ s$
Electric potential	*V*	volt	1	volt
Resistivity	ρ	ohm m	10^2	ohm cm

To use this table, 1 SI unit = (factor) x 1 laboratory unit. For example, 1 tesla = 10^4 gauss.

A.3.2 Nomenclature

The equations below appear twice - once in SI units, once in laboratory units. In all cases, voltages are measured in volts, electric currents are measured in amperes, and resistances are measured in ohms. All other measured quantities appear with their respective unit in brackets. For example, the width of a sample in SI units appears as $w[m]$. The equations below indicate voltages and currents as follows:

VOLTAGE NOMENCLATURE
$_{,kl}(\pm B)$ indicates a voltage difference $V_k - V_l$ measured between terminals *k* and *l*. Terminal *i* is connected to the excitation current source and terminal *j* is connected to the current sink.
e superscript ±. Indicates the sign of the excitation current supplied by the current source. ±B indicates the sign of the applied magnetic induction *B*, measured in the direction shown on the drawings.
ample: $V^{-}_{56,12}(+B)$ indicates a voltage difference $V_1 - V_2$ measured while a negative current was supplied by a current source at terminal 5 and flowed to terminal 6, in the presence of a positive applied magnetic induction.
CURRENT NOMENCLATURE
$(\pm B)$ indicates a current flowing from terminal *i* to terminal *j* of polarity given by the superscript ± and with the indicated magnetic field polarity.

A.3.3 Van der Pauw Measurements

The van der Pauw structure is probably the most popular Hall measurement geometry, primarily because it requires fewer geometrical measurements of the sample. In 1958, van der Pauw[13] solved the general problem of the potential in a thin conducting layer of arbitrary shape. His solution allowed Hall and resistivity measurements to be made on any sample of uniform thickness, provided that the sample was homogeneous and there were no 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 and carrier concentration. These relaxed requirements on sample shape simplify fabrication and measurement in comparison to Hall bar techniques.

On the other hand, the van der Pauw structure is more susceptible to errors caused by the finite size of the contacts than the Hall bar. It is also impossible to accurately measure magnetoresistance with the van der Pauw geometry, so both Hall effect and magnetoresistance (i.e. the whole conductivity tensor) measurements must be done with a Hall bar geometry.

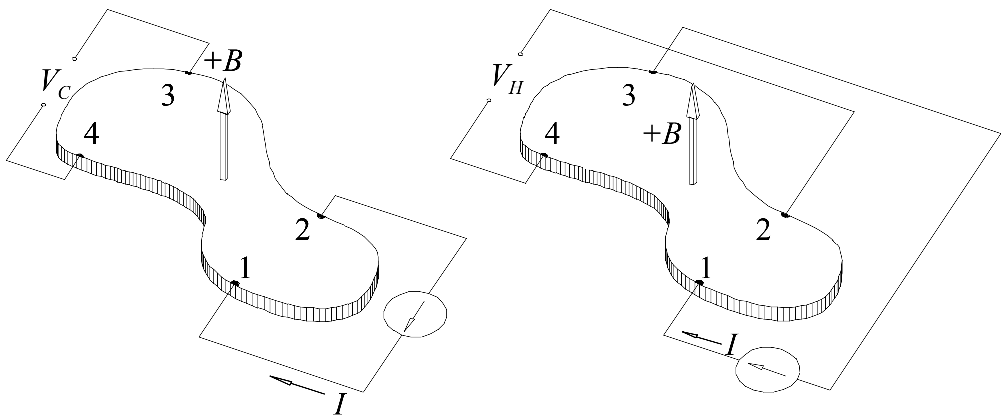

Figure A-3 Measuring Resistivity and Hall Coefficient Using a van der Pauw Geometry.

In the basic van der Pauw contact arrangement, the four contacts made to the sample are numbered counter-clockwise in ascending order when the sample is viewed from above with the magnetic field perpendicular to the sample and pointing toward the observer. The sample interior should contain no contacts or holes. The sample must be homogeneous and of uniform thickness.

Resistivity

Again, let V^{+}_{ijkl} indicate a voltage measured across terminals *k* and *l,* with *k* positive, while a positive current flows into terminal *i* and out of terminal *j*. In a similar fashion, let R^{+}_{ijkl} indicate a resistance $R^{+}_{ijkl} = V_{kl} / I_{ij}$, with the voltage measured across terminals *k* and *l*, while a positive current flows into *i* and out of *j*. First calculate the two resistivities:

$$\rho_A = \frac{\pi\, f_A\, t[m, cm]}{\ln(2)} \left\{ \frac{V^{+}_{12,43} - V^{-}_{12,43} + V^{+}_{23,14} - V^{-}_{23,14}}{I^{+}_{12} - I^{-}_{12} + I^{+}_{23} - I^{-}_{23}} \right\} \quad [\Omega \cdot \mathrm{m}, \Omega \cdot \mathrm{cm}],$$

and

$$\rho_B = \frac{\pi\, f_B\, t[m, cm]}{\ln(2)} \left\{ \frac{V^{+}_{34,21} - V^{-}_{34,21} + V^{+}_{41,23} - V^{-}_{41,23}}{I^{+}_{34} - I^{-}_{34} + I^{+}_{41} - I^{-}_{41}} \right\} \quad [\Omega \cdot \mathrm{m}, \Omega \cdot \mathrm{cm}].$$

Geometrical factors f_A and f_B are functions of resistance ratios Q_A and Q_B, respectively, given by:

$$Q_A = \left(\frac{R^{+}_{12,43} - R^{-}_{12,43}}{R^{+}_{23,14} - R^{-}_{23,14}} \right) = \left(\frac{V^{+}_{12,43} - V^{-}_{12,43}}{I^{+}_{12} - I^{-}_{12}} \right) \left(\frac{I^{+}_{23} - I^{-}_{23}}{V^{+}_{23,14} - V^{-}_{23,14}} \right),$$

and

$$Q_B = \left(\frac{R^{+}_{34,21} - R^{-}_{34,21}}{R^{+}_{41,23} - R^{-}_{41,23}} \right) = \left(\frac{V^{+}_{34,21} - V^{-}_{34,21}}{I^{+}_{34} - I^{-}_{34}} \right) \left(\frac{I^{+}_{41} - I^{-}_{41}}{V^{+}_{41,23} - V^{-}_{41,23}} \right).$$

If either Q_A or Q_B is greater than one, then use the reciprocal instead. The relationship between f and Q is expressed by the transcendental equation

$$\frac{Q-1}{Q+1}=\frac{f}{\ln 2}\cosh^{-1}\left\{\frac{1}{2}\exp\left[\frac{\ln 2}{f}\right]\right\},$$

which can be solved numerically.

The two resistivities ρ_A and ρ_B should agree to within ±10%. If they do not, then the sample is too inhomogeneous, or anisotropic, or has some other problem. If they do agree, the average resistivity is given by

$$\rho_{av}=\frac{\rho_A+\rho_B}{2}\quad[\Omega\cdot\mathrm{m},\Omega\cdot\mathrm{cm}].$$

Magnetoresistivity

If desired, calculate the magnetoresistivity as

$$\rho_A(B)=\frac{\pi f_A\ t[m,cm]}{\ln(2)}\left\{\frac{V_{12,43}^{+}(+B)-V_{12,43}^{-}(+B)+V_{23,41}^{+}(+B)-V_{23,41}^{-}(+B)}{I_{12}^{+}(+B)-I_{12}^{-}(+B)+I_{23}^{+}(+B)-I_{23}^{-}(+B)}\cdots\right.$$
$$\left.\frac{+V_{12,43}^{+}(-B)-V_{12,43}^{-}(-B)+V_{23,41}^{+}(-B)-V_{23,41}^{-}(-B)}{+I_{12}^{+}(-B)-I_{12}^{-}(-B)+I_{23}^{+}(-B)-I_{23}^{-}(-B)}\right\}\quad[\Omega\cdot\mathrm{m},\Omega\cdot\mathrm{cm}],$$

and

$$\rho_B(B)=\frac{\pi f_B\ t[m,cm]}{\ln(2)}\left\{\frac{V_{34,21}^{+}(+B)-V_{34,21}^{-}(+B)+V_{41,23}^{+}(+B)-V_{41,23}^{-}(+B)}{I_{34}^{+}(+B)-I_{34}^{-}(+B)+I_{41}^{+}(+B)-I_{41}^{-}(+B)}\cdots\right.$$
$$\left.\frac{+V_{34,21}^{+}(-B)-V_{34,21}^{-}(-B)+V_{41,23}^{+}(-B)-V_{41,23}^{-}(-B)}{+I_{34}^{+}(-B)-I_{34}^{-}(-B)+I_{41}^{+}(-B)-I_{41}^{-}(-B)}\right\}\quad[\Omega\cdot\mathrm{m},\Omega\cdot\mathrm{cm}].$$

Calculate factors f_A and f_B the same way as at zero magnetic field, and the average magnetoresistivity is:

$$\rho_{av}(B)=\frac{\rho_A(B)+\rho_B(B)}{2}\quad[\Omega\cdot\mathrm{m}],[\Omega\cdot\mathrm{cm}].$$

This measurement does not give the true magnetoresistance, as defined in terms of the material's conductivity tensor. Van der Pauw's calculation of resistivity is invalid in the presence of a magnetic field, since the magnetic field alters the current density vector field inside the sample. On the other hand, magnetoresistance measurements are routinely performed on van der Pauw samples anyway.

Hall Coefficient

Calculate two values of the Hall coefficient by the following:

$$R_{HC} = \frac{t[\mathrm{m}]}{B[\mathrm{T}]}\frac{V_{31,42}^{+}(+B) - V_{31,42}^{-}(+B) + V_{31,42}^{-}(-B) - V_{31,42}^{+}(-B)}{I_{31}^{+}(+B) - I_{31}^{-}(+B) + I_{31}^{-}(-B) - I_{31}^{+}(-B)} \quad \left[\mathrm{m}^3 \cdot C^{-1}\right]$$

$$= 10^8 \frac{t[\mathrm{cm}]}{B[\mathrm{gauss}]}\frac{V_{31,42}^{+}(+B) - V_{31,42}^{-}(+B) + V_{31,42}^{-}(-B) - V_{31,42}^{+}(-B)}{I_{31}^{+}(+B) - I_{31}^{-}(+B) + I_{31}^{-}(-B) - I_{31}^{+}(-B)} \quad \left[\mathrm{cm}^3 \cdot C^{-1}\right],$$

and

$$R_{HD} = \frac{t[\mathrm{m}]}{B[\mathrm{T}]}\frac{V_{42,13}^{+}(+B) - V_{42,13}^{-}(+B) + V_{42,13}^{-}(-B) - V_{42,13}^{+}(-B)}{I_{42}^{+}(+B) - I_{42}^{-}(+B) + I_{42}^{-}(-B) - I_{42}^{+}(-B)} \quad \left[\mathrm{m}^3 \cdot \mathrm{C}^{-1}\right]$$

$$= 10^8 \frac{t[\mathrm{cm}]}{B[\mathrm{gauss}]}\frac{V_{42,13}^{+}(+B) - V_{42,13}^{-}(+B) + V_{42,13}^{-}(-B) - V_{42,13}^{+}(-B)}{I_{42}^{+}(+B) - I_{42}^{-}(+B) + I_{42}^{-}(-B) - I_{42}^{+}(-B)} \quad \left[\mathrm{cm}^3 \cdot \mathrm{C}^{-1}\right].$$

These two should agree to within ±10%. If they do not, then the sample is too inhomogeneous, or anisotropic, or has some other problem. If they do, then the average Hall coefficient can be calculated by

$$R_{Hav} = \frac{R_{HC} + R_{HD}}{2} \quad \left[\mathrm{m}^3 \cdot \mathrm{C}^{-1}, \mathrm{cm}^3 \cdot \mathrm{C}^{-1}\right]$$

Hall Mobility

The Hall mobility is given by

$$\mu_H = \frac{|R_{Hav}|}{\rho_{av}} \quad \left[\mathrm{m}^2 \cdot \mathrm{V}^{-1} \cdot \mathrm{s}^{-1}, \mathrm{cm}^2 \cdot \mathrm{V}^{-1} \cdot \mathrm{s}^{-1}\right],$$

where ρ_{av} is the magnetoresistivity if it was measured, and the zero-field resistivity if it was not.

A.3.4 Hall Bar Measurements

Hall bars approximate the ideal geometry for measuring the Hall effect, in which a constant current density flows along the long axis of a rectangular solid, perpendicular to an applied external magnetic field.

A.3.4.1 Six-contact 1-2-2-1 Hall Bar

An ideal six-contact 1-2-2-1 Hall bar geometry 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 geometry 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 geometry is included in ASTM Standard F76, the contact numbering given here differs from the standard.

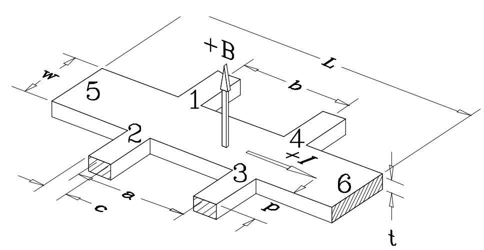

Figure A-4 Six-Contact 1-2-2-1 Hall Bar Geometry

Resistivity

To calculate resistivity at zero field, first calculate

$$\rho_A = \frac{V^+_{56,23}(B=0) - V^-_{56,23}(B=0)}{I^+_{56}(B=0) - I^-_{56}(B=0)} \frac{w[\mathrm{m}]\, t[\mathrm{m}]}{a[\mathrm{m}]} \quad [\Omega \cdot \mathrm{m}]$$

$$= \frac{V^+_{56,23}(B=0) - V^-_{56,23}(B=0)}{I^+_{56}(B=0) - I^-_{56}(B=0)} \frac{w[\mathrm{cm}]\, t[\mathrm{cm}]}{a[\mathrm{cm}]} \quad [\Omega \cdot \mathrm{cm}],$$

and

$$\rho_B = \frac{V^+_{56,14}(B=0) - V^-_{56,14}(B=0)}{I^+_{56}(B=0) - I^-_{56}(B=0)} \frac{w[\mathrm{m}]\, t[\mathrm{m}]}{b[\mathrm{m}]} \quad [\Omega \cdot \mathrm{m}]$$

$$= \frac{V^+_{56,14}(B=0) - V^-_{56,14}(B=0)}{I^+_{56}(B=0) - I^-_{56}(B=0)} \frac{w[\mathrm{cm}]\, t[\mathrm{cm}]}{b[\mathrm{cm}]} \quad [\Omega \cdot \mathrm{cm}].$$

These two resistivities should agree to within ±10%. If they do not, then the sample is too inhomogeneous, or anisotropic, or has some other problem. If they do, then the average resistivity is given by

$$\rho_{av} = \frac{\rho_A + \rho_B}{2} \quad [\Omega \cdot \mathrm{m}, \Omega \cdot \mathrm{cm}] .$$

Magnetoresistivity

Magnetoresistivity is typically used in mobility spectrum calculations, but not in Hall mobility calculations. To calculate magnetoresistivity, first calculate

$$\rho_A(B) = \frac{V^+_{56,23}(+B) - V^-_{56,23}(+B) + V^+_{56,23}(-B) - V^-_{56,23}(-B)}{I^+_{56}(+B) - I^-_{56}(+B) + I^+_{56}(-B) - I^-_{56}(-B)} \frac{w[\mathrm{m}]\, t[\mathrm{m}]}{a[\mathrm{m}]} \quad [\Omega \cdot \mathrm{m}]$$

$$= \frac{V^+_{56,23}(+B) - V^-_{56,23}(+B) + V^+_{56,23}(-B) - V^-_{56,23}(-B)}{I^+_{56}(+B) - I^-_{56}(+B) + I^+_{56}(-B) - I^-_{56}(-B)} \frac{w[\mathrm{cm}]\, t[\mathrm{cm}]}{a[\mathrm{cm}]} \quad [\Omega \cdot \mathrm{cm}],$$

and

$$\rho_B(B) = \frac{V^+_{56,14}(+B) - V^-_{56,14}(+B) + V^+_{56,14}(-B) - V^-_{56,14}(-B)}{I^+_{56}(+B) - I^-_{56}(+B) + I^+_{56}(-B) - I^-_{56}(-B)} \frac{w[\mathrm{m}]\, t[\mathrm{m}]}{b[\mathrm{m}]} \quad [\Omega \cdot \mathrm{m}]$$

$$= \frac{V^+_{56,14}(+B) - V^-_{56,14}(+B) + V^+_{56,14}(-B) - V^-_{56,14}(-B)}{I^+_{56}(+B) - I^-_{56}(+B) + I^+_{56}(-B) - I^-_{56}(-B)} \frac{w[\mathrm{cm}]\, t[\mathrm{cm}]}{b[\mathrm{cm}]} \quad [\Omega \cdot \mathrm{cm}].$$

These two resistivities should agree to within ±10%. If they do not, then the sample is too inhomogeneous, or anisotropic, or has some other problem. If they do, then the average magnetoresistivity is given by

$$\rho_{av}(B) = \frac{\rho_A(B) + \rho_B(B)}{2} \quad [\Omega \cdot \mathrm{m}, \Omega \cdot \mathrm{cm}].$$

Hall Coefficient

First, calculate the individual Hall coefficients

$$R_{HA} = \frac{t[\mathrm{m}]}{B[\mathrm{T}]} \frac{V^+_{56,34}(+B) - V^-_{56,34}(+B) + V^-_{56,34}(-B) - V^+_{56,34}(-B)}{I^+_{56}(+B) - I^-_{56}(+B) + I^-_{56}(-B) - I^+_{56}(-B)} \quad \left[\mathrm{m}^3 \cdot C^{-1}\right]$$

$$= 10^8 \frac{t[\mathrm{cm}]}{B[\mathrm{gauss}]} \frac{V^+_{56,34}(+B) - V^-_{56,34}(+B) + V^-_{56,34}(-B) - V^+_{56,34}(-B)}{I^+_{56}(+B) - I^-_{56}(+B) + I^-_{56}(-B) - I^+_{56}(-B)} \quad \left[\mathrm{cm}^3 \cdot C^{-1}\right],$$

and

$$R_{HA} = \frac{t[\mathrm{m}]}{B[\mathrm{T}]} \frac{V^+_{56,21}(+B) - V^-_{56,21}(+B) + V^-_{56,21}(-B) - V^+_{56,21}(-B)}{I^+_{56}(+B) - I^-_{56}(+B) + I^-_{56}(-B) - I^+_{56}(-B)} \quad \left[\mathrm{m}^3 \cdot \mathrm{C}^{-1}\right]$$

$$= 10^8 \frac{t[\mathrm{cm}]}{B[\mathrm{gauss}]} \frac{V^+_{56,21}(+B) - V^-_{56,21}(+B) + V^-_{56,21}(-B) - V^+_{56,21}(-B)}{I^+_{56}(+B) - I^-_{56}(+B) + I^-_{56}(-B) - I^+_{56}(-B)} \quad \left[\mathrm{cm}^3 \cdot \mathrm{C}^{-1}\right].$$

If R_{HA} and R_{HB} do not agree to within ±10%, then the sample is too inhomogeneous, or anisotropic, or has some other problem. If they do agree, then the average Hall Coefficient is given by

$$R_{Hav} = \frac{R_{HA} + R_{HB}}{2} \quad \left[\mathrm{m}^3 \cdot \mathrm{C}^{-1}, \mathrm{cm}^3 \cdot \mathrm{C}^{-1}\right].$$

Hall Mobility

$\mu_H = \frac{|R_{Hav}|}{\rho_{av}} \quad \left[\mathrm{m}^2 \cdot \mathrm{V}^{-1} \cdot \mathrm{s}^{-1}, \mathrm{cm}^2 \cdot \mathrm{V}^{-1} \cdot \mathrm{s}^{-1}\right]$ gives the Hall mobility where ρ_{av} is the zero-field resistivity.

A.3.4.2 Six-contact 1-3-1-1 Hall Bar

The ideal 1-3-1-1 Hall bar geometry places contacts 2 and 4 directly across from one another in the exact middle of the sample's length and contacts 1 and 3 symmetrically on either side of contact 2.

This geometry allows no homogeneity checks, but measuring the Hall voltage in the exact center of the sample's length helps minimize the shorting of the Hall voltage via the end contacts. The 1-3-1-1 Hall bar is not included in ASTM Standard F76.

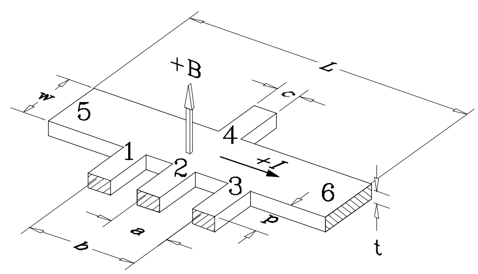

Figure A-5 Six-Contact 1-3-1-1 Hall Bar Geometry

Resistivity

Calculate the resistivity at zero field by

$$\rho = \frac{V^+_{56,13}(B=0) - V^-_{56,13}(B=0)}{I^+_{56}(B=0) - I^-_{56}(B=0)} \frac{w[\mathrm{m}]\, t[\mathrm{m}]}{b[\mathrm{m}]} \quad [\Omega \cdot \mathrm{m}]$$

$$= \frac{V^+_{56,13}(B=0) - V^-_{56,13}(B=0)}{I^+_{56}(B=0) - I^-_{56}(B=0)} \frac{w[\mathrm{cm}]\, t[\mathrm{cm}]}{b[\mathrm{cm}]} \quad [\Omega \cdot \mathrm{cm}].$$

Magnetoresistivity

If desired, calculate the magnetoresistivity by

$$\rho(B) = \frac{V^+_{56,13}(+B) - V^-_{56,13}(+B) + V^+_{56,13}(-B) - V^-_{56,13}(-B)}{I^+_{56}(+B) - I^-_{56}(+B) + I^+_{56}(-B) - I^-_{56}(-B)} \frac{w[\mathrm{m}]\, t[\mathrm{m}]}{b[\mathrm{m}]} \quad [\Omega \cdot \mathrm{m}]$$

$$= \frac{V^+_{56,13}(+B) - V^-_{56,13}(+B) + V^+_{56,13}(-B) - V^-_{56,13}(-B)}{I^+_{56}(+B) - I^-_{56}(+B) + I^+_{56}(-B) - I^-_{56}(-B)} \frac{w[\mathrm{cm}]\, t[\mathrm{cm}]}{b[\mathrm{cm}]} \quad [\Omega \cdot \mathrm{cm}].$$

Hall Coefficient

Calculate the Hall coefficient by

$$R_H = \frac{t[\mathrm{m}]}{B[\mathrm{T}]} \frac{V^+_{56,24}(+B) - V^-_{56,24}(+B) + V^-_{56,24}(-B) - V^+_{56,24}(-B)}{I^+_{56}(+B) - I^-_{56}(+B) + I^-_{56}(-B) - I^+_{56}(-B)} \quad [\mathrm{m}^3 \cdot \mathrm{C}^{-1}]$$

$$= 10^8 \frac{t[\mathrm{cm}]}{B[\mathrm{gauss}]} \frac{V^+_{56,24}(+B) - V^-_{56,24}(+B) + V^-_{56,24}(-B) - V^+_{56,24}(-B)}{I^+_{56}(+B) - I^-_{56}(+B) + I^-_{56}(-B) - I^+_{56}(-B)} \quad [\mathrm{cm}^3 \cdot \mathrm{C}^{-1}].$$

Hall Mobility

The Hall mobility is given by $\mu_H = \frac{|R_H|}{\rho} \quad [\mathrm{m}^2 \cdot \mathrm{V}^{-1} \cdot \mathrm{s}^{-1}, \mathrm{cm}^2 \cdot \mathrm{V}^{-1} \cdot \mathrm{s}^{-1}]$,

where ρ is the magnetoresistivity if it was measured, and the zero-field resistivity if it was not.

A.3.4.3 Eight-contact 1-3-3-1 Hall Bar

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.

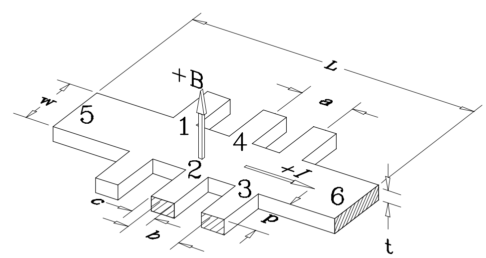

Figure A-6 Eight-Contact 1-3-3-1 Hall Bar Geometry

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. Either the 1-2-2-1 or 1-3-1-1 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.

Resistivity

First calculate the two resistivities

$$\rho_A = \frac{V_{56,23}^{+}(B=0) - V_{56,23}^{-}(B=0)}{I_{56}^{+}(B=0) - I_{56}^{-}(B=0)} \frac{w[\mathrm{m}]\, t[\mathrm{m}]}{b[\mathrm{m}]} \quad [\Omega \cdot \mathrm{m}]$$

$$= \frac{V_{56,23}^{+}(B=0) - V_{56,23}^{-}(B=0)}{I_{56}^{+}(B=0) - I_{56}^{-}(B=0)} \frac{w[\mathrm{cm}]\, t[\mathrm{cm}]}{b[\mathrm{cm}]} \quad [\Omega \cdot \mathrm{cm}],$$

and

$$\rho_B = \frac{V_{56,14}^{+}(B=0) - V_{56,14}^{-}(B=0)}{I_{56}^{+}(B=0) - I_{56}^{-}(B=0)} \frac{w[\mathrm{m}]\, t[\mathrm{m}]}{b[\mathrm{m}]} \quad [\Omega \cdot \mathrm{m}]$$

$$= \frac{V_{56,14}^{+}(B=0) - V_{56,14}^{-}(B=0)}{I_{56}^{+}(B=0) - I_{56}^{-}(B=0)} \frac{w[\mathrm{cm}]\, t[\mathrm{cm}]}{b[\mathrm{cm}]} \quad [\Omega \cdot \mathrm{cm}]$$

at zero magnetic field.

If these two values disagree by more than ±10%, then the sample is too inhomogeneous, or anisotropic, or has some other problem. If they do agree, then the average resistivity is given by

$$\rho_{av} = \frac{\rho_A + \rho_B}{2} \quad [\Omega \cdot \mathrm{m}],[\Omega \cdot \mathrm{cm}]\ .$$

Magnetoresistivity

If desired, calculate the two magnetoresistivities

$$\rho_A = \frac{V_{56,23}^{+}(+B) - V_{56,23}^{-}(+B) + V_{56,23}^{+}(-B) - V_{56,23}^{-}(-B)}{I_{56}^{+}(+B) - I_{56}^{-}(+B) + I_{56}^{+}(-B) - I_{56}^{-}(-B)} \frac{w[\mathrm{m}]\, t[\mathrm{m}]}{b[\mathrm{m}]} \quad [\Omega \cdot \mathrm{m}]$$

$$= \frac{V_{56,23}^{+}(+B) - V_{56,23}^{-}(+B) + V_{56,23}^{+}(-B) - V_{56,23}^{-}(-B)}{I_{56}^{+}(+B) - I_{56}^{-}(+B) + I_{56}^{+}(-B) - I_{56}^{-}(-B)} \frac{w[\mathrm{cm}]\, t[\mathrm{cm}]}{b[\mathrm{cm}]} \quad [\Omega \cdot \mathrm{cm}],$$

and

$$\rho_B = \frac{V_{56,14}^{+}(+B) - V_{56,14}^{-}(+B) + V_{56,14}^{+}(-B) - V_{56,14}^{-}(-B)}{I_{56}^{+}(+B) - I_{56}^{-}(+B) + I_{56}^{+}(-B) - I_{56}^{-}(-B)} \frac{w[\mathrm{m}]\, t[\mathrm{m}]}{b[\mathrm{m}]} \quad [\Omega \cdot \mathrm{m}]$$

$$= \frac{V_{56,14}^{+}(+B) - V_{56,14}^{-}(+B) + V_{56,14}^{+}(-B) - V_{56,14}^{-}(-B)}{I_{56}^{+}(+B) - I_{56}^{-}(+B) + I_{56}^{+}(-B) - I_{56}^{-}(-B)} \frac{w[\mathrm{cm}]\, t[\mathrm{cm}]}{b[\mathrm{cm}]} \quad [\Omega \cdot \mathrm{cm}].$$

If these two values disagree by more than ±10%, then the sample is too inhomogeneous, or anisotropic, or has some other problem. If they do agree, then the average magnetoresistivity is given by

$$\rho_{av}(B) = \frac{\rho_A(B) + \rho_B(B)}{2} \quad [\Omega \cdot \mathrm{m}, \Omega \cdot \mathrm{cm}].$$

Hall Coefficient

Calculate the Hall coefficient by

$$R_H = \frac{t[\mathrm{m}]}{B[\mathrm{T}]} \frac{V_{56,24}^{+}(+B) - V_{56,24}^{-}(+B) + V_{56,24}^{-}(-B) - V_{56,24}^{+}(-B)}{I_{56}^{+}(+B) - I_{56}^{-}(+B) + I_{56}^{-}(-B) - I_{56}^{+}(-B)} \quad \left[\mathrm{m}^3 \cdot \mathrm{C}^{-1}\right]$$

$$= 10^8 \frac{t[\mathrm{cm}]}{B[\mathrm{gauss}]} \frac{V_{56,24}^{+}(+B) - V_{56,24}^{-}(+B) + V_{56,24}^{-}(-B) - V_{56,24}^{+}(-B)}{I_{56}^{+}(+B) - I_{56}^{-}(+B) + I_{56}^{-}(-B) - I_{56}^{+}(-B)} \quad \left[\mathrm{cm}^3 \cdot \mathrm{C}^{-1}\right].$$

Hall Mobility

The Hall mobility is given by

$$\mu_H = \frac{|R_{Hav}|}{\rho_{av}} \quad \left[\mathrm{m}^2 \cdot \mathrm{V}^{-1} \cdot \mathrm{s}^{-1}, \mathrm{cm}^2 \cdot \mathrm{V}^{-1} \cdot \mathrm{s}^{-1}\right],$$

where ρ_{av} is the magnetoresistivity if it was measured, and the zero-field resistivity if it was not.

A.4 COMPARISON TO ASTM STANDARD

The contact numbering and voltage measurement indexing given above differ in several ways from that given in the ASTM Standard F76[15].

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.

Second, the ASTM standard 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 counter-clockwise in ascending order when the sample is viewed from above with the magnetic field perpendicular to the sample and pointing toward the observer, as shown in Figure A-3 **Measuring Resistivity and Hall Coefficient Using a van der Pauw Geometry.**

Finally, the 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 220. 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. This requires a more sophisticated notation for voltage measurements:

$$V_{ij,kl}^{\pm}(\pm B)$$

In this notation, terminal i refers to the contact to which the current source output attaches, terminal j is the current return contact, terminal k is the positive voltmeter terminal, and terminal l is the negative voltmeter terminal. The superscript ± refers to the sign of the programmed current, while $\pm B$ refers to the sign of the applied magnetic field relative to the positive direction indicated in the figures.

A.5 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.[2] There are two kinds of error sources: intrinsic and geometrical.

A.5.1 Intrinsic Error Sources

The apparent Hall voltage, V_{Ha}, 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_S):** 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_s. 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 e**v**x**B** force shunts slow (cool) and fast (hot) electrons to the sides in different numbers and causes an internally 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_{Ha}, measured with a single reading contains all of the above spurious voltages: $V_{Ha} = V_H + V_o + V_S + V_E + V_N + V_R + V_M$.

All but the Hall and Ettingshausen voltages can be eliminated by combining measurements, as shown in Table B-1. 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 Rh(+B) and Rh(-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.

Table A-2 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.

	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

A.5.2 Geometrical Errors in Hall Bar Samples

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.

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%.[15] Therefore, it's important $l / w \geq 3$.

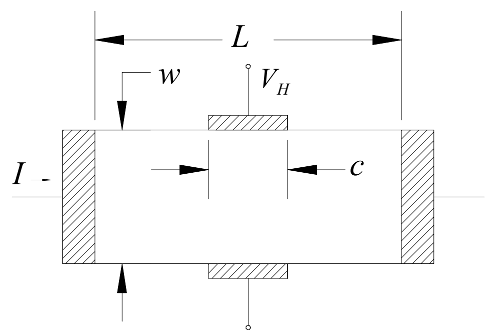

Figure A-7 Hall Bar
With Finite Voltage Contacts

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.

For a simple rectangle, the error in the Hall mobility can be approximated (when µB << 1) by[16]

$$\frac{\Delta\mu_H}{\mu_H} = 1 - (1 - e^{-\pi l/2w})(1 - 2c/\pi w).$$

Here, $\Delta\mu_H$ is the amount μ_H must *increase* to obtain a true value.

If *l/w* = 3, and *c/w* = 0.2, then $\Delta\mu_H / \mu_H = 0.13$, which is certainly a significant error.

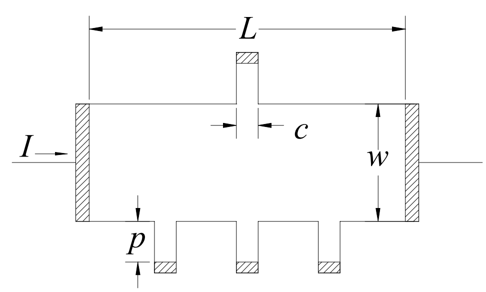

Figure A-8 Hall Bar With Contact Arms

Reduce the contact-size error to acceptable levels by placing contacts at the ends of contact arms.[17] The following aspect ratios yield small deviations from the ideal: $p \approx c, c \leq w/3, l \geq 4w$.

A.5.3 Geometrical Errors in van der Pauw Structures

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[2] presents the results of both theoretical and experimental determinations of the correction factors for some of the most common geometries. We summarize these results here, and compare the correction factors for a 1:6 aspect ratio of contact size to sample size.

A.5.3.1 Square Structures

The resistivity correction factor $\Delta\rho/\rho$ for a square van der Pauw structure is roughly proportional to $(c / l)^2$ for both square and triangular contacts. At $(c / l) = 1/6$, $\Delta\rho/\rho$ = 2% for identical square contacts, and $\Delta\rho/\rho$ < 1% for identical triangular contacts[18]. Hall voltage measurement error is much worse, unfortunately. The correction factor $\Delta R_H / R_H$ 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 Hall angle increases from $\tan\theta = 0.1$ to $\tan\theta = 0.5$.

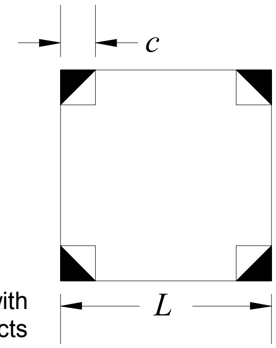

Figure A-9 Square van der Pauw Structure with Either Square or Triangular Contacts

A.5.3.2 Circular Structures

Circular van der Pauw structures fare slightly better. van der Pauw[14] gives a correction factor for circular contacts of

$$\frac{\Delta\rho}{\rho} \cong -\frac{1}{16\ln 2}\left(\frac{c}{l}\right)^2 \qquad \text{(per contact)},$$

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

$$\frac{\Delta R_H}{R_H} \cong \frac{2}{\pi^2}\frac{c}{l} \qquad \text{(per contact)}.$$

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

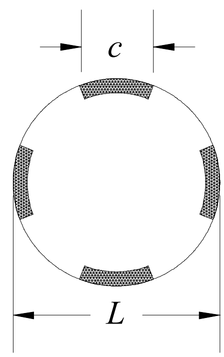

Figure A-10 Circular van der Pauw Structure

van Daal[19] 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.

The clover leaf 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.

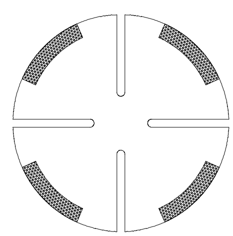

Figure A-11 Cloverleaf van der Pauw Structure

A.4.3.3 Greek Cross Structures

The Greek cross is one of the best van der Pauw geometries to minimize finite contact errors. Its advantage over simpler van der Pauw structures is similar to placing Hall bar contacts at the ends of arms. David and Beuhler[20] analyzed this structure numerically. They found that the deviation of the actual resistivity ρ from the measured value ρ_m obeyed

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

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

Hall coefficient results are substantially better. De Mey[21,22] has shown that

$$\frac{\mu_H - \mu_{Hm}}{\mu_H} = \frac{\Delta\mu_H}{\mu_H} \cong 1.045e^{-\pi a/c} \quad \text{(four contacts)},$$

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

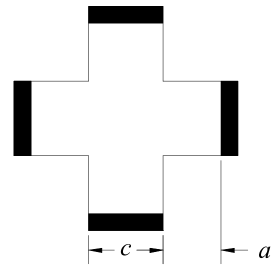

Figure A-12 Greek Cross van der Pauw Structure

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APPENDIX B

ELECTRICAL CONTACTS TO SEMICONDUCTORS

Contents:

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B.1 GENERAL

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.

The word "ohmic" ideally means "obeying Ohm's Law", a condition that is technically impossible to achieve in a metal-semiconductor interface[1]. "Ohmic" usually means a contact with a small resistance compared to the resistance of the sample being studied, and therefore 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 $\Omega \cdot \mathrm{cm}^2$. Contact resistivity is the product of the contact resistance R_c and the area A of the contact. Other common contact parameters include the barrier height Φ_B, measured in eV, and the semiconductor doping concentration, measured in cm^{-3}.

Three primary mechanisms govern current transport across a metal-to-semiconductor interface: Thermionic emission, field emission, and thermionic-field emission[2]. They differ mainly by the interface potential barrier height and width as determined by the work function of the metal, the semiconductor electron affinity, and the semiconductor doping concentration near the interface.

Thermionic emission is important when both the barrier and doping concentration are low. In thermionic emission, electrons thermally excited to energies above the barrier, pass directly over it. As a result, contact resistance where thermionic emission dominates depends strongly on temperature.

Field emission is important when both the barrier and doping concentration are high. A high doping concentration reduces the width of the carrier depletion region near the semiconductor's surface. This in turn produces a thin barrier that electrons tunnel through directly. A field emission is only weakly dependent on temperature.

Thermionic-field emission is important when both barrier and doping concentration are moderate. In thermionic-field emission, electrons are thermally excited part way up the potential barrier, at which point they tunnel the rest of the way through. Thermionic-field emission is moderately temperature-dependent. Typically, some sort of thermionic-field emission is the most likely transport mechanism.

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 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 seconds).

This appendix discusses methods of making electrical contacts to a variety of semiconductor materials. In most cases, it indicates contact materials, method of deposition and annealing, contact resistivity and doping concentration, and references to original publications.

B.2 SILICON

Much effort has been made to produce reliable, small, low-resistance contacts to silicon for VLSI electronics. Gildenblat and Cohen[3] give an excellent review of the art and include the following reference table for silicon contacts. Cooke gives an additional review of LPCVD metallization techniques.

Making Electrical Contacts to Silicon

Contact resistivities are minimum values reported in the references. Usually, these were obtained with the highest dopant concentration employed. Conventional sintering typically involves a furnace anneal at 400-450 ^{O}C for 30-60 minutes. All surfaces are assumed to be $\langle 100 \rangle$ unless indicated otherwise.[3]

Metallization	Semicon-ductor Type	Sintering Conditions	$\rho_c(\Omega \cdot \mu m^2)$	Comments	Reference
Aluminum	p^+	Conventional	3700	$\langle 111 \rangle$ Si	4
	p^+	Conventional	26	$\langle 111 \rangle$ Si	5
	n^-	Conventional	410000	$\langle 111 \rangle$ Si	4
	n^+	Conventional	100	$\langle 111 \rangle$ Si , High Doping	6
	n^+	Conventional	<120	$\langle 111 \rangle$ Si	7
	n^+	Conventional	100	$\langle 111 \rangle$ Si	8
	n^+	Conventional	400	---	9
	n^+	Conventional	<60	---	10
	n^+	E-beam	310	---	11
	n^+	Laser,e-beam	104-1000	---	12,13,14
	n^+	Conventional	100	Polysilicon	15
	p^+	Conventional	300	$\langle 111 \rangle$ Si	7
	p^+	Conventional	<100	Ion Beam Deposition	16
	p^+	Halogen Lamp	15	---	17
	p^+	E-beam	110	---	11
	p^+	Conventional	20	Polysilicon	15
Al-Si Alloys	p^+	Conventional	15	0.9% Si in alloy	18
	n^+	Conventional	90	---	18
	n^+	Conventional	70	1-2% Si	10,19
	n^+	Conventional	<200	1% Si	19
	p^+	Conventional	<500	---	10,19
PtSi	n^+	Conventional	5000	Al Overlayer	20
	n^+	Conventional	20	Al Overlayer	21
	n^+	Conventional	4	Al Overlayer	22
	n^+	Conventional	5	Mo Overlayer	23
	n^+	CW Laser	<100	Ti Overlayer	24
	p^+	Conventional	10000	Al Overlayer	20
	p^+	Conventional	7	Al Overlayer	22
	p^+	Conventional	10	Patterning by Liftoff	25
	p^+	Conventional	7	Mo Overlayer	5

Metallization	Semicon-ductor Type	Sintering Conditions	$\rho_c(\Omega \cdot \mu m^2)$	Comments	References
Pd_2Si	n^-	Conventional	400	---	26
	n^-, p^+	Conventional	63,68	Both $\langle 111 \rangle$ and $\langle 100 \rangle$	5
$MoSi_2$	n^-	Laser	100	---	27
$CoSi_2$	n^-	Laser	<50	---	28
	p^+	Laser	700	---	29
$TiSi_2$	n^-	Laser	100	---	30
	n^-	Laser	<150	---	31
	n^-	Laser	15	---	32
	p^+	Laser	<40	---	31
	p^+	Laser	100	---	32
$TiSi_{1.86}$	p^+	Laser	<50	---	31
	n^-	Laser	<30	---	31
Tungsten	n^-	Laser	20	Selective Deposition	33
	p^+	Laser	25	Selective Deposition	33
WTi	p^+	Laser	20	Al overlayer	34
	n^-	Laser	7	Al overlayer	34
	n^-	E-beam	17	---	11
	p^+	E-beam	13	---	11
Molybdenum	p^+	Conventional	440	---	4
	p^+	Conventional	600	---	35
	p^+	Conventional	5	Sintered at 650 °C	36
	n^-	Conventional	8000	---	4
	n^-	Conventional	800	---	35
	n^-	Conventional	<100	---	37
	n^-	Conventional	2	Sintered at 650 °C	36
Mo_xNi_{1-x}	n^-	Conventional	<350	---	38
	p^+	Conventional	<150	---	38
$Fe_{45}W_{36}$	p^+	Conventional	110	---	39
	n^-	Conventional	10	---	39
Nickel	n^-, p^+	Conventional	200	---	35
Vanadium	p^+	Conventional	520	---	4
	n^-	Conventional	7300	---	4
Cobalt	n^-	Conventional	14000	---	4
	p	Conventional	780	---	4
Chromium	p	Conventional	400	---	35
	n^-	Conventional	300	---	35
TiN,HfN	p	Conventional	<10	Solar cell type Si	40

B.3 GALLIUM ARSENIDE AND OTHER III-V COMPOUNDS

Electrical contact to gallium arsenide has grown due to the popularity of GaAs in the electronic industry, particularly for electro-optical and high-speed digital applications which exploit other III-V compounds as well. In his book, David Look reviews a variety of techniques to contact GaAs and closely related compounds[41]. A more recent article by T. C. Shen, G. B. Gao, and H. Morkoç[2] discusses the emerging role of rapid thermal annealing/processing in contacting GaAs, and electrical contacts to several other III-V compounds.

Electrical Contacts to III-V Compound Semiconductors

Semicon-ductor	Carrier Conc. (10^{18} cm^{-3})	Metallization	Preparation	ρ_c (10^{-6} $\Omega \bullet cm^2$)	Ref.
n-GaAs	2.2	Au/Pd/Ge	evap. surf. heater, 450 °C, 30 s	0.5	42
	2.2	Au/Ge/Ni	evap. surf. heater, 450 °C, 30 s	0.4	42
	5	Ni/AuGe	evap., laser, 40 ns	56	43
	5	Ni/AgGe	evap., laser, 40 ns	95	43
	1	Au/Ni/AuGe	evap. surf. heater, 320 °C, 60 s	15	44
	10	Ni/Au/Ge	evap. no alloying	0.2	45
	1.8	AuGe/Ni	evap., laser, 20 ns	1.5	46
	2	Au/Pd	electroless dep., furnace, 350°C, 2 min	8	47
	100	Au/Cr	evap. no alloying	2.5	48
	0.5	WSi_x	evap. RTA, 800°C, few s	1	49
	0.3	In	evap. surf. heater, 350°C, 15 s	12	50
	0.15	In/Pt	evap. surf. heater, 400°C	2	51
	2	Au/In	electroless dep., furnace, 350°C, 2 min	15	47
	low 10^{18}	Ge/Pd, Pd/Ge	furnace, 325-375°C, up to 30 min, or RTP	~1	42,52
	low 10^{18}	Si/Pd	RTP	~1	53,54
	1	MoGeW	RTP	0.3 Ω mm[1]	55
	4	MoGeW	RTP	0.4	56
	3.5 x 10^{13} cm^{-2}[2]	MoGeInW	RTP	0.5 Ω mm	57
	3.5 x 10^{13} cm^{-2}	GeInW	RTP	0.5 Ω mm	58
	3.5 x 10^{13} cm^{-2}	NiInW	RTP	0.3 Ω mm	58
	6.6 x 10^{13} cm^{-2}	NiInW(Si)	RTP	0.1 Ω mm	59
	6.6 x 10^{13} cm^{-2}	NiInW(Ge)	RTP	0.3 Ω mm	59
	3.5 x 10^{13} cm^{-2}	NiInW	RTP	---	60
	0.01	$Au/WSi_2/Ge$ $Au/W_{40}N_{40}$ Ge/Ni	RTP	50	61
	0.1	Au/W/Pd/Ge	RTP	~5	62
	0.1	Au/W/Mo/ Ge	RTP	~5	62

[1] Ω mm can convert to Ω cm^2 if the contact width is known[2]   [2] Layer doping in units of cm^{-2} is the dose obtained by ion implantation[2].

Semicon-ductor	**Carrier Conc. (10^{18} cm^{-3})**	**Metallization**	**Preparation**	**ρ_c (10^{-6} Ω • cm^2)**	**Ref.**
n-GaAs (continued)	1	W-In	RTP	3	63
	1	NiGe(Au)W	RTP	0.16 Ω mm	64
	3.5 x 10^{13} cm^{-2}	W/Ni/InAs	RTP	0.4 Ω mm	65
	6 x 10^{13} cm^{-2}	WInTe		5	66
	3.5 x 10^{13} cm^{-2}	W/Ni/InAs /Ni	RTP	0.4 Ω mm	65
	---	Pd/In	RTP	~2	67
p-GaAs	4	Au/Pd	electroless dep., furnace, 250°C, 2 min	200	47
	2	Ag/TiN/Pt/ Mg	evap., furnace, 450°C, 30 min	100	68
	1	Ag/W/Pt	evap., furnace, 400°C, 30 min	300	69
	100	Ni/AuZn	evap., furnace, 450°C, 2.5 min	10	70
	---	Si/Ni/Mg/Ni	RTP	0.7	71
p-AlGaAs	10-100	AuBe, Pt/Ti	RTP	---	72
n-InGaAs	---	Au/Cr	evap., no alloying	2.2	73
	15	Au/Pt/Ti	evap., no alloying	0.05	74
	1.8	Al	evap., no alloying	0.5	75
	1	Ni/Au-Sn/Ni	---	0.04	76
	30	Al	---	0.48	75
p-InGaAs	---	Au/Cr	evap., no alloying	82	73
	1	Ni/AgZn/Ti	evap. furnace, 400°C, 2 min	11	77
	1	Ni/Au-Zn/Ni	---	20	76
n-InAlAs/ InGaAs	1	Au/Ag/Au/ Ge/Ni	evap., furnace, 480°C, 60 s	0.8	78
n-AlGaAs /GaAs	3	Au/Ni/AuGe	evap. 500°C, 50 s	0.1	79
p-InGaAsP	5	AuBe	---	0.49	80
	20	Pt/Ti	---	1	80
	23	Pd/Ge	Solid-phase epitaxy	2.3	81
p-GaSb	1	Au-Zn	furnace	10	82

Semicon-ductor	**Carrier Conc. (10^{18} cm^{-3})**	**Metallization**	**Preparation**	**ρ_c (10^{-6} $\Omega \cdot cm^2$)**	**Ref.**
n-InP	---	Ni/Zn/Au, Ni/Hg/Au, InPd	electroless dep.	---	83
	2	AuGe/Ni/Au	Si-implanted, RTP	0.2	84
	---	Pt/Ti	RTP >400°C	0.8	85
	0.8	Au/Sn/In	400°C, 2 min	300	86
	0.8	Ni/AuGe/Ni	350°C 2 min after AuGe, 400°C 1 min after Ni	2.3	86
p-InP	1	Au/Cr/AuBe	RTP	10	87
	0.9	Au/Zn 90/10	400°C, 2 min	110	86
p-InAs	10	Pt/Ti	Zn-doped, RTP, 450°C, 30 s	0.099	88
n-GaN	---	Al	evap. no annealing	0.01-0.1	89
n-GaN		Au	evap. 575°C, 10 min	0.01-0.1	89
	0.1	Al/Ti	evap., RTA 900°C, 30 s	8	90
	5	InN/GaN	superlattice, InN cap, no annealing	60	91
n- & p- AlN	---	Al, Pt, Au	sputtering	---	92

B.4 DIAMOND (CARBON)

Semiconducting diamond is gaining popularity thanks to its unique combination of electronic and physical properties, including high breakdown voltage, high thermal conductivity, low dielectric constant, and radiation hardness. Tachibana and Glass[93] and by Das *et al.*[94] review the art of making both ohmic and Schottky contacts to diamond.

There are several methods to produce ohmic contacts on diamond: roughening or damaging the surface, welding noble metal/transition metal alloys, ion implantation, *in situ* doping with B during CVD film growth, solid-state diffusion doping, and deposition of carbide-forming metals.

Electrical Contacts to Diamond

Metallization	Doping	Preparation	*A*	Ref.
Ag Paint	natural	Mechanical Roughening	---	95
Colloidal Graphite	natural	Mechanical Roughening	---	96
W point probes	natural	Mechanical Roughening	---	97
Au(99%)-Ta(1%)	natural	Welding: E-Beam and Joule Heating	---	95-97
Au(90%)-Ta(9%)-Al(1%)	natural	Welding: E-Beam and Joule Heating	---	95-97
Pd-Ta	natural	Vacuum Brazing	---	98
Pt-Au-Ta	natural	Vacuum Brazing	---	98
Au, Ag, Cu	B, 3×10^{16} cm^{-3}	35 keV Ion Implantation at 200°C, Annealed at 1200°C, Etched	36 Ω cm	99
Au/Ti	B, 10^{20} cm^{-3}	Ion Implantation at 200°C	10^{-5} — 10^{-6} Ω cm^2	100
---	B, 3×10^{20} cm^{-3}	In Situ Vapor-Phase Doping	10^{-4} Ω cm^2	101
Ti	B, 10^{19} cm^{-3}	Solid State Diffusion, cBN at 1400°C, 20-60 s in Ar	---	102,103
Ti, Mo, Ta	natural	Carbide Formation, Annealing at >400°C	10^{-5} Ω cm^2	96, 104-108
Al/Si	B, 4.9×10^{21} cm^{-3}	Annealed 450°C	2.3×10^{-7} Ω cm^2	109
Ti-Au	B, 4.9×10^{20} cm^{-3}	Annealed 450°C	14×10^{-5} Ω cm^2	109
TiWN-Au	B, 4.9×10^{20} cm^{-3}	Annealed 450°C	6.6×10^{-5} Ω cm^2	109

B.5 II-VI MATERIALS

Wide and narrow bandgap II-VI compounds are increasingly sought for optoelectronic applications ranging from IR to UV wavelengths. HgCdTe is a "gapless" semiconductor used in IR detectors. ZnTe is a wide bandgap semiconductor that can be heavily doped with N, making it a potentially attractive material for blue and UV optoelectronics. ZnSe is the focus of considerable effort in the area of blue and UV semiconductor lasers, but it is extremely difficult to produce ohmic contacts to this material[110].

Electrical Contacts to II-VI Compound Semiconductors

Material	Carrier Concentration (cm^{-3})	Metallization	Process	ρ_c ($\Omega \cdot cm^2$)	Ref.
HgCdTe	~10^{15}	Au	Ar presputter, evap.	~1×10^{-4}	111
	4×10^{14}	Sn/In	evap.	1×10^{-5} - 1×10^{-5}	112
p-ZnTe	3×10^{19}	Au/Pt/Ti/N	e-beam evap., 120°C	1.1×10^{-6}	113

B.6 SILICON CARBIDE

Like diamond, silicon carbide is potentially useful for high-power, high-speed, and high-frequency devices, due to its large bandgap, high breakdown field and high thermal conductivity. However, ohmic contacts to this material have not been studied extensively.

Electrical Contacts to Silicon Carbide.

Material	Metallization	Process	ρ_c ($\Omega \cdot cm^2$)	Reference
SiC	Cr and alloys	ohmic to p-type	---	114
	Al	---	---	115
	Ti	sputter, 300°C, 30 min	9.2×10^{-3}	116
	$TiSi_2$	450°C, 390 min	1×10^{-4}	116
	WSi_2	450°C, 120 min	3×10^{-4}	116

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